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Effects of Dredging and Disposal on Some Benthos at Monterey Bay, California

by

John S. Oliver and Peter N. Slattery

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The specific objectives of this study were to document; (a) Natural temporal variations in benthic assemblages and changes related to substrate stability, (b) the initial effects of dredging and subsequent recolonization, (c) the effects of disposal of dredged material on the benthos and subsequent recovery of the fauna, and (d) the role of faunal distribution and reproductive abilities upon recovery or recolonization of disturbed areas.

The natural benthic assemblages differed with changes in the amount of sediment movement or substrate stability. Many animals characterized the relatively stable submarine ridges but few inhabited the unstable terrace slopes of the submarine canyon in Monterey Bay, California (Monterey Canyon); even fewer animals were found in channeled areas.

Dredging in the channel areas removed 60 percent of the original population of bottom animals. After 1.5 years, the number of individuals was low but the species diversity and evenness indexes were higher than before dredging.

Disposal of dredged material near the Monterey Canyon head at Moss Landing, California, removed 60 percent of the individuals. After 1.5 years, the number of individuals remained low but the species diversity and evenness indexes were higher than before disposal. Organisms adapted to unstable bottom conditions survive burial better than others.

The ultimate recovery of a disturbed area depends upon the timing of the action in relation to the reproductive cycles and distributive abilities of the benthic organisms in the area. In Monterey Bay, spring and fall are the most active spawning seasons for many benthic animals; dredging or dumping should be avoided during these seasons.

Underwater disposal of dredged material should be made in unstable bottom areas if possible.

PREFACE

This report is published to assist coastal engineers in evaluating the possible effects of dredging and disposal of dredged material upon benthic organisms. The work was carried out under the coastal ecology research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by John S. Oliver and Peter N. Slattery of the Moss Landing Marine Laboratories, Moss Landing, California, under CERC Contract No. DACW72-73-C-0010, and was revised for publication by R.M. Yancey, CERC.

Mr. R.M. Yancey, Chief, Ecology Branch, was the CERC contract monitor for the report, under the general supervision of Mr. R.P. Savage, Chief, Research Division.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

John H. Cousins

JOHN H. COUSINS
Colonel, Corps of Engineers
Commander and Director

CONTENTS

APPENDIX

TABLES

CONTENTS

TABLES-Continued

FIGURES

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.1745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use forumla: $K = (5/9)(F - 32) + 273.15$.

EFFECTS OF DREDGING AND DISPOSAL ON SOME BENTHOS AT MONTEREY BAY, CALIFORNIA

by
John S. Oliver and *Peter N. Slattery*

I. INTRODUCTION

There have been a number of large-scale surveys of the effects of dredging and dredged material disposal on benthic communities. Most pertinent to this study were parts of multidisciplinary field studies on the gross physical and biological effects of disposal of dredged material in the Chesapeake Bay (Virginia Institute of Marine Science, 1967; Pfitzenmeyer, 1970) and the Rhode Island Sound (Sailia, Pratt, and Polgar, 1972). Additional reviews were presented by Sherk (1971), O'Neal and Sceva (1971), and Thompson (1973). Sherk and Cronin (1970) published an annotated bibliography of selected references on the same subject.

Because of the shortcomings of some surveys, the practical problems encountered, and the limitations of the local situation, a number of specific objectives and designed sampling procedures were established to produce detailed answers. A minimum of laboratory work was planned so that maximum effort could be devoted to field sampling and experimentation. The development of a quantitative sampling plan (App. A) and exploration of sampling techniques preceded the study.

The objectives of the study were to:

(a) Document changes in benthic assemblages related to sediment movement or substrate stability;

(b) document natural temporal variations within a benthic assemblage and investigate the biological and physical processes that might explain these variations;

(c) document the initial effects of dredged material disposal and subsequent recovery of the benthic fauna;

(d) document the sequence of recolonization of a benthic assemblage within a dredged bottom area;

(e) study the mechanisms controlling benthic recovery and recolonization, especially faunal distributions and reproductive abilities;

(f) compare the effect of mass accumulation of sediment on benthic assemblages adapted to different levels of substrate stability; and

(g) provide additional information relevant to the planning of local dredging operations.

For clarification, the events at the dredged harbor station were separated from those at the station receiving dredged material. Since disposal did not destroy the whole assemblage, it was referred to as dredged material disturbance with subsequent recovery. Dredging at the harbor station removed all the fauna; however, the area was recolonized.

Maintenance dredging of the Moss Landing Harbor was done during August 1971. A bucket dredge was used to load dredged material aboard barges that were towed to the disposal area at the Monterey Canyon head (Fig. 1). About 91,400 cubic meters of material were disposed of in water depths of 10 to 60 meters. Coarse sand from between harbor jetties was dredged first; finer sediments were dredged later as dredging progressed into the inner harbor. From November 1971 to April 1972, "cleanup" dredging operations were performed by the Moss Landing Harbor District, using a small pipeline dredge. Material was periodically piped to the end of the Moss Landing Pier and dumped in 10 meters of water. Cleanup involved less than 9,100 cubic meters of material.

Permanent biological stations were established in the canyon head, on an adjacent flat bottom, and in the harbor (Fig. 1). Sampling began before dredging in June 1971 and continued after dredging from September 1971 to April 1973.

II. SEDIMENT MOVEMENT AT THE MONTEREY CANYON HEAD

Monterey Canyon is the largest submarine canyon on the west coast of the United States. Sediment movement at the canyon head, which involves the dynamics of sediment transport to greater depths, was reported by Shepard (1948), Charlock (1970), and Arnal (1971). This study was initiated in 1971 in response to the need for recommendations on optimal disposal techniques and periods required for a better understanding of sediment movement in the canyon.

The canyon head is fed by three main branches: (a) The jetty branch, (b) the main branch, and (c) the southern branch which has several smaller tributaries. The axis of the southern branch is flanked on the east by a large submarine ridge with a fairly flat top, located in approximately 15.2 meters of water (Fig. 2). North of this ridge is the main branch of the canyon head (Shepard, 1948). The main branch is bounded on the south by a smaller submarine ridge that begins in 18.3 meters of water and slopes steeply to about 30.5 meters. The primary disposal station for biological studies (P-3) is located at a depth of 18.3 meters on the shoreward edge of this ridge (Figs. 2, 3, and 4). A smaller southern tributary runs parallel to the main axis to the south, then joins it in about 30.5 meters of water (Figs. 2 and 3). The main branch leads directly to the head of the Moss Landing Pier. A number of shallow channels or tributarie with heads at the shoreward end of the north ridge (Fig. 2), traverse the north canyon wall of the main axis. The bottom slopes gently to 4.6 or 6.1 meters near the end of the Moss Landing Pier, then dips abruptly to 12.2 meters. A shallow-water terrace up to 6.1 meters high borders most of the southern branch at these depths (Fig. 2). Its slope ranges from

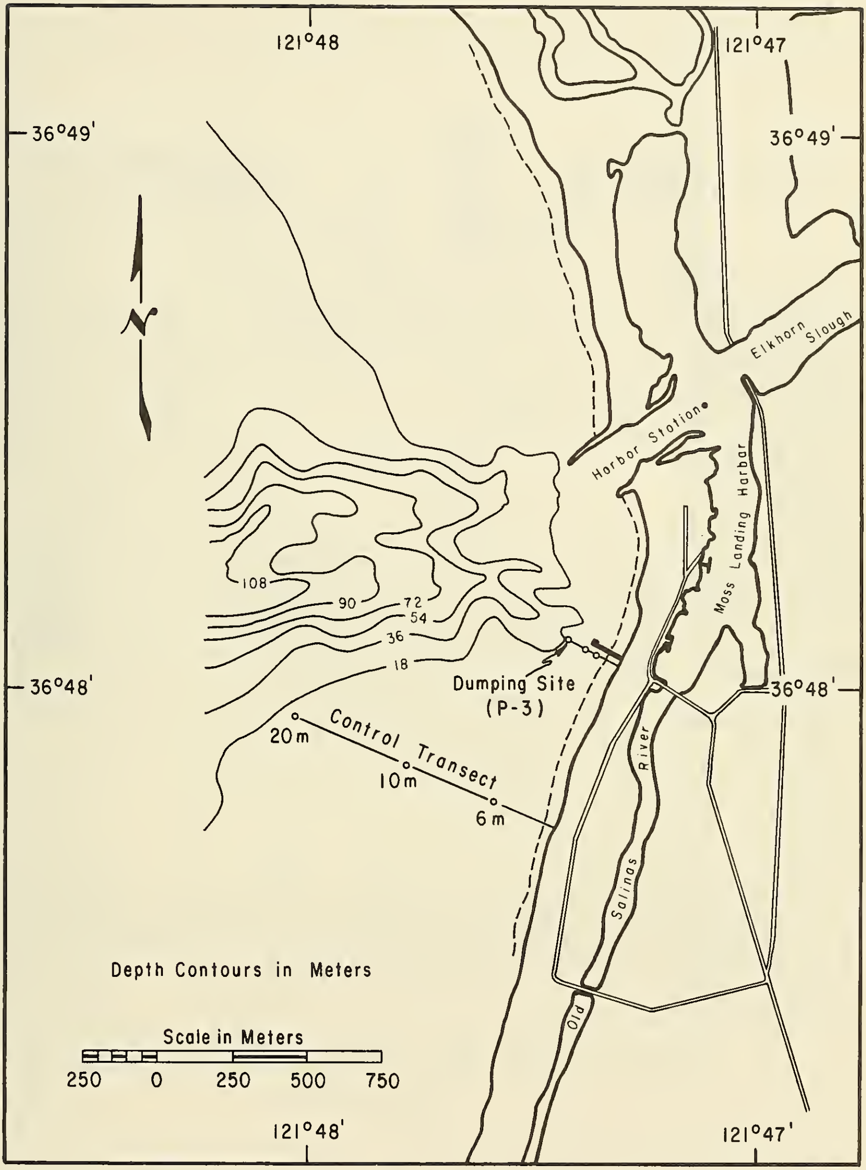


Figure 1. Moss Landing study area. Benthic sample stations are marked with circles.

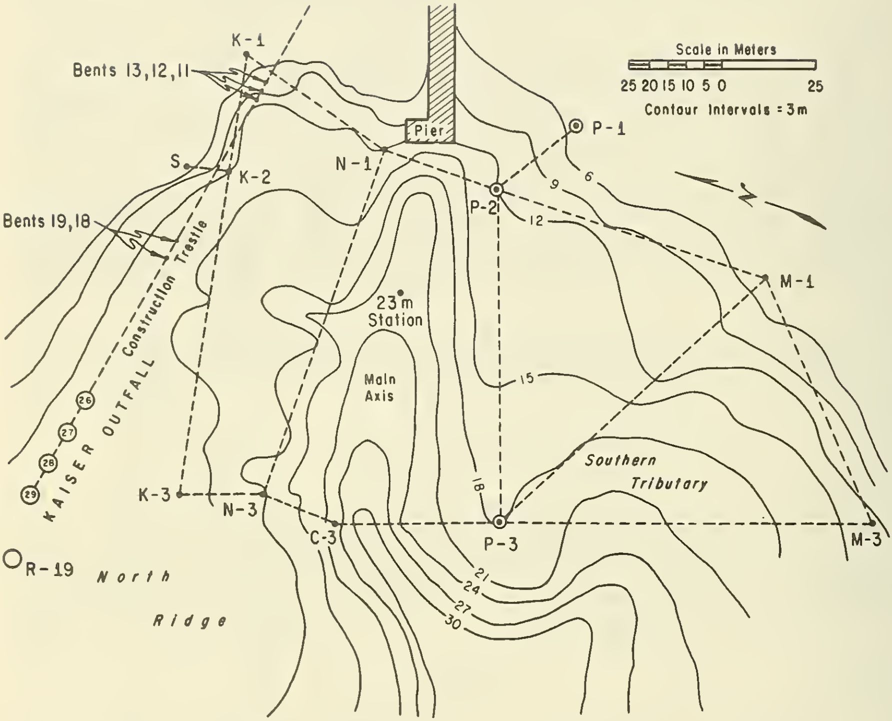


Figure 2. Southern branch of the Monterey Canyon head, based on observations and measurements by divers along transects. Large circles are biological sampling stations, and small circles major topographic measurement stations on the transect grid.

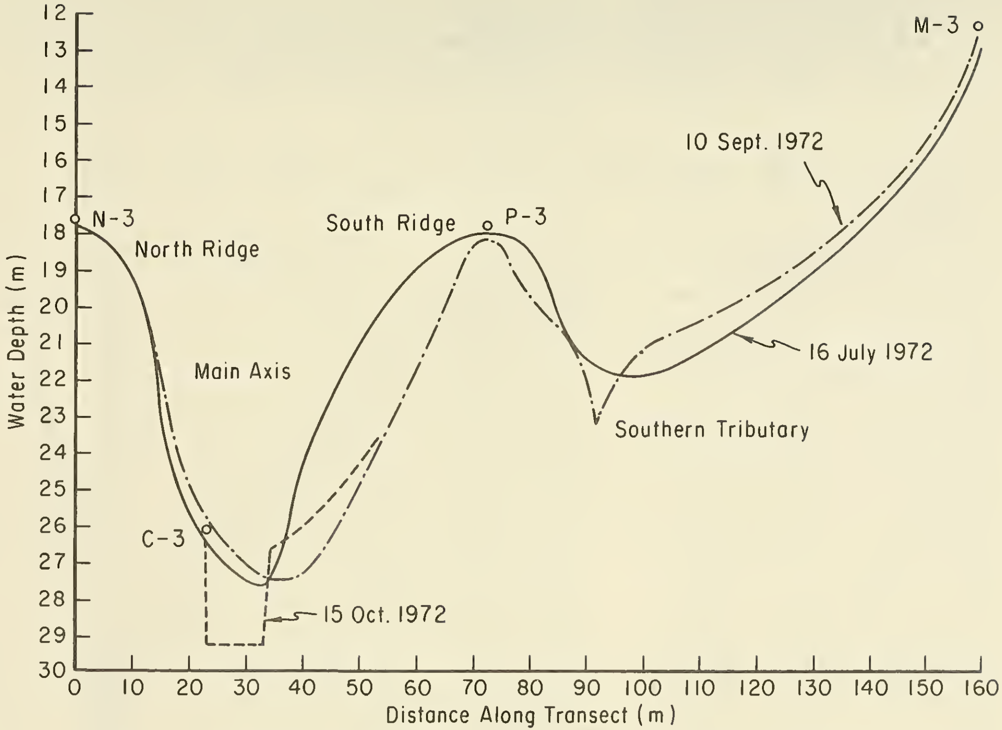


Figure 3. Profile of the southern branch along M-3 to N-3 transect (Fig. 2), showing changing slopes and axes at three different dates. Depth measurements were made every 10 meters along the transect.

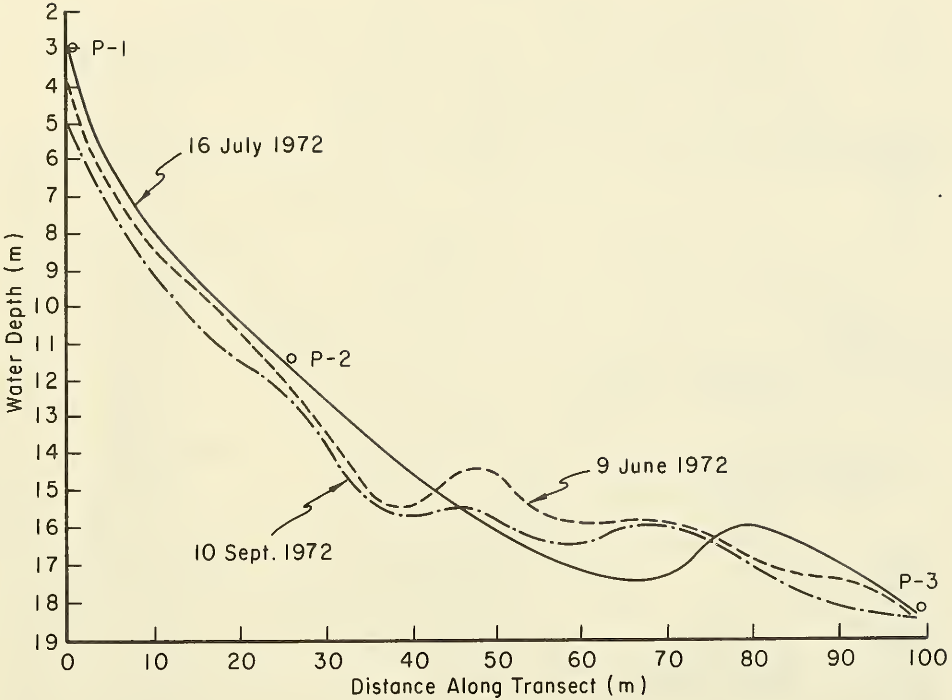


Figure 4. Profile of the south canyon wall along the P-transect (Fig. 2), showing the changing slope at three different dates. Depth measurements were made every 10 meters along the transect.

10 to 50 percent and varies seasonally. Shepard (1948) observed a 50-percent slope from a similar shallow sandflat on the north wall of the main branch (Fig. 1).

A Kaiser Company submarine outfall was placed parallel to the terrace along the edge of the north submarine ridge (Fig. 2). Trenching operations exposed an underlying, consolidated silt-clay material to depths of 6.1 meters below the existing bottom in some areas. In the main axis, several silt-clay outcrops were present on the steep part of the north wall. These outcrops contained a number of living burrowing bivalves, indicating that the outcrops were usually free of sand cover. Vertical walls of consolidated silt-clay material were also exposed in the main axis after a sediment slump in October 1972 (Fig. 3). Thus, the head of the southern branch appeared to be formed of a consolidated silt-clay material covered to varying depths by fine sand.

Observation dives and sample collections were made between June 1971 and November 1972, using scuba and underwater diver vehicles (Farallons). Underwater visibility (0 to 1.2 meters) was usually poor. Maximum information was obtained on the few days that visibility increased 3 to 7.6 meters.

In late spring of 1972, permanent transect lines were established to detect changes in gross topographic features and sediment movement. Transects were marked at 9.1-meter intervals between permanent stations by 2.4-meter fence anchors (Slattery and Oliver, 1972), and the distance from the top of the anchor to the bottom was periodically measured. Figure 2 was compiled from the diver observations and measurements made along these transects from April to October 1972.

Seasonal physical changes of the canyon axis and the south canyon wall were of special interest. To test the dynamic conditions present in the axis at a 30.5-meter depth, five 0.6-meter fence anchors were arranged in a straight line across the 10.7-meter width (Fig. 2, line C-3 to P-3), and oriented normal to the canyon walls. To test the southern slope conditions, a similar transect was placed at right angles to the contours of the steep slope south of the P-3 transect line (Fig. 1).

The greatest changes in topography occurred along the shallow-water terraces (6.1 to 12.2 meters) and in the channeled areas. Submarine ridges and deeper canyon walls were more stable.

Water depths at the head of the Moss Landing Pier changed from 6.1 to 7.6 meters in the summer of 1972, and 10.7 to 12.2 meters in the fall and early winter. In the summer the bottom under the pier consisted of coarse sand; in the fall the surface sand moved away from the pier. The slope from the end of the pier to the flat part of the canyon floor was considerably steeper during the summer. In early fall of 1972, three sand terraces, 0.6 to 0.9 meter high, about 15.2 to 30.5 meters apart, and arranged perpendicular to the main axis, occurred along this slope. The activity around the Moss Landing Pier indicated periodic migration of large amounts of shallow-water sediment into the main axis of the canyon head.

In September and October 1972, large depth changes in the main axis of the southern branch (Fig. 3) coincided with the slumping of the shallow-water terraces above the north wall and at the end of Moss Landing Pier, and activity on the southern wall of the main axis shoreward of the submarine ridge (Fig. 4). The probable sequence was: (a) Shallow areas shoaled in calm summer months and sediment accumulated on the walls and especially in the channels, and (b) rough seas caused sediments to move down channel, stimulating slumps in deeper channels. The main axis accumulated more sediment, received more input from shallow water, and changed in depth more than the other channels.

Sediment input at the canyon head was primarily from longshore drift and tidal scour of the Elkhorn Slough and Moss Landing Harbor. Fragments of thallophytic algae accumulated all year but input was highest in the summer. In June and July 1971, the main axis floor contained a 0.3-meter-deep mud layer; algal fronds were half-buried in the sediment. Oxygen concentration was low and the hydrogen sulphide odor was strong in water samples taken 1.5 meters above the substrate. By September the fronds had broken into many smaller pieces and were mixed into the sediment. In December 1971 the floor was covered with coarse sand.

Further evidence of activity during most of the year came from observations of dredged material deposition. Material was piped to the head of Moss Landing Pier at three different times during the year. Coarse sediments accumulated in a pile directly below the end of the pipe, then slumped into the canyon. During a previous monitoring (Harville, et al., 1968), the dredged material had been dumped in August 1967 and the piles had moved completely into the axis by December 1967. Diver observations revealed a mound of sediment in the axis at a depth of about 30.5 meters. Material deposited in November 1969 and April 1972 appeared to move within 1 to 2 months.

Shepard (1948) concluded that there was little change in the major topography of the canyon head since earlier soundings were made by the U.S. Coast and Geodetic Survey in 1933. Observations in the southern branch indicated no major changes in the topography described by Shepard. Thus, main topographic features have appeared stable for the last 40 years.

Summary

a. Sediment and algae accumulation was highest during the calm summer months.

b. Sediment movement increased in the fall and continued through the winter into early spring.

c. Accumulation was low in the winter; activity was high.

d. The largest topographic changes occurred during the fall with the first rough seas.

e. Largest topographic changes also occurred along shallow sand terraces and in canyon axes.

f. Sediment probably moves by "creeping" down slopes, especially in canyon or axes.

III. FAUNAL DISTRIBUTION AND SEDIMENT MOVEMENT

Barnard (1966) reported a distinct relationship between dominants and sediment grain size in two adjacent shallow-water communities, and Masse (1972) described the effect of exposure to wave energy on faunal distribution. Substrate consolidation is mostly a function of grain size which is determined by waves moving sediment. Since no attempt was made to separate these phenomena, sediment movement here refers to the general instability of a moving substrate.

This section discusses the physical aspects of sediment movement described previously, and shows the significance of sediment movement in determining animal distributions.

In addition to the observations and measurements of sediment movement in the canyon and the routine biological sampling, a sampling line (transect) was located along the outer end of the Kaiser Company's construction trestle (Fig. 2, bents 26 to 29). The transect followed a gradient of substrate stability on the 18-meter isobath parallel to the submarine terrace north of the canyon. The seaward end of the transect (station R19) was on the stable part of the northern submarine ridge. Shoreward of station R19, stations were adjacent to terrace slopes of increasing incline and decreasing stability as they approached the area of large topographic change and sediment activity near bents 18 and 19 (Fig. 2). Because all stations were located at equal depths (18 meters), the effects of sediment movement could be isolated from other factors associated with changes in water depth.

One sample (five replicate cores) was taken from each of the four ridge stations (stations R26 to R29) in December 1972 and abundance changes of the major groups of animals with increased substrate stability were noted (Table 1). In a comparison of fauna at control stations (C6, C10, and C20) with fauna from less stable canyon stations (P6, P10, and P20), stability was a greater influence on abundance than depth although there was a gradual but distinct change in the fauna with increasing water depth (Table 2). Resuspension and migration of sediment caused by wave action was of major importance in determining animal distributions.

In the canyon head the benthic assemblages changed abruptly in response to sediment movement or substrate stability. Many animals characteristic of the control stations were also found on the relatively stable submarine ridges but few inhabited the unstable terrace slopes; e.g., the fauna on the flat, stable part of the north ridge (Fig. 2) was more similar to the assemblage at a comparable depth on the control transect (Fig. 1) than the fauna on the deeper south ridge (Fig. 2, P-3), which had a

Table 1. Ridge stations of equal depths (18 meters) in order of increasing sediment stability from left to right[1].

Fauna	Stations			
	R26	R27	R28	R29
Worms	140	160	240	230
Crustaceans	390	510	480	140
Mollusks	12	36	80	85
Sand dollar	40	200	80	25

[1] Mean numbers of organisms per 0.018 square meter times 10.

Table 2. Comparison of fauna at control stations (C) in stable areas with fauna at canyon stations (P) at 6-, 10-, and 20-meter depths.

Fauna	Stations					
	C6	P6	C10	P10	C20	P20
	(6 m)		(10 m)		(20 m)	
Worms	43	20	196	64	420	400
Crustaceans	390	63	300	106	143	84
Mollusks	136	0	120	0	54	0
Sand dollars	0	0	280	0	44	0

steeper slope. Fewer animals were found in channeled areas and their number decreased with increasing sediment movement and accumulation. Accumulation of both algae and sediment accompained by high decomposition rates decreased available oxygen and increased hydrogen sulfide concentration, thereby limiting many benthic animals.

The canyon and control transects had many species in common but the general composition of assemblages differed (Tables 3 and 4). The number and kinds of animals at the two shallow-water canyon stations were variable with seasonal lows occurring in winter when topographic changes were greatest. Most species were present only intermittently; the few constant ones were also found at the same depths on the control transect.

The most convincing evidence of sediment movement as the main factor controlling benthic faunal distribution in the study area came from the comparison of ridge stations at the same depth arranged by substrate stability along the Kaiser Company trestle (Table 1). The total numbers of worms increased with increased stability. Crustaceans were most abundant at low and intermediate substrate stability; mollusks were more abundant with increasing stability.

The distribution and relative abundance of many species were similar. The worms, *Amaeana occidentalis*, *Nothria elegans*, *Lumbrineris* nr. *luti*, and the crustaceans, *Paraphoxus daboius*, *Euphilomedes oblonga*, *E. carcharodonta*, were characteristic of deeper stations and found in areas of increasing substrate stability on the ridge. The worms, *Dispio uncinata*, *Scoloplos armiger*, *Onuphus erimita*, *Paraphyoxus lucubrans*, *cumaceans*, and the mollusk, *Olivella*, were characteristic of shallow stations and found in areas of decreasing substrate stability along the ridge. The crustaceans, *Euphilomedes longiseta*, the mollusk, *Tellina modesta*, and the common sand dollar, *Dendraster excentricus*, were characteristic of stations of intermediate depths and found in areas of intermediate substrate stability along the ridge gradient.

The overwhelming trend was for species composition and abundance to change in a similar manner with stability changes rather than with depth. Sediment movement was the most important environmental parameter affecting the distribution of macroinvertebrates at the control area and in the canyon.

Many small crustaceans (amphipods and ostracods) are well adapted to shifting or gradual accumulation of sediment. They are characteristic of coarse, unconsolidated sediments (Barnard, 1963; Masse, 1972), but intolerant of the mass accumulation of sediments in the burial experiment. The crustaceans' presence at the shoreward ridge stations indicated that sediment probably did not move in mass slumps; instead, the sediment crept gradually down adjacent terrace walls, as suggested by Shepard and Dill (1966), creating an environment to which crustaceans can readily adjust.

No active or passive migration of species characteristic of shallow-water stations along the control or canyon transects was evident which

Table 3. Species at the 20-meter control station.

Name	July 71	Sept. 71	Nov. 71	Jan. 72	Mar. 72	June 72	Oct. 72	Dec. 72	Apr. 73	May 73
Anthozoa	--	--	--	--	--	8	--	--	--	5
Nemertinea	3	--	--	2	--	3	--	2	--	3
Phoronida	--	--	--	--	--	2	--	--	--	--
Amaena occidentalis	--	--	--	--	--	--	2	--	2	4
Armandia bioculata	5	--	--	--	3	--	--	--	--	--
Glycera spp.	--	--	--	--	--	--	--	--	--	2
Gyptis brevipalpa	--	--	--	--	2	1	--	--	--	2
Haploscolopos pugettensis	--	3	2	4	3	--	--	2	2	--
Lumbrinerus nr. *luti*	7	5	7	4	5	6	3	4	5	5
Mediomastus californiensis	8	3	10	4	6	4	4	2	9	9
Magelona sacculata	16	25	23	12	38	41	11	10	20	20
Magelona spp.	2	2	--	--	8	3	--	--	--	--
Nepthys cornuta	--	--	--	--	--	6	6	--	--	--
Nothria elegans	2	6	4	5	8	7	3	6	4	7
Prionospio pygmaeus	3	3	3	3	16	7	--	--	--	3
Prionospio cirrifera	--	--	5	2	10	23	3	--	--	3
Spiophanes missionensis	--	--	--	--	3	--	--	--	--	--
Tharyx sp.	--	--	2	--	--	--	--	--	--	--
Olioella pycna	--	--	--	--	--	3	--	--	--	--
Nassarius rhinetes	--	--	--	--	2	--	--	--	--	--
Lyonsia californica	--	--	--	--	--	--	2	--	--	--
Mysella aleutica	--	--	--	--	--	2	6	--	--	--
Nemocardium sp.	--	4	--	--	--	--	--	--	--	--
Protothaca staminea	--	15	--	--	--	--	--	--	--	--
Siliqua patula	5	6	--	4	4	2	--	--	--	--
Solen sicarius	--	4	--	--	--	--	--	--	--	--
Tellina meropsis	--	2	--	2	--	--	--	--	--	--
Tellina modesta	--	19	26	48	36	12	48	2	2	--
Euphilomedes carachodonta	--	--	--	--	2	3	3	--	5	--
Euphilomedes oblonga	--	--	--	--	2	--	3	2	2	3
Euphilomedes longiseta	--	2	--	--	--	--	--	--	--	--
Euphilomedes spp. (juvenile)	--	--	--	--	--	10	--	--	--	--
Hemilamprops californica	--	--	--	--	7	--	--	--	--	--
Paraphoxus daboius	8	7	10	8	17	17	13	9	6	8
Paraphoxus epistomus	--	--	--	2	--	--	--	--	--	--
Synchelidium spp.	--	--	--	--	4	--	--	--	--	--
Pinnixia franciscana	--	--	--	--	--	--	--	--	--	8
Scleroplax granulata	2	--	--	--	--	--	--	--	--	--

Table 4. Species at the 20-meter disposal station.

Name	July 71	July 71	Sept. 71	Oct. 71	Nov. 71	Jan. 72	Mar. 72	June 72	Sept. 72	Dec. 72	Apr. 73	Apr. 73
Anthozoa	4	3	--	---	--	--	--	11	6	--	--	--
Nemertinea	2	4	--	---	--	--	3	6	--	--	--	--
Amaena occidentalis	--	--	--	---	--	--	--	9	9	2	--	4
Armandia bioculata	2	4	3	6	16	2	5	--	--	--	--	--
Capitella capitata	43	33	29	213	33	--	3	--	--	6	--	--
Eteone sp. (juvenile)	--	--	--	---	--	2	--	--	--	--	--	--
Gyptis brevipalpa	--	--	--	---	--	--	--	--	--	--	--	2
Haploscolopus pugettensis	--	--	--	---	--	--	--	--	--	--	4	3
Harmothoe lunulata	--	--	--	---	--	--	--	--	4	--	--	--
Heteromastus filobranchus	59	77	19	23	16	25	28	20	19	9	4	12
Lumbrinerus nr. *luti*	--	2	--	---	--	--	--	--	--	2	--	3
Magelona sacculata	3	6	--	---	3	--	5	6	--	--	4	--
Mediomastus californiensis	--	--	--	---	--	--	--	--	--	8	8	9
Nepthys cornuta	--	--	--	---	--	7	--	7	--	--	--	--
Nothria elegans	--	2	--	---	--	--	--	5	4	--	5	4
Prionspio pygmaeus	--	--	--	---	2	--	15	4	--	--	--	--
Scolopos arminger	--	--	--	---	--	--	--	--	--	--	--	2
Spiophanes missionensis	--	--	--	---	--	--	22	4	--	--	--	--
Mysella alentica	--	--	--	---	--	6	--	--	5	2	--	--
Siliqua patula	--	--	--	---	--	6	8	--	--	--	11	--
Tellina meropsis	--	--	--	2	--	--	--	--	--	--	--	--
Tellina modesta	--	--	--	4	33	23	--	2	24	--	--	--
Tresus nuttallii	--	--	--	---	--	--	--	--	--	51	--	--
Listriella diffusa	--	--	--	---	--	--	--	--	--	6	2	--
Synchelidium sp.	--	--	--	---	--	--	3	--	--	--	--	--

strongly indicated there was also no occurrence along the north ridge terrace. The only exception was the polychaete, *Nephtys californiensis*, which lives on the intertidal and very shallow subtidal beach. A few individuals were found during the winter and early spring only at the shallow canyon station P-1. The large amount of sediment slumping around the pier and the proximity of the canyon head to the beach probably explain this seasonal occurrence. Generally, populations appeared local and immobile within the confines of the sampling stations.and periodicity.

In summary, benthic macroinvertebrate assemblages in the canyon head changed, as predicted, in response to changes in sediment movement or substrate stability. A naturally controlled experiment indicated that sediment movement was also the critical factor determining the distribution of animals along a gently sloping sand bottom.

IV. REPRODUCTIVE ACTIVITY OF SELECTED INVERTEBRATES

Knowledge of the reproductive activity of the local fauna is essential to understand natural variations in benthic assemblages, to interpret the sequence rate and end state of recolonizations, and to increase predictive abilities.

Reproductive data are from larval settling jars and benthic sampling. The larval settling jars were similar to those used by Thorson (1946) and Reish (1961a). Widemouthed plastic jars were positioned vertically in a rack 1.5 meters above the bottom at the 20-meter control station (Fig. 1). Exposure intervals of 8, 16, and 32 days were tested; jars exposed for 16 days produced more species and individuals. A collection was made every 8 days and the jars with and without sediment added were compared. The added sediment did not appear to stimulate larval settling. The contents of each jar were washed through a screen with 0.25-millimeter-square openings, stained with rose bengale, preserved in 10-percent Formalin, and sorted under a dissecting microscope. Animals were identified, enumerated, and transferred to 70-percent ethanol and 5-percent glycerin. A thin layer of particulate material accumulated in the jars in 1 day and was 1 to 4 centimeters thick by the end of 16 days.

Jars were first tested in March and April 1972. Regular sampling began on 12 September 1972 and ended on 1 June 1973. The three summer months were not included; however, some information is available on the macroinvertebrates in the benthic samples.

The jars must be considered as selective sampling devices. Animals may brood their young (many crustacea (amphipods and ostracods) and some polychaetes (*S. arminger*)), have a very short or suppressed pelagic larval stage, or do not settle in jars. The degree of selection is unknown. Wilson (1951) made numerous laboratory studies of substrate selection by invertebrate larvae. However, very little is known about selection under natural conditions.

Gravid (egg-bearing) females and polychaetes and crustacea juveniles were identified and recorded when found in the benthic samples. Size measurements and counts were made of males, females, gravid females, and juveniles of several common amphipod species taken at the control stations. Larval settling time and growth rates were observed for a few abundant colonizers at the dredging and disposal sites.

Most of the bivalves that settled in the jars were too small to be identified to species. Therefore, only the total number of bivalve individuals per exposure interval was presented. Although settling occurred sporadically throughout the study period (Fig. 5), a larger number of individuals settled in the winter and in the spring. Most of the individuals were the juveniles of several species commonly found in fine sediments. A few adult organisms present were too large and deep in the sediment to be adequately sampled. A high mortality was caused by physical events subsequent to larval settling. There was no obvious indication of predation (e.g., shells with boring), although it was a possibility.

The reproductive activity for many of the common nonmolluskan macroinvertebrates is shown in Figure 5. Most of the species of the worm fauna that settled in the jars were polychaetes. The number of species was highest in the spring. The large number of individuals in the fall was primarily due to *Capitella capitata*; in the spring, *Armandia bioculata* and *Nephtys cornuta* accounted for most of the individuals.

Armandia bioculata had two distinct settling periods, the spring and fall (Fig. 6). The worms also occurred in large numbers at the dredged harbor station in late fall 1971, and during March and April 1972 when the jars were first tested.

Capitella capitata larva settled in large numbers at disposal and dredged stations in October 1971 and in the jars in October 1972 (Fig. 6). They had also been present in March and April 1972, but none were found at the end of the testing on 1 June 1973. Although settling varied during spring and summer, there was a similarity between the 1971 and 1972 fall peaks.

Magelona sacculata was the dominant polychaete at the 20-meter control station. It had a definite pelagic larval stage, but did not settle in the jars. Large numbers of juveniles were present in the spring benthic samples (Fig. 7). Presumably, magelonids prefer a sandier substrate and respond negatively to the fine sediment accumulated in the jars.

Phoronopsis viridis (phoronid) had many juveniles settle in the jars and at the harbor station during late March, April, and early May 1973 (Table 5). The spring settling seemed distinct, and agreed with the findings of Rattenbury (1953).

Reproductive patterns of crustaceans can be determined by examining egg-carrying females and the size classes in populations. The patterns

Figure 5. Settling jar occurrence during study period. Each bar represents the number of individuals or species per jar per overlapping 16-day exposure interval.

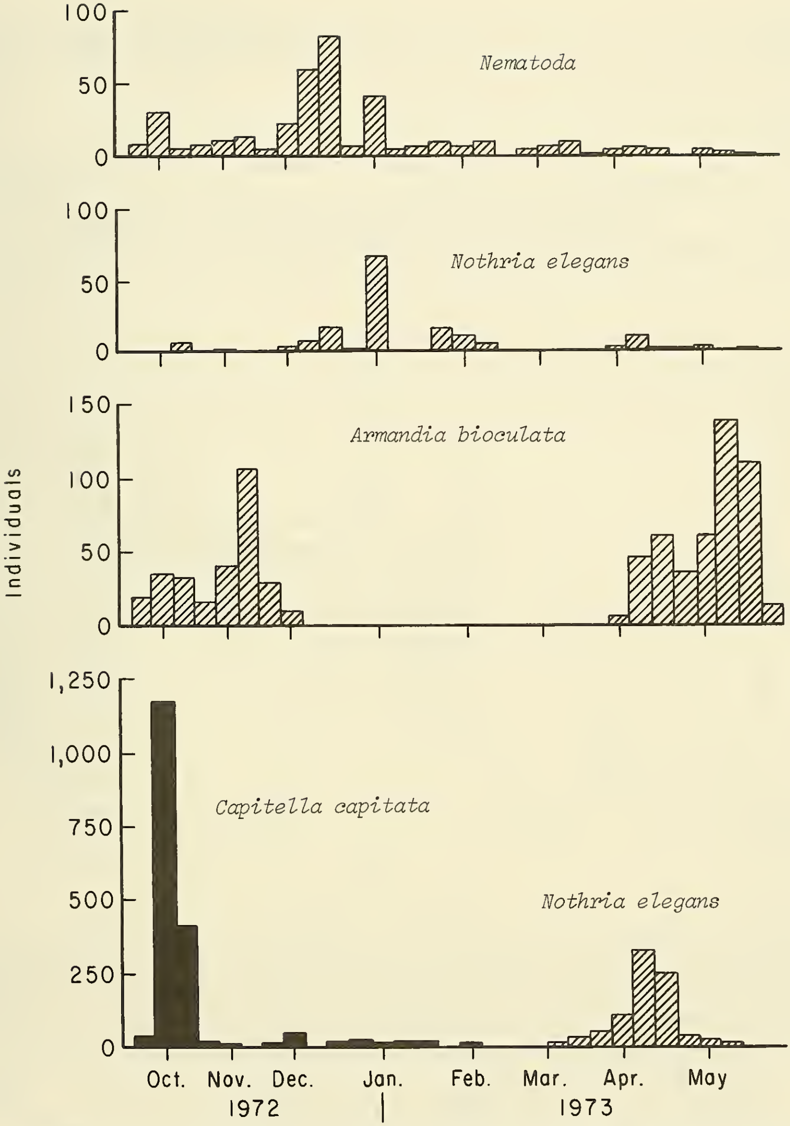


Figure 6. Settling jar occurrence during study period. Each bar represents the number of individuals per jar per overlapping 16-day exposure interval.

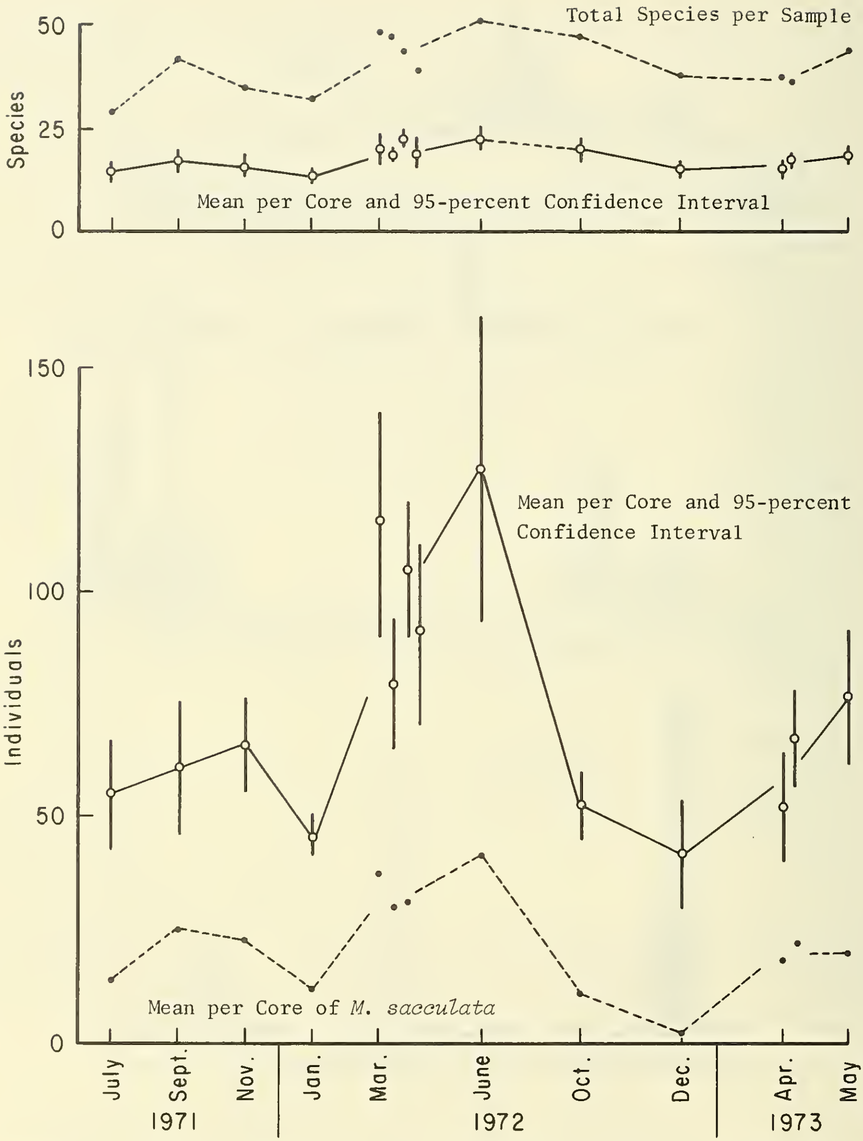


Figure 7. Number of species of worm fauna (upper graph) and number of individuals of worm fauna and *Magelona sacculata* (upper graph) at the control station.

Table 5. Species at the harbor station.

Name	July 71	July 71	Sept. 71	Oct. 71	Nov. 71	Jan. 72	Mar. 72	June 72	Sept. 72	Dec. 72	Apr. 72
Anthozoa	--	--	-	--	---	---	-----	-----	---	---	3
Nemertinea	--	2	-	--	3	2	2	3	3	5	2
Phoronopsis viridis	8	5	-	--	---	---	1,240	1,100	412	154	766
Oligochaeta	97	60	8	--	3	---	4	18	7	16	26
Armandia bioculata	--	--	5	25	241	230	152	104	---	---	---
Capitella capitata	--	--	-	55	93	---	-----	6	---	8	2
Eumida tubiformis	--	--	-	--	4	---	-----	-----	---	---	---
Glyptis brevipalpa	--	--	-	--	---	---	-----	4	---	---	---
Heteromastus filobranchus	5	6	-	--	---	---	-----	-----	---	---	---
Mediomastus californiensis	14	8	-	--	3	---	2	5	2	5	7
Magelona succulata	2	2	-	--	---	---	-----	-----	---	---	---
Nepthys cornuta	--	--	-	--	---	---	2	4	---	---	---
Nereis zonata	2	--	-	--	---	---	-----	2	4	---	2
Nothria elegans	--	--	-	--	---	---	-----	-----	3	5	---
Notomastus tenuis	15	11	-	--	---	---	-----	3	---	---	2
Phyllodocidae	--	--	-	--	---	---	-----	-----	---	---	---
Platynereis bicanaliculata	--	--	-	--	---	---	-----	33	---	---	---
Prionospio cirrifera	2	--	-	--	---	---	-----	-----	---	---	---
Prionospio pygmaeus	--	--	-	2	3	2	4	-----	2	---	---
Aoroides columbiae	--	--	-	--	---	---	-----	5	---	---	---
Caprella californica	--	--	-	--	---	---	-----	-----	---	---	7
Caprella sp.	--	--	-	--	---	---	-----	14	---	---	---
Cryptomya californica	--	--	-	--	---	---	-----	-----	---	---	19
Macoma nasuta	3	3	-	--	---	---	-----	-----	---	---	---
Macoma yoldiformis	--	--	-	--	---	---	3	36	---	---	---
Modiolus sp.	--	--	-	--	---	---	-----	13	---	---	---
Munna ubiquita	--	--	-	--	---	---	-----	3	---	---	---
Mya arenaria	--	--	-	2	---	---	-----	-----	---	---	---
Mysella aleutica	--	--	-	--	---	---	3	12	---	---	---
Mysella sp.	--	--	-	--	---	---	-----	-----	---	---	2
Protothaca staminea	--	--	-	--	---	---	3	32	10	9	9
Siliqua patula	--	--	-	--	---	---	13	-----	---	---	---
Tellina meropsis	--	--	-	--	---	---	4	5	6	3	---
Tellina modesta	--	--	-	--	4	9	22	39	---	3	8
Tresus nuttallii	--	--	-	--	55	---	62	8	16	---	---
Clinocardium nuttallii	--	--	-	--	---	---	3	3	2	---	---
Cooperella sp.	--	--	-	--	---	---	-----	2	---	---	---

of the amphipods and ostracods (*Euphilomedes*) are seasonal; ovigerous females are present to some extent all year but peaks of relative abundance occur early in the year (Table 6).

Three species of ostracods, *E. carcharodonta*, *E. longiseta*, and *E. oblonga*, were predominantly represented by females and juveniles. Females of this genus swarm in the water column to mate, chew off the ends of the bristles on their swimming antennae, and spend the rest of their lives on the bottom. They brood their eggs mostly through winter to late spring (Table 6); an influx of juveniles occurs later in spring. The males are strong swimmers but they die soon after mating (Kornicker, personal communication), which probably accounts for their low abundance in the samples.

The peaks of relative abundance of reproductive females of *Eohaustorius sencillus* were followed by peaks of juveniles in the next sampling period (Fig. 8). There was a predominance of reproductive females in the 2.5- to 3-millimeter size range; few were larger. This suggests that the females breed once and die. *Paraphoxus daboius* and *P. epistomus* seem to follow a similar pattern to that of *E. sencillus* but later in the year (Fig. 8).

Relative abundance of reproductive females was highest in March, followed in the next sampling period by peaks of juveniles. Since amphipods brood their young which are burrowers with relatively immobile females, an influx of juveniles from another population is not likely. Males are active swimmers and generally more mobile than females. This may be partly the reason for the 1:20 ratio of males to females. Fecundity is difficult to estimate because eggs are usually lost from the females marsupium (egg pouch) during collection. Larger females carry more eggs than the smaller females. *Paraphoxus epistomus*, 5 millimeters long, carry 18 eggs; the smaller females, 3.5 to 4 millimeters long, carry 7 to 12 eggs. *Paraphoxus daboius*, 3 millimeters long, carry 8 eggs. The fairly distinct peak of reproductive females with a small variation in their sizes (most *P. epistomus* are 3.5 to 4 millimeters; most *P. daboius*, 3 to 3.5 millimeters). The low occurrence of larger females indicate that they probably breed only once.

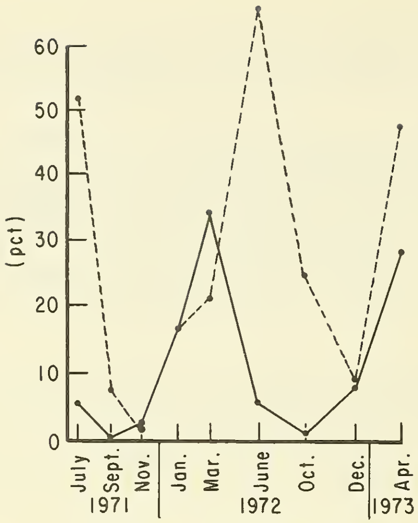
The main influx of polychaete juveniles occurred in the fall and spring; the main influx of crustacea occurred in the spring. Distinct winter reproductive activity was apparent for certain species, but settling of bivalves was more sporadic. Polychaetes are more flexible in their reproductive strategies than crustaceans or mollusks. A single species which will often occur over a large geographical range, may be capable of brooding young in higher latitudes and producing pelagic larvae in warmer seas.

Many of the polychaetes in the study area are found in deeper parts of the Monterey Bay (Hartman, 1963; Hodgson and Nybakken, 1973), and along the coast of southern California (Allan Hancock Foundation, 1965) and Washington (Lie and Kisher, 1970). In contrast, most of the shallow

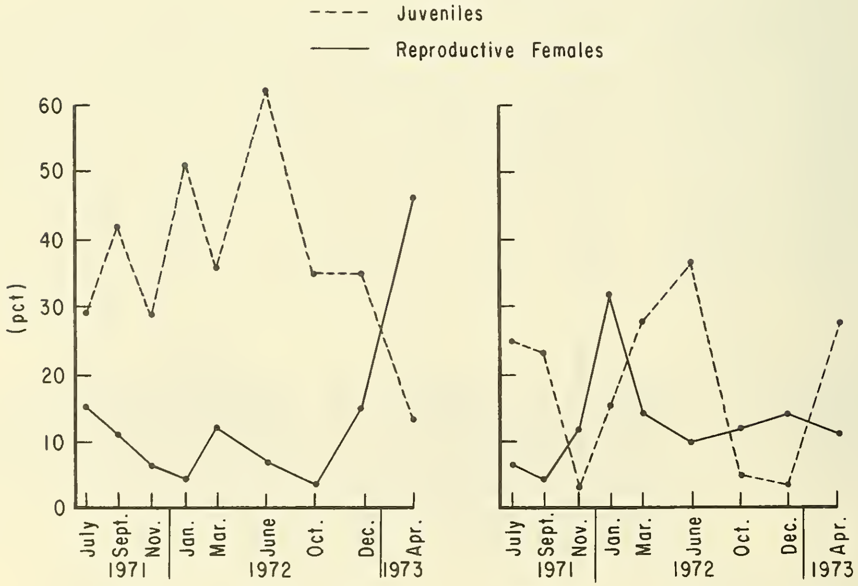
Table 6. Reproductive activity of selected benthic invertebrates.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Evidence	
Polychaetes														
Amaeana occidentalis		---	---	---	---								J[1]	B[2]
Armandia bioculata				---	---				---	---	---		J	B
Capitella capitata				---					---	---			J	B
Eteone sp.	---	---	---	---						---	---	---	J	B
Haploscoloplos pugettensis			---		---						---	---	J	
Harmothoe spp.			---	---						---			J	
Magelona sacculata			---	---									J	B
Nephtys cornuta			---	---	---								J	
Nothria elegans	---	---		---								---	J	
Phylo felix	---		---										J	
Polydora neocardalia			---	---									J	
Prionospio cirrifera			---	---	---								J	
Prionospio pygmaeus		---	---	---							---		J	
Spiophanes missionensis			---	---								---	J	
Miscellaneous Worms														
Anthozoa				---	---								J	
Nemetoda	---								---	---	---	---	J	
Phoronopsis viridis			---	---									J	
Crustaceans														
Synchelidium spp.			---	---	---	---	---						BO[3]	
Paraphoxus daboius			---										BO	
Paraphoxus epistomus			---										BO	
Paraphoxus lucubrans			---										BO	
Eohaustorius sencillus	---	---	---									-	BO	
Euphilomedes carcharodonta	---	---										--	BO	
Euphilomedes longiseta	---	---										--	BO	
Euphilomedes oblonga	---	---										--	BO	

[1] J, settling jars.
[2] B, benthic sampling.
[3] BO, ovigerous females in benthic samples.



Paraphoxus epistomus (10m)



Paraphoxus daboius (10m)

Eohaustorius sencillus (10m)

Figure 8. Seasonal peaks of reproductive females and juveniles by percentages of total population for three amphipod species.

amphipod and ostracod species have more restricted distributional patterns.

Thorson (1946) discussed the importance of temperature as a critical reproductive cue, and the synchrony of spawning with yearly plankton blooms. The monthly temperature and standing stock chlorophyll values at several hydrographic stations in Monterey Bay are shown in Figure 9. Although the chlorphyll data are extremely variable, distinct fall and spring blooms are common in the bay and at this latitude.

V. EFFECT OF DISPOSAL OF DREDGED MATERIAL ON THE BENTHIC FAUNA

1. The Control Area.

There are no published studies of the spatial and temporal variations of the fauna within an exposed subtidal sand-bottom community on the west coast. Barnard (1966) described some shallow-water communities from Santa Barbara to San Diego but no seasonal data were presented. Many of the genera and species listed by Barnard were common to this study. Lie and Kisher (1970) surveyed the benthos off the coast of Washington; the shallowest station was at the same depth as the present study's deepest, but he had sampled only once. Temporal studies have been made in other benthic environments on this coast. Jones (1961) studied a mudflat in San Francisco Bay and found that the variations within that community had no seasonal trend. Lie (1968) found no such trends in Puget Sound. On the east coast, Smith (1971) observed no seasonal trend in the changes in community structure on a bottom similar to that in the present study area.

Masse (1972) investigated the fauna in a number of sand bottoms in shallow waters (1.5 to 11 meters) in the Mediterranean. He discussed three major changes that explain the range of variation in quantitative data: (a) Short-term changes that are often correlated with hydrographic or trophic conditions and affect mainly motile macrofauna with little effect on biomass; (b) seasonal changes that are correlated with reproductive and recruitment processes that often vary for different species and have little effect on biomass; (c) long-term changes that are correlated with successful recruitment of new or uncommon species that are irregular and unpredictable events which can affect biomass. For many quantitative data, sampling error must also be added to the list; however, this source of variation can be reduced by establishing permanently marked stations and by prior investigation of sampling methodology, including the detection of gross patchiness or spatial heterogeneity of the fauna.

A quantitative sampling plan was developed at the 20-meter control station in March 1971 and substantiated in March 1972 (App. A). Eight replicate cores sampled 82 percent of the species of worms present in 28 cores; cumulative species diversity stabilized after 4 to 5 cores. Samples of 10 replicates from four progressively larger areas did not differ significantly; the benthos appeared homogeneous along the 20-meter depth contour. Variation among samples at nearly the same time is a good

Figure 9. Seasonal changes in chlorophyll a at several shallow-water stations in Monterey Bay (upper graph) and the mean surface water temperatures from stations in the central bay and the range of station means, (lower graph) (from Broenkow, 1972; Broenkow and Benz, 1973).

check on the adequacy of a sampling methodology. Since variation was low at the 20-meter control station, temporal changes were confidently studied and partitioned into the three groups proposed by Masse (1972).

Because of the bottom stability and general accessibility of the 20-meter control station, ancillary studies were made on the vertical distribution of the infauna (Oliver, 1973), the effect of experimental mass accumulation of sediment, larval settling, and fish predation. Although the faunal assemblage differed between the control station and the disposal area, it did provide an adequate and important measure of the natural variations within a benthic assemblage.

The control transect was located perpendicular to the shoreline on a gently sloping sandflat approximately 1.6 kilometers south of the Monterey Canyon head (Fig. 1). The transect consisted of three stations at 6-, 10-, and 20-meter depths. Prevailing winds and waves approached from the northwest, although the largest winter storms often approached from the south. Currents were primarily tidal, with a net southerly flow. Velocities often reached 50 centimeters per second (Broenkow and McKain, 1972). During many low tides a plume of suspended material from the Elkhorn Slough and Moss Landing Harbor reaches the control area. Turbidity varies seasonally, and is usually highest in the winter because of storms. The Salinas and Pajaro Rivers also add a large amount of particulate matter in the winter rainy season. Yearly temperature fluctuations are presented in Figure 9. Upwelling in the Monterey Canyon head causes periodic temperature changes in most seasons; a variation of 4° Celsius occurred in one tidal cycle. The standing stock of chlorophyll in shallow water fluctuates with the seasons. High chlorophyll values occur in spring and summer; low values in the winter (Fig. 9).

The bottom sediment is mostly fine sand. Seasonal changes at the beach move sand to depths of at least 10 meters (Fager, 1968; Oliver, 1973). Large waves create a dense layer of suspended sand that oscillates inshore and then offshore. The intensity of movement and resuspension of sediments decrease with increasing water depth.

Development of the sampling plan began in March 1971. The first regular sampling was in July 1971 and the last in May 1973. Generally, 8 replicate cores were taken from each station per sampling period; 10 cores were taken in March 1972. All sampling was done by divers using scuba. The corers were 1.4-kilogram coffee cans which were opened at both ends and could be capped underwater and easily transported. Depth of corer penetration was 15 centimeters, and the surface area sampled was 0.018 square meter (15-centimeter diameter). With few exceptions, biological data are presented as number of animals per core or sample (eight cores). Ninety-six percent of the individuals were found about 10 centimeters in the sediment at the 10-meter station, and 93 percent (excluding one species) at the 20-meter station (Table 3). Samples were washed through a 0.5-millimeter mesh screen. The residue was stained with rose bengale and preserved in 10-percent Formalin. All animals were sorted from the debris under a dissecting microscope, transferred to 70-percent ethanol and 5-percent glycerin, and identified to the lowest possible taxon; the number of individuals per taxon was recorded for each core.

One sediment sample per sampling period was taken at each station. Median diameter, sorting (Folk and Ward, 1957), and percent sand and silt were computed using Emery's (1938) tube analysis. Total carbon was measured by a Leco Carbon Analyzer (Table 7).

Table 7. Average sedimentological parameters at the three control stations.

Parameter	Stations 6 m	 10 m	 20 m
Pct carbon	0.08	0.08	0.12
Pct sand	97.3	90.4	92.2
Pct silt	2.7	9.6	7.8
Sorting	0.41	0.44	0.40
Median grain size	0.11	0.99	0.95

Biomass was estimated because of the shallow penetration (15 centimeters) and the small area sampled (0.018 square meter) by the corers. Large animals have the most effect on biomass; they are more widely distributed and live deeper in the sediment (Holm, 1964; Masse, 1972; Smith and Howard, 1972; Oliver, 1973). At the 10-meter control station, 54 percent of the biomass was above 10 centimeters in the sediment; 95 percent was above 20 centimeters (from the top 50 centimeters) of the sediment (Oliver, 1973). At the 20-meter control station, 39 percent was above 10 centimeters and 61 percent above 20 centimeters.

For brevity and clearness, a number of groups were classed under "worms"; over 80 percent of the species and individuals of the worm fauna were polychaetes. The taxa were grouped because of their obvious morphological and ecological similarities (App. B).

The number of species (lowest taxon) was presented in two ways: (a) The total number of species per sample (usually in eight replicates), and (b) the mean number of species per core (0.018 square meter) with 95-percent confidence intervals. These are two distinct parameters, but they generally follow the same trend. The number per core gives a measure of variation.

Species diversity was measured by Shannon and Weaver's (1963) equation; evenness by J (Pielou, 1966). Both were computed for the total sample (Peterson, 1972):

Species diversity = $H'' = \sum_{i=1}^{s} \frac{n_i}{N} \log \frac{n_i}{N}$

S = total number of species

n_i = the proportion of the i^{th} species

N = total number of individuals

H_{max} = natural log of S.

Evenness = $J = H''/H_{max}$

The most important environmental parameters along the control transect are related to wave action. Grain size increases and substrate consolidation decreases with increasing wave action. Movement or resuspension of sediment is undoubtedly the most significant ecological factor. Sediment stability effects species composition and abundance.

The 6-meter station was located near the edge of a large bed of the common sand dollar, *Dendraster excentricus*. The bed moved inshore and offshore in response to wave action. Adult sand dollars were present at the shallow station during certain times of the year; juvenile sand dollars (1 millimeter) occurred sporadically in relatively large numbers at the two deeper stations.

There was a distinct change in sediment stability between the 10- and 20-meter depth and a consequent change in the fauna. The composition of deep sediment strata changed; substrate consolidation and the vertical distribution of the infauna increased (Oliver, 1973). The number of permanent tube and burrow-dwelling animals and the commensals living in the burrows and tubes of other animals (e.g., pinnotherid crabs and scale worms) increased with increasing water depth. The permanent tube and burrow inhabitants included many polychaetes and *Callianassa*. In addition, a number of large bivalves that live deep in the sediment were also present at the 20-meter station. The gaper clam (*Tresus*) was the most conspicuous. Maximum density was reached in 30 meters of water; only a few individuals were found in water shallower than 15 meters. *Tresus* is a sedentary suspension feeder which is intolerant of scouring, deposition, and resuspension of coarse sediment in shallow water.

The crustaceans were dominant at the two shallow stations (Table 8). These were mostly small amphipods and ostracods that are motile and burrow in the top few centimeters of sediment. At the 20-meter station, the worm fauna dominated; this trend also continued into deeper water (Oliver, 1973).

Most of the mollusks were juveniles of the bivalve, *T. modesta* (1 millimeter). A number of other species of juvenile bivalves were present as transient, sporadic members of the assemblages and suffered high mortality

Table 8. Average number of species (S) per sampling period and individuals (N) per core at the 6-, 10-, and 20-meter control stations.

Fauna		Depth					
		6 m	Pct	10 m	Pct	20 m	Pct
Crustaceans	N	34	72	91	56	22	17
	S	10	37	11	22	14	21
Mollusks	N	3	6	35	21	30	24
	S	5	19	11	22	13	19
Worms	N	10	21	37	23	75	59
	S	12	44	28	56	41	60
Total	N	47	--	163	--	127	--
	S	27	--	50	--	68	--

after settlement. The rare adult bivalves were usually found at the 20-meter station.

The 10- and 20-meter control stations were characterized by *N. elegans*. *Euphilomedes* spp. and *Paraphozus* spp. were codominants with *N. elegans* at the 10-meter station; *Magelona* spp. was codominant with *N. elegans* at 20 meters. Adult *Tellina* were rare; they were common in a shallow (16 meters) area studied in the north Monterey Bay (Watson and Stephenson, 1972). The 6-meter station was characterized by small crustaceans and *D. eccentricus*.

Barnard (1963) found that crustacean abundance increased to a depth of 60 meters and was more abundant in deeper water; however, a benthic survey of the north Monterey Bay (16- to 60-meter depths) indicated that crustacean density was highest at the shallowest station sampled (Hodgson and Nybakken, 1973). At the control area, crustaceans were more abundant at the 10-meter station. Lie and Kisher (1970) and Masse (1972) also found a greater number of crustaceans in considerably shallower water than Barnard (1963) did. In addition, the number of crustaceans per meter square at the control area was an order of magnitude greater than that reported by Barnard.

Lie and Kisher (1970) and Masse (1972) noted the same general increase in crustaceans and decrease in worm fauna in shallow water that was observed along the control transect. The primary reason for this separation is the physical stress created by wave-induced sediment movement. Tubes, burrows, and other structures are difficult to maintain in shallow water. Sediment stability allows an increase in habitat diversity, which probably accounts for much of the increase in species from the shallow to deeper stations.

The dominant crustacean at the 20-meter control station was *P. daboius*. There was a highly significant correlation ($r = 0.89$, p 0.001) between the number of *P. daboius* and the total number of individuals. The correlation between the number of species and individuals was not significant ($r = 0.50$, $0.1 < p > 0.05$). *Paraphoxus daboius* was a persistent member of the assemblage and the dominant crustacean in every sampling period, but there was a fairly distinct seasonal trend. The numbers of species and individuals decreased toward the winter and increased in the spring. *Paraphoxus daboius* breeds year round and has a reproductive peak in spring. Most individuals probably live only 1 year.

The only echinoderm present was *D. eccentricus* which was represented only by occasional juveniles and is not included in the total fauna analysis.

The dominant mollusk was *T. modesta*. There was a significant correlation between the total number of individuals and the number of *T. modesta* ($r = 0.91$, $< p > 0.001$), and between the number of species and individuals ($r = 0.76$, $0.01 < p > 0.001$). The only discrepancy was in September 1971 when *Protothaca staminea* were as abundant as *T. modesta*. The *P. staminea* were gone by the next sampling period. *Tellina modesta* abundance through the year characterizes the general temporally sporadic density of juvenile bivalves in the study areas. Again, the largest part of the individuals were juvenile bivalves.

Over 80 percent of the worm fauna were polychaetes. The dominant species was *M. sacculata* with the highest number of species and individuals in summer. There was no seasonal trend in species diversity or evenness in the worm fauna (Fig. 10). Both parameters remained relatively stable through time. The high diversity in October 1972 was primarily due to a large decrease in density; the number of species stayed fairly constant (Figs. 7 and 10).

Species diversity was not computed for the other parts of the fauna because the numbers were too small.

Polychaetes dominated the 20-meter control station (Table 8). *Magelona sacculata*, *N. elegans*, *Lumbrineris luti*, *Prinospio pygmaeus*, *P. cirrifera*, and *Haploscoloplos elongatus* were common persistent members of the worm fauna. An average of 80 percent of the species had an abundance of less than two individuals per core. Seasonal changes in relative abundances were much greater than changes in species composition (Table 3). Many species were found in all the sampling periods. A notable exception was the large terebellid polychaete, *A. occidentalis*, which was common after June 1972, but had not been found before then.

At the 10-meter station, the worm fauna accounted for 60 percent of the number of species and individuals. Changes in the number of species, number of individuals, species diversity, and evenness for the total fauna (Figs. 10 and 11) were similar to changes in the same parameters for the worm fauna (Figs. 7 and 10). The seasonal trend in the number of species and individuals was observed for the total fauna (Fig. 11), and species diversity was fairly constant (Fig. 10). The low values in July 1971 cannot be explained without samples from previous seasons.

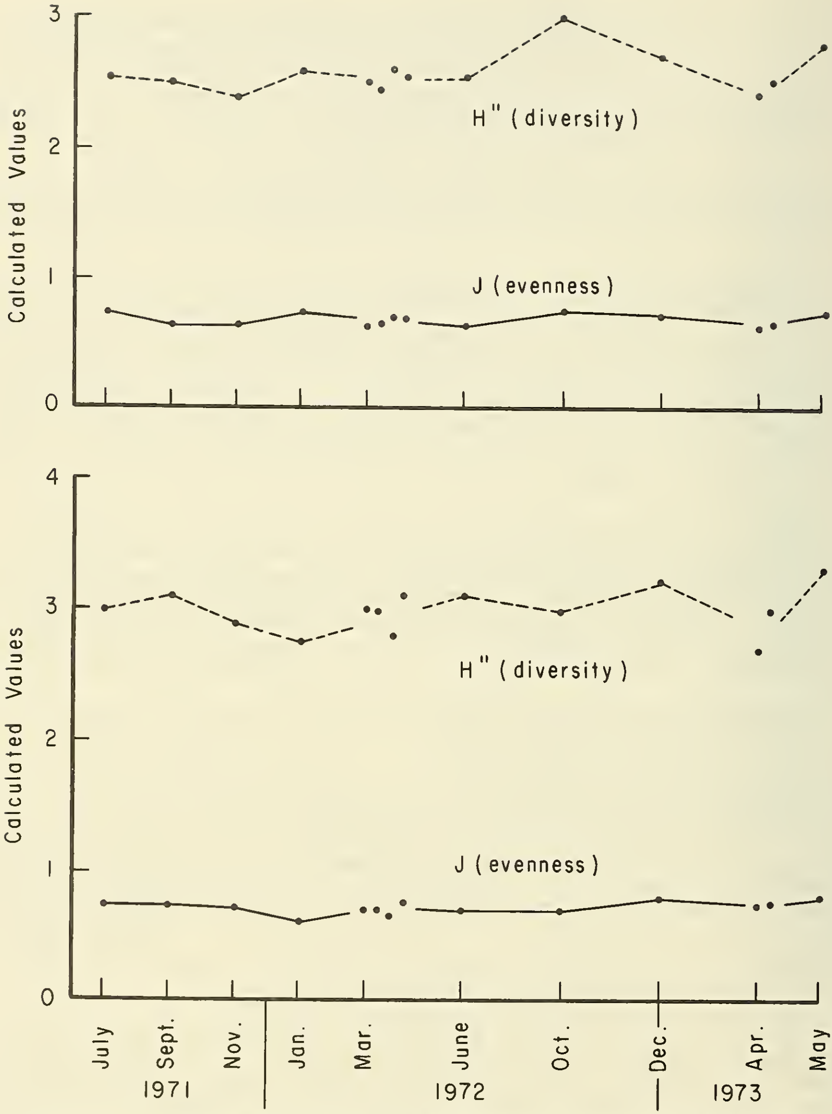


Figure 10. Species diversity and evenness for the worm fauna (upper graph) and the total fauna (lower graph) at the control station.

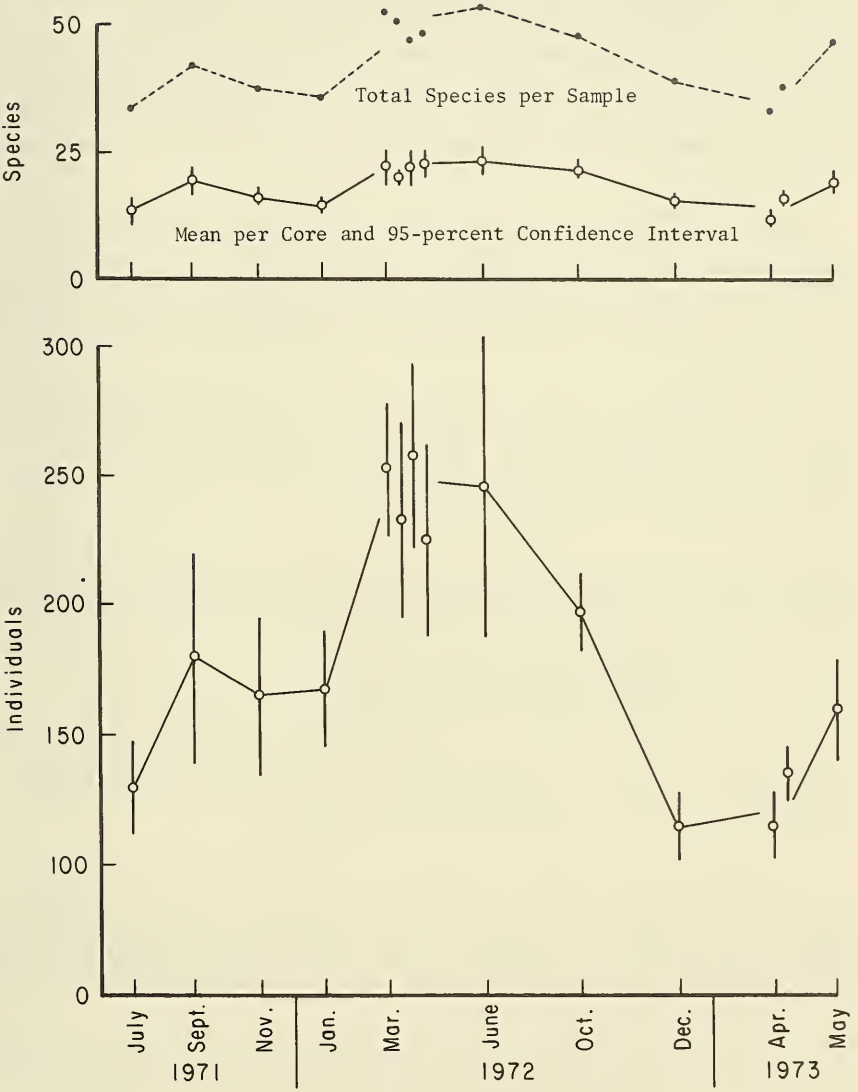


Figure 11. Number of species of total fauna (upper graph) and number of individuals of total fauna (lower graph) at the 10-meter control station.

Short-term changes and cause and effect relationships were the most difficult to detect. Seasonal changes were distinct. Similar seasonal phenomena were also observed at the shallower stations. Reproductive cycles, recruitment processes, and natural mortality explain the general trends. Adverse physical conditions increased mortality and restricted recruitment during winter months. Winter recruitment was probably more successful in deeper water, where wave action had less effect on substrate stability. Thus, physical and biological conditions were both important in determining the observed seasonal variations.

Long-term changes were also observed. The most noteworthy was the successful recruitment and persistence of *A. occidentalis* from June 1972. Another factor that caused long-term irregular variations in the fauna was yearly changes in climatic conditions. These irregular changes favor the successful recruitment of different species at different times. Milder conditions during the first year caused less mortality and spring recruitment was high.

Significant correlations between dominant species and number of individuals indicated that dominants were of major importance in determining the variations. However, at the same time significant correlations between the number of species and individuals indicated a general increase in mortality and recruitment of all species.

The decrease in the number of species with decreasing depth and in the number of species and individuals during winter months suggests that these assemblages are primarily physically controlled (Saunders, 1968).

2. Experimental Burial of the Benthic Fauna.

The 20-meter control station was located on a relatively stable, flat bottom (Fig. 1). The benthic population at this station consisted of small epifauna and shallow infauna. To test the effect of burial under controlled conditions, bottom areas were experimentally buried on two occasions near the 20-meter control station (Fig. 1).

Two open-ended sheet metal frames 1.5 by 1.5 by 1 meter high were pushed 0.5 meter into the sediment. Each enclosed a 2.25-square meter bottom area. Sediment, which was devoid of animals, was dumped into the framed areas until a 15-centimeter layer covered the old substrate. The first frame was positioned on 26 August 1972; the second on 3 May 1973.

Coarse beach sand (median diameter 0.32 millimeter) was placed in the first enclosure in August 1972. Six small cores (7.5-centimeter diameter, 30-centimeter height) were taken at various times from the experimental area during the 2 weeks following burial, and one large core (15 by 30 centimeters) at the end of 3 weeks (Table 9). The cores were partitioned at the interface of the old and new sediment and processed.

Table 9. Effect of experimental burial on benthic fauna[1].

Fauna	Buried enclosure (n = 7)	Control (n = 10)
Crustaceans and mollusks		
Nc	0	153
S	0	24
Worms		
Nc	63	125
S	20	60
Nematodes		
Nc	25	3
S	NA[2]	NA
Mediomastus californiensis		
Nc	12	7
Prionospio cirrifera		
Nc	11	52
Nothria elegans		
Nc	9	5
Gyptis brevipalpa		
Nc	4	2
Notomastus tenuis		
Nc	1	1

[1] Average number of individuals per 0.018-square meter core (Nc) and total number of species (S) are given for the enclosure buried August 1972 and for the nearby unburied control area.

[2] Not available.

Fine sand (median diameter 0.111 millimeter) was dumped into the second enclosure in May 1973. After 1 day, the new bottom was still 15 centimeters above the old; by the third day almost all of the introduced sediment had been scoured out of the enclosure and the original bottom was exposed. The scouring was probably the result of rough seas and use of finer sediment than that of the first experiment. Five days after burial, five cores (15 by 15 centimeters) were taken from the second experimental area, and one from the nearby unburied control area.

Both experiments were concerned with the immediate effects of heavy sedimentation or burial on the benthic fauna. The introduced sand layer in the first enclosure remained intact for the 3-week observation period; the fauna in the second enclosure was buried only 2 days. Since the experimental conditions were not the same, each enclosure is discussed separately.

The first enclosure was observed 24 hours after the initial burial. A large specimen of *Callianassa* sp. (ghost shrimp) and one *Solen sicarius* (razor clam) were found on the surface of the introduced sediment. In addition, the tube-dwelling polychaete, *N. elegans*, had burrowed through the coarse sand and constructed new tubes from it. *Nothria elegans* was one of the few animals whose abundance was not decreased by burial (Table 1); it is also a dominant large polychaete (5 to 15 centimeters long) in water depths from 10 to 30 meters on the open coast of central and southern California (Barnard, 1963).

Specimens of the gaper, *Tresus nuttallii*, had extended siphon holes to the surface of the introduced sediment, similar to those described for the mahogany quahog, *Arctica islandica*, after burial by 9 to 17 centimeters of sediment (Hale, 1972). Neither the gapers nor the quahogs had moved upward. Sailia, Pratt, and Polgar (1972) concluded that slow sedimentation would probably not endanger mahogany quahogs.

The first enclosure data are presented in Table 9, and were compared to samples taken from undisturbed control areas in July and August 1972. All of the small crustaceans and mollusks were killed by burial. They were found dead at the old bottom surface.

Compared with the control, 66 percent of the worm species and about 50 percent of the individuals were killed by burial (Table 9). Polychaetes were the dominant group of worms. There were more nematodes in the experimental area than in the control area. All of the animals that survived the burial are commonly found in lower sediment strata.

There are several animals characteristic of lower strata. Two polychaete worms, *N. elegans* and *Magelona* spp., are active at the sediment surface, live in vertical burrows, and withdraw deep into the sediment when disturbed. Consequently, they were often recorded in lower strata; however, their reactions to burial are different. *Nothria elegans* adjusted to the accumulation of sediment but the magelonids suffered a 90-percent mortality.

In addition to those animals that use the lower strata as a refuge, some are commensals in the tubes and burrows of other organisms. Deep-living commensals must be able to withstand the physical conditions in lower strata, but probably have limited burrowing abilities. They may tolerate a short-term burial, but may be incapable of vertical migration. *Prinospio cirrifera* was commensal in the burrows of *Callianassa* sp. (Oliver, 1973), and survived burial.

Several of the species actively burrowed into the lower strata. Some were usually below 10 centimeters (e.g., *Notomastus tenuis*), but most species were more common nearer the surface. Larger species or larger individuals of these species were generally found deeper in the sediment (Smith and Howard, 1972; Oliver, 1973); however, there were exceptions. One of these *Mediomastus californiensis*, a small capitellid polychaete worm, occurred deep in the sediment.

Low oxygen concentration, low interstitial water content, increased compaction, and high-reducing conditions result from burial, and are characteristic of lower sediment levels.

The bottom in the second enclosure was buried for only 2 days. Data from the five cores taken inside the enclosure, and cores from the control area are presented in Table 10.

Table 10. Effect of experimental burial on benthic fauna[1].

Fauna	Buried enclosure (n = 5)	Control (n = 7)
Crustaceans and mollusks		
Nc	6	34
Sc	4	11
St	9	29
Worms		
Nc	50	76
Sc	14	19
St	27	44
Total fauna		
Nc	55	110
Sc	17	30
St	36	73

[1] Average number of individuals per 0.018-square meter core (Nc), average number of species per core (Sc), and total number of species (St) are given for the enclosure buried May 1973 and for the nearby unburied control area.

Larger animals were able to withstand the short-term burial better than smaller ones. About 82 percent of the individuals and 69 percent of the species of crustaceans and mollusks were killed by the burial (Table 10). Percentages are based on a comparison of sample from the enclosure and control stations. Survivors in these groups were all larger individuals.

Worm mortalities were again low. About 34 percent of the number of individuals and 39 percent of the species were killed (Table 10). Most of the larger worms lived after burial; mortality was higher for smaller species and individuals. Very few juveniles of polychaete worm, *Magelona sacculata*, and no specimens of the polychaete, *A. occidentalis*, were present in the enclosed area, yet they were common outside.

Two polychaete worms, *M. californiensis* and *P. cirrifera*, survived the burial and their numbers remained similar to those of the control stations. They also tolerated burial in the first experiment (Table 9), and were common below 10 centimeters in the sediment.

In both experiments, members of the worm fauna (primarily polychaetes) were least affected by burial. Survival was highest in the active burrowers, and especially those active burrowers common in lower sediment strata. Small species and individuals of larger species were generally less tolerant of burial. The only exceptions were inhabitants of the lower strata. Surface-dwelling crustaceans and mollusks were most affected by the deposition; all died in the first experiment.

Capability to withstand burial can be predicted by animals' morphology, behavior, usual vertical distribution in the sediment, and stability of the substrate inhabited. These experiments present new information and agree with the review presented by Sailia, Pratt, and Polgar (1972).

At the disposal site (canyon head), the fauna is adapted to a larger amount of seasonal sediment movement. The dominant animals were active deposit-feeding polychaetes that apparently restricted the presence of small crustaceans and mollusks. The disposal caused a 60-percent reduction in the number of individuals and an 8-percent reduction in the number of species. On the stable flat bottom, 50 percent of the individuals and 66 percent of the species were killed by the first experimental burial. The two locations were subjected to different types of deposition, but the data are still comparable. Canyon fauna is much better adapted to the effects of mass accumulation of sediments. Investigations have involved only the shallow canyon head, and do not necessarily apply to deepwater assemblages.

3. The Effect of Disposal on the Benthos.

The effect of dumping dredged materials on the benthos was reported by O'Neal and Sceva (1971) and Sherk (1971). Sailia, Pratt, and Polgar (1972) reviewed the most pertinent studies. Where disposal did create a continuous stress and the toxic content was low, recovery of the benthos was completed within 1 to 3 years (Virginia Institute of Marine Science, 1967; Harville, et al., 1967; Pfitzenmeyer, 1970; Sailia, Pratt, and Polgar, 1972).

This section deals primarily with the 20-meter canyon station, which received most of the dredged material. It describes the effect of dumping on an assemblage adapted to conditions of natural sediment movement and the details of recovery.

Stations (Fig. 1) were marked with permanent buoy systems (Slattery and Oliver, 1972). Major disposal occurred in August 1971. Twelve samples of eight cores each were taken between July 1971 and April 1973. Two predisposal samples of eight replicate cores each were taken on 14 July 1971, the first postdisposal samples on 6 September 1971, and the last two samples on 4 April 1973. Sample replication in July and April is presented as a measure of spatial variation within the 20-meter station. Sampling dates are shown in Figure 12.

The benthic assemblages at the 20-meter station were dominated by two species of capitellid polychaetes, *Heteromastus filobrachus* and *Capitella capitata*. The *C. capitata* were mostly large adults. *Heteromastus filobrachus* were commonly found in the longshore submarine canyon by Hartman (1963). Both animals are deposit feeders that do not maintain a permanent burrow system. Permanent tube or burrow dwellers present were the polycheates, *M. sacculata* and *N. elegans*. Mollusks and crustaceans were scarce (one or two per core). Thus, the benthos consisted primarily of an active burrowing deposit-feeding assemblage of polychaetes.

Approximately 0.26 meter of dredged material was deposited at the 20-meter station. Fine sands were dredged and dumped first; muds were last. Median particle size of the bottom sediment changed from 0.212 millimeter before disposal to 0.111 millimeter soon after disposal (September 1971), total carbon from 0.13 to 0.64 percent by weight, sorting from 0.51 to 0.97, and silt from 07.8 to 22.2 percent. In November 1971, 0.26 meter of sand moved over the station from shallow water. Most of the finer dredged material was transported to deeper water, but some was covered by sand. A mud layer of varying thickness was present below this. The layer was not observed 2 months later. Changes in topography caused by the disposal probably allowed more sand than usual to move over the station. Sediment parameters changed little during the remainder of study. Average median particle size was 0.125 millimeter, total carbon 0.12 percent, sorting 0.45, and silt 8.5 percent. Bottom surface level was relatively stable during the 1972-73 winter.

Disposal caused approximately a 60-percent reduction in the number of individuals. No large *C. capitata* were found in September 1971, but a number of small individuals had settled. By October 1971, the density of small *C. capitata* was 200 per core. *Capitella capitata* also settled in large numbers at the dredged harbor station in October 1971 and in the settling jars in October 1972. In November 1971, they were found in dense patches that caused the high variation in the data that month; by January 1972 they were gone.

Capitella capitata is a well-known opportunistic species which appears in disturbed areas where competition is low (Hutchinson, 1951; Margalef,

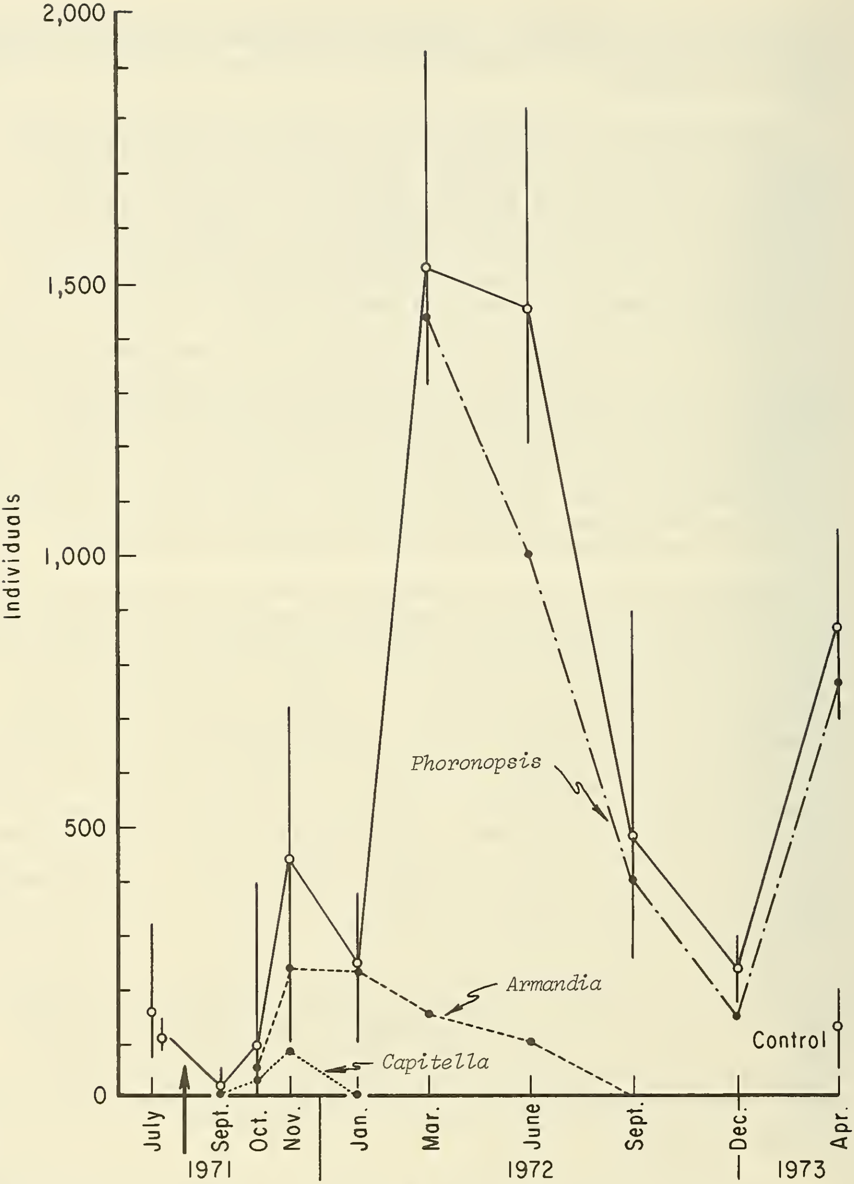


Figure 12. Number of individuals of the total fauna and dominant species at the 20-meter station before and after dumping (arrow indicates dredging).

1963; Connell, 1972). It has a short reproductive cycle (1 month) and probably has poor competitive and high dispersal abilities (personal communication, Dr. Reish, Long Beach State College, 1972). The worm is often found in polluted marine harbors, near sewage discharges, and in other areas of natural or unnatural stress (Reish, 1955, 1957; Felice, 1959; Rosenberg, 1972); it is also common in the mudflats and muddy bottoms in Elkhorn Slough and Moss Landing Harbor.

The dredge spoil disturbance caused a slight drop in the number of species. During recovery the total number of species rose to a high in June 1972, and decreased steadily thereafter. The number of species and individuals at the control (Fig. 11) and the dredged harbor stations (Figs. 12 and 13) were also highest in June 1972. These June peaks may be related to seasonal or possibly long-term variations rather than any time sequence characteristic of recovery. The sequence and rate of recovery (or recolonization) are probably a function of the initial time of exposure and the particular set of ecological conditions present during the recovery period.

During recovery, species composition was more stable than relative abundance. The common species and their abundances for each sampling period are listed in Table 4. Mollusks and crustaceans were irregular members of the assemblage; many of the worm species were present throughout the study period.

In June 1972, the polychaete worm, *A. occidentalis*, settled at the disposal and control stations. It was uncommon at both locations before June, but was more abundant later at the disposal station. This large terebellid polychaete lives in a semipermanent U-shaped burrow, and is capable of burrowing deep into the sediment. Its tentacles are usually spread just below the bottom surface and their expanded distal ends extend into the water column.

Changes in species diversity and evenness followed a trend similar to that for the number of species (Fig. 14). Disposal had little effect on their values. The bloom of *Capitella* in October 1971 lowered evenness and consequently diversity. Both parameters increased until June 1972. After the dumping, density was much lower (Fig. 15), but the dominants accounted for a similar percentage of the total. In June, no dominant mollusks (Fig. 15) were present and the number of species was highest (Fig. 14). A large population of juvenile *Tresus* settled in December 1972 (Fig. 15), and both parameters decreased (Fig. 14). The combination of an increase in the number of species and a decrease in the abundance of the two predisposal dominants *Heteromastus* and *Capitella*, caused evenness and diversity to increase. Thus, recovery from disposal resulted in a more diverse fauna, although an earlier large decrease was observed because of the large number of juvenile *Capitella*. This general increase in diversity is undoubtedly related to the increase in substrate stability and structural diversity due to the presence of *Amaeana*.

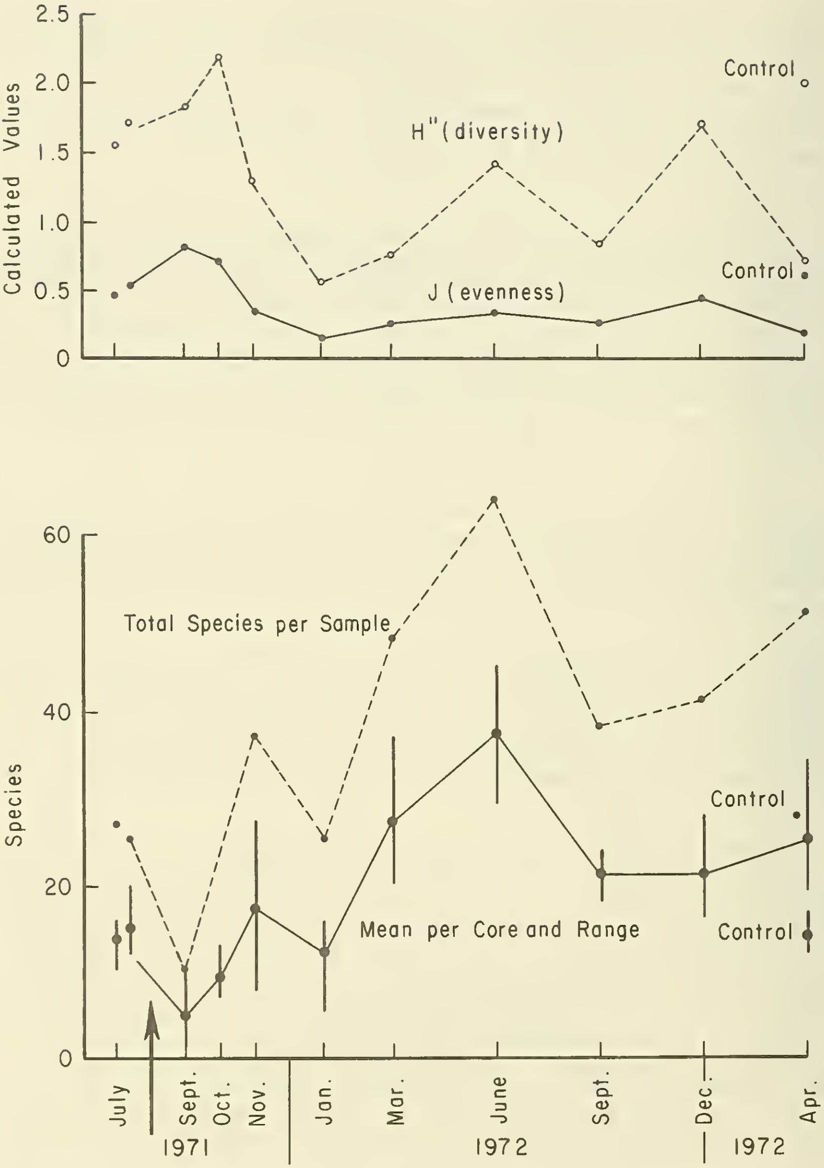


Figure 13. Species diversity and evenness of the total fauna (upper graph) and number of species of the total fauna (lower graph) (arrow indicates dredging).

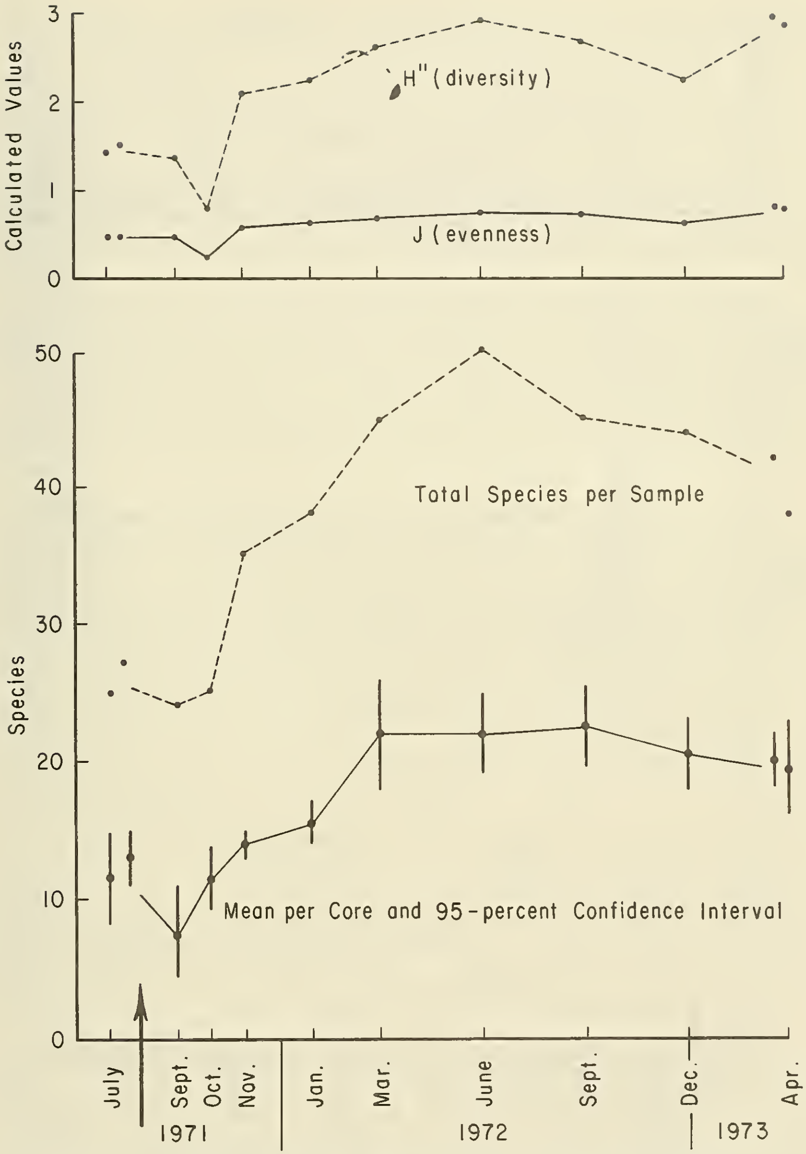


Figure 14. Species diversity and evenness of the total fauna (upper graph) and number of species of the total fauna (lower graph) (arrow indicates disposal).

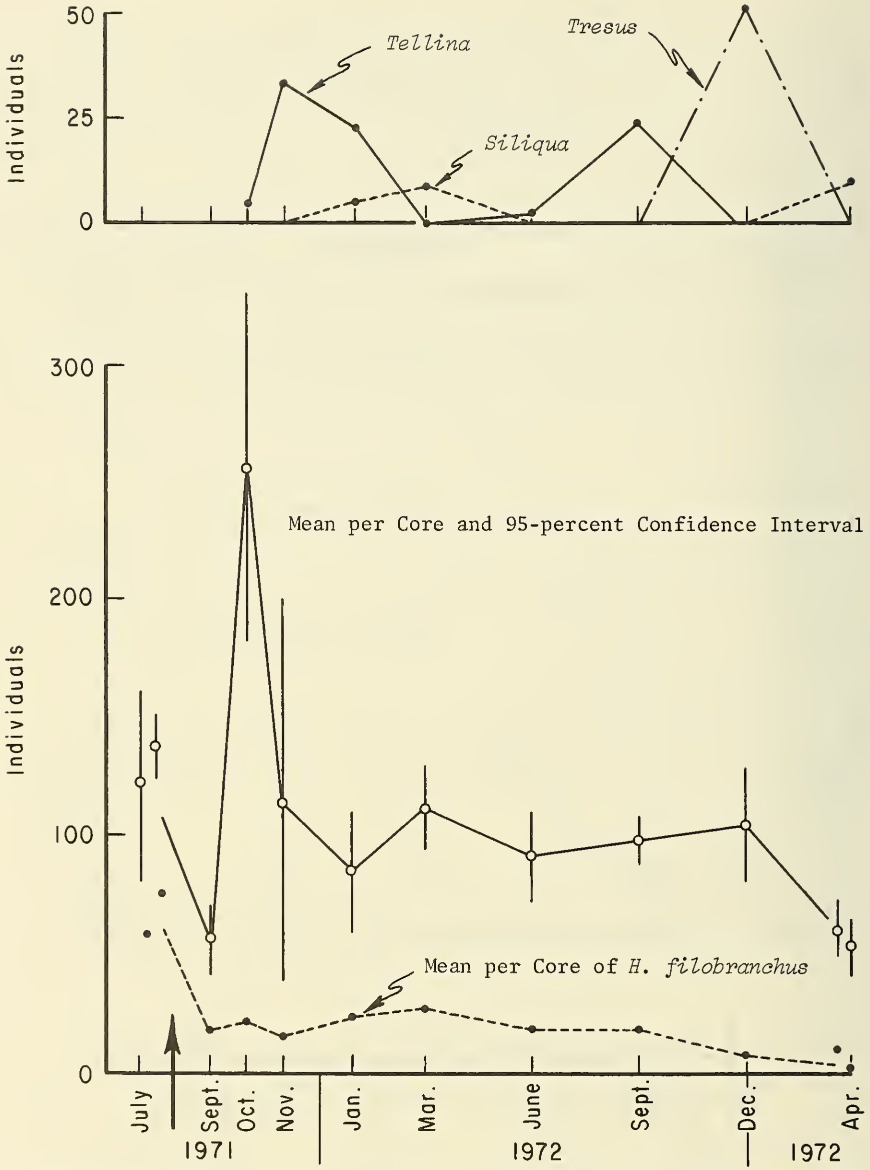


Figure 15. Mean per core of juvenile bivalves (upper graph) and number of individuals of the total fauna and *Heteromastus filobranchus* (lower graph) (arrow indicates disposal).

About 1.5 years after disposal, the number of individuals was still 60 percent lower than before disposal. This reduction was as great as that immediately after the disposal (Fig. 15). The number of species and species diversity and evenness were considerably higher (Fig. 14). There was little change in biomass because of the large terebellid, *A. occidentalis*. These results were different from those reported by Pfitzenmeyer (1970) who studied the recovery of a disposal site in an estuarine environment. He concluded that after 1.5 years the same species reestablished in the disposal area, and biomass and species diversity were similar to predisposal levels. The general pattern of recovery in the present study was similar to that observed by Sailia, Pratt, and Polgar (1972).

Paine (1966) and Dayton (1971) described the effect of biological and physical disturbances increasing diversity in rocky intertidal communities after clearing space occupied by the competitive dominant. Dayton and Hessler (1972) discussed the role of disturbance in maintaining high diversity in the deep sea. In contrast, Deevey (1969) reviewed the negative correlation between disturbance and evenness; in southern California, Peterson (1972) experimentally disturbed bivalve assemblages and reduced evenness.

No general trend exists between disturbance and species diversity or its components. Sampling over a large disposal area, Sailia, Pratt, and Polgar (1972) reached the same conclusion in relation to disturbance of the bottom by dredged material dumping. In the present study, dredged material disturbance reduced the numerical dominants (and possibly competitive dominants); species richness and evenness increased during recovery. The bottom consisted of fine sand. Although turbidity is generally high, strong tidal currents flush the channel several times a day, keeping the bottom free of fine sediments and stagnant water. Current velocities often exceed 100 centimeters per second. The average water temperature was 13° Celsius (range, 9° to 17° Celsius, and salinity varied from 31.5 to 33.8 parts per thousand with a mean of 33.4 parts per thousand) (Broenkow and Smith, 1972).

In July 1971, two samples of eight replicates each were taken from the harbor station before dredging; the fauna at the control and dredge stations were similar. Individual species (three capitellid polychaetes and one oligochaete) (Table 5) were dominant. The dominant polychaete was *Notomastus tenuis*, which was also dominant in the mudflats of lower Elkhorn Slough and in the north harbor. The oligochaete occurred in the highest numbers, but represented less than 5 percent the biomass of *N. tenuis*.

Two species of large bivalves dominated the biomass. The bent-nosed clam, *Macoma nasuta*, which is an active suspension and deposit feeder, was more numerous than the large suspension-feeding gaper clam, *Tresus nuttallii*. Both animals live in the lower intertidal mudflats to water depths of a least 40 meters. Because the gaper was uncommon, essentially sedentary, and lived deep in the sediment, it probably had little direct effect on community structure.

VI. THE EFFECT OF DREDGING ON THE BENTHOS

1. Introduction.

There are few studies of community development in unconsolidated marine sediment. Reish (1961a, 1962, 1963) observed no obvious sequence of colonization in recently dredged boat harbors in southern California. The principal species were present during the entire study period. Sailia, Pratt, and Polgar (1972) described a general pattern of colonization for the Rhode Island Sound disposal area that was similar to the disposal area in this study. Species arrived in order of their power of dispersal. Motile animals moved in first, and within a year nonselective larvae of opportunists settled.

Migrations of animals into the dredged and the disposal areas at Moss Landing were not observed. Larvae of opportunists were the first to settle in the dredging and disposal areas, although at the disposal station their numbers were apparently restricted by the presence of animals that survived the dumping.

There is no evidence that opportunists alter or prepare the environment for later species. Evidence does support Connell's (1972) argument that the sequence is related to life history characteristics of opportunists and dominants rather than site modification by pioneers.

2. The Control and Harbor Stations Before Dredging.

A permanent station was located in 6 meters of water along the edge of the Moss Landing Harbor entrance channel (Fig. 1) where dredging occurred. The middle of the channel was not dredged in this part of the harbor; the area served as a control station about 25 meters from the dredged station.

In summary, before dredging the harbor station and control were inhabited by a deposit-feeding assemblage of active, burrowing infauna. The dominant species are listed in order of abundance in Table 5.

3. Recovery of the Benthic Fauna.

The harbor station was dredged in late August 1971. The bottom was dredged 1.5 meters below its original level, exposing patches of clay that were gradually covered by fine sand from the steeply cut channel wall. The first postdredging sample was taken on 12 September 1971; the last ones on 2 April 1972. Lateral movement of fauna into the dredged area was slight and restricted to large mobile epifauna (decapods and gastropods), and possible some bivalves (Peterson, 1972).

Eighty-six percent of the total number of individuals were removed by the dredging. Most of the specimens taken in September 1971 were recently settled *A. bioculata* (polychaete), and some oligochaetes. The dominant deposit-feeding capitellids and bivalves were absent; the biomass was drastically reduced.

In October 1971 the polychaetes, *A. bioculata* and *C. capitata*, settled in large numbers. Both animals have a larval settling peak in the fall, are small (1 centimeter) surface deposit feeders, and are common in the slough and harbor. *Capitella capitata* is generally found in muddy deposits, but is known to invade disturbed habitats. By January 1972, all the *C. capitata* were gone.

The density of *A. bioculata* remained about the same from November 1971 to January 1972, decreased in March and June 1972, and further decreased in September 1972 (Fig. 12). From November to January there was a definite increase in individual size. *Armandia bioculata* had another settling peak in the spring and additional recruitment probably occurred at that time.

The decline in the number of *A. bioculata* was undoubtedly precipitated by the tremendous settling of *Phoronopsis viridis* in March 1972 (Fig. 12). *Phoronopsis viridis* is a suspension-feeding phoronid worm that builds and lives in a permanent sand tube. The new population reached adult size by June 1972, with a density of about 1,000 individuals per 0.018 square meter. As the phoronids grew, their tubes occupied more space, drastically reducing the amount of the deposit-feeding habitat, thus, decreasing the number of *A. bioculata*. Woodin (1972) supports this conclusion with experimental evidence. She found that the density of *A. brevis* on San Juan Island, Washington, increased when the larvae of several tube-building polychaetes were prevented from settling. She concluded that the increase in *A. brevis* abundance was the result of decreased interspecific competition for space.

Little is known about the ecology of *A. bioculata* which has the characteristic of an opportunistic species, similar to *C. capitata*.

From March 1972 until April 1973, *P. viridis* dominated the benthic assemblage. Its density dropped steadily from the March settlement to December 1972, and in April 1973 there was a second large recruitment. *Phoronopsis viridis* may spawn into the early summer; however, in both years early recruitment and fast growth left little space for additional settlement. In March 1972, about 1,200 individuals per core settled, and 200 *A. bioculata* per core were present. In April 1973, about 500 phoronids per core settled in a population of large adults (200 per core). The difference in recruitment between successive springs again suggests that available space limits the number of settling larvae.

Several species of bivalves settled in relatively large numbers at times during recolonization (Table 5). Most were gone by the next sampling period and very few reached adult size. The situation was similar at the disposal station. Settling conditions were optimal for a short period, and subsequent events caused heavy mortality. Apparently, the environment was marginal for most of the bivalves.

Very few crustacea were present, although occasionally a number of amphipods, *Caprella* sp., were found on small clumps of algae (*Ulva*) or hydroids (*Aglaophenia*).

Larval settling in the harbor was observed at the control station and the dredged station. At the control station, undisturbed by dredging, no great number of larvae settled and persisted, either because they selected not to settle or they settled and were eaten by the existing residents, *Notomastus tenuis*, a large deposit-feeding worm. In contrast, a newly exposed surface at the dredging station was recolonized by several species in large numbers (the tube worm, *Capitella*, the polychaete, *Armandia*, and the plumed worm, *Phoronopsis*). Presumably, competition for space resulted in phoronid dominance. By April 1973, the dredged area supported a population of adult *P. viridis*. At that time, there was another large recruitment of phoronids and no significant, detectable settlement of polychaetes, although *Armandia* was present in the water and a persistent patch of *P. viridis* was established at the dredged station. What was once an active-burrowing, deposit-feeding assemblage was replaced by sedentary, suspension-feeding tube worms. The patchy distribution of animal assemblages in the slough and harbor probably increases the number of alternate sequences and end products of recolonization. In a stable, homogeneous benthic community such as the offshore 20-meter control station, the probability of reestablishing both trophic and taxonomic structure after disturbance is considerably higher.

The number of species decreased over 60 percent from July to September 1971, immediately following dredging. The biomass was small in September because the individuals were small and apparently newly settled. After September the number of species increased to a maximum in June 1972, when there were twice as many species as before dredging. By September 1972, the number of species remained relatively stable, but was above predredging values. There was a decrease in the number of species in January 1972, and an increase in April 1973. This was probably the result of winter mortality and spring recruitment, respectively.

The control area was sampled in April 1973 and the fauna was similar to that at the dredge station before dredging (Figs. 12 and 13). The variation in species per core was small at all stations. There was a significant difference between the values in July 1972 and the species per core after recolonization (April 1973).

The rate of recolonization (Fig. 13) and also the rate of recovery at the disposal station (Fig. 14) were similar to that determined in other investigations (Reish, 1963; Odum 1969; Simberloff and Wilson 1969, 1970).

Species diversity, H'' and evenness, J, did not follow the same trend as the number of species (Fig. 13). Species diversity and evenness before dredging and at the control station in April 1973 were similar, but differed from the dredged station after recolonization (Fig. 13). Diversity increased directly after dredging, although the density and number of species decreased (Figs. 12 and 13). This was primarily due to the even apportionment of individuals among the few species present. In October 1971, evenness dropped slightly, but the number of species increased from 10 to 22; diversity also increased (Fig. 13). In November 1971, the dominant species were *Capitalla* and *Armandia*. By January 1972, the number of species had decreased and *Armandia* was the only abundant animal (Fig. 12). Both diversity and evenness dropped by winter. From January to June 1972, the number of species more than doubled (Fig. 13); *Armandia* and several species of bivalves (mostly juveniles) were present in large numbers. Despite the fact that the density of *Phoronopsis* was an order of magnitude greater than the second most abundant animal (Fig. 12; Table 5), both evenness and diversity increased (Fig. 13). In September 1972, *Armandia* and bivalve densities were very low; the number of species decreased from 64 to 38 (Fig. 13), and *Phoronopsis* was the only abundant species. Evenness and diversity both decreased (Fig. 13). From September to December 1972, *Phoronopsis* density decreased from 412 per core to 154 per core (Fig. 12), causing an increase in evenness and diversity (Fig. 13). Finally in April 1973, the large spring recruitment tripled the density of *Phoronopsis* (Fig. 12), and evenness and diversity decreased again (Fig. 13).

By comparing Figures 12 and 13 it is apparent that species diversity cannot be properly interpreted without information on the number of species (richness) and their relative abundances (evenness).

Some of the decreases in species diversity were related to life history characteristics, mortality caused by physical stress, or perhaps predation and competition. Increases were associated with the same phenomena under differing conditions, except there was no indication that competition increased diversity.

At the disposal station, there was a marked increase in the number of species, species diversity, and evenness during the later phase of recovery (Fig. 14). At the dredged station, there was an increase in species diversity and evenness after almost complete removal of the native fauna; 1.5 years later the diversity was still much lower than it was before dredging because of *Phoronopsis* dominance (Fig. 13). Thus, the effect of dredging and disposal was not a decrease in species diversity. The reestablished or recuperated assemblages differed considerably from the originals; in one case, the diversity was higher and in the other, lower.

There is no positive correlation between species diversity and the "health" or "desirability" of any of the above situations. Therefore, the use of this parameter in summarizing community structure or changes in this structure due to man's activity is not recommended.

The sequence of recolonization at the dredged station involved two relatively distinct phases. In the earlier phase, the opportunistic or fugitive species quickly colonized the open space; i.e., *Capitella* and *Armandia*. They are generally considered poor competitors, and are relatively small, with short reproductive cycles, fast growth rates, and high dispersal capacities (Hutchinson, 1951; Margalef, 1963; Odum, 1969; Connell, 1972). In the second phase, the community dominant was established; i.e., *Phoronopsis*. Dominant species have a longer life cycle, larger size, and superior competitive abilities (Margalef, 1963; Odum 1969; Connell, 1972).

Whether the colonized phoronid patch is a stable assemblage or merely a stage in a long-term sequence of recolonization is unknown. The dominant deposit feeders present before dredging and adjacent to the patch might invade and successfully exclude the tube dwellers. There is a spectrum of possibilities, and as mentioned earlier, it is just as likely that the patchy nature of the slough bottom increases the number of possible sequences of recolonization and stable end products. In Buzzards Bay and Cape Cod Bay, Massachusetts, studies have shown the persistent separation of communities of deposit-feeding and suspension-feeding animals (Rhoads and Young, 1970, 1971; Levington, 1972). Maintenance of this separation is apparently due to sediment characteristics and the behavior and ecological requirements of the two trophic groups. In this study, the sediments do not differ, but the adults of one trophic group may prevent recruitment of the other.

The similarity between the predredging and control conditions 1.5 years later is remarkable. It appeared to be a very stable deposit-feeding assemblage, although there were changes in the species composition. In contrast, the recolonized harbor area was completely different, in terms of species number, composition, number of individuals, species diversity, evenness, and trophic dominance.

There is a need for experimental studies to determine the importance of physical phenomena, life history characteristics, and animal interactions in benthic communities. If this information was available, the relationship between community structure (spatial heterogeneity) and temporal changes, including recolonization, could be adequately studied for marine ecosystems.

VII. SUMMARY AND CONCLUSIONS

The benthic assemblages differed with changes in amount of sediment movement or substrate stability. Many animals were characteristic of the relatively stable submarine ridges but few inhabited the unstable terrace slopes. Even fewer animals were found in channeled areas, and their numbers decreased with increasing sediment movement and accumulation. Accumulation of sediment directly buried animals and seaweed. Burying the animals and algae raises the decomposition rate, thereby decreasing available oxygen and increasing hydrogen sulphide concentrations to toxic levels. Sediment movement was the most important environmental factor affecting the distribution of macroinvertebrates at the control area and in the canyon.

Dredging removed 60 percent of the original population of benthic animals. After 1.5 years, the number of individuals was low but the species diversity and evenness indexes were higher than before dredging.

Reproductive activity of the benthic organisms has two peak periods correlated with the winter-spring and fall-winter seasons. Both seasons are characterized by the rapidly changing length of days. Two peak phytoplankton blooms also coincide with the two periods of high reproductive activity by the benthos that frequently have young that form part of the zooplankton and feed upon phytoplankton. Many of the benthic animals are sporadic spawners; some spawn in winter and others almost all year long. Yearly changes in currents, water temperatures, and wave energy at critical early life can affect the successful settlement of benthic animals and cause the composition of benthic populations to differ yearly.

Experimental burials were made at two enclosed areas on the stable flat bottom at a water depth of 20 meters. One of the areas was covered with coarse sand to a depth of 15 centimeters and sampled at various times during the 2 weeks following burial. The other area was covered with fine sand to the same depth but by the third day the covering had been scoured away and the original bottom exposed. This area was sampled 2 and 5 days after burial.

The first enclosure had several tube-dwelling worms (*Nothria*) burrow up through the coarse sand and construct tubes from it. *Nothria* was one of the few animals whose abundance was not decreased by burial. Some gaper clams extended their siphon holes to the new surface. All the small crustaceans and mollusks were killed by burial; burial also killed 66 percent of the worm species and 50 percent of the individuals. All of the animals that survived burial are commonly found deep in the bottom. Nematode worms increased in the experimental area.

The bottom of the second area was buried for only 2 days. About 69 percent of the species and 82 percent of the individual crustaceans and mollusks were killed by the short burial. Worm mortalities were low.

Disposal of the dredged material affected benthic animals in a less stable substrate. There was an 8-percent reduction in the number of species and a 60-percent reduction in the number of individuals.

Capability to withstand burial can be predicted by the animals' structure, behavior, usual vertical distribution in the bottom, and the stability of the substrate normally inhabited.

One and one-half years after disposal, the number of individuals was still 60 percent less than before disposal. However, the number of species, species diversity, and evenness was higher than before. Biomass was little changed although the species composition had changed.

The immediate effect of dredging upon the channel area was to remove the two species of large bivalves (the bent-nosed clam and the gaper clam) that dominated the biomass. The bent-nosed clam was more numerous than the larger gaper. Many oligochaete and polychaete worms were also removed. The original population was a stable deposition-feeding assemblage. In contrast, the recolonized area was completely different after dredging and also differed from the control area. Species number and composition, number of individuals, species diversity, evenness, and trophic dominance all changed.

The sequence of recolonization after dredging occurred in two parts: First, two opportunistic species (worms *Capitella* sp. and *Armondis* sp.) quickly occupied the newly exposed bottom. They are poor competitors, and have a short reproductive cycle and high dispersal capabilities. Second, the community dominant, *Phoronopsis*, became established and was still dominant after 1.5 years.

Temporal variations in bottom communities, the sequence and rate of colonization, and the end state of recolonization can be predicted only if the reproductive patterns of the local benthic fauna are known; e.g., larvae settling jars and benthic samples. Data from the different sources show that many of the benthic organisms spawn in the spring and fall seasons although some animals reproduce throughout the year.

Organisms adapted to unstable bottom conditions survive burial better than others do; however, disposal caused about 60-percent reduction in the number of individuals in the area. The number of different species dropped slightly. During recovery the number of species increased for the first year then decreased. Species composition was more stable than relative abundance. Many worm species were present throughout the study period but mollusks and crustaceans occurred irregularly. The number of individuals was still 60 percent lower 1.5 years after disposal, but the species diversity and evenness were higher.

The results of this study suggest:

1. The ultimate recovery or recolonization of a dredged area or a disposal area depends upon the timing of the action in relation to the reproduction cycles and distributive abilities of the benthic organisms present in and around the area.

2. In Monterey Bay, spring and fall are the most active spawning seasons for many benthic organisms; dredging or dumping should be avoided at those times.

3. Underwater disposal of dredged material should be made in unstable areas if possible.

4. Dredged areas or disposal areas may take more than 1.5 years to return to the original conditions.

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APPENDIX A

DEVELOPMENT OF A QUANTITATIVE SAMPLING PLAN

I. INTRODUCTION

Generally, it is not possible to study the sampling problems involved with a particular environment and set of research objectives before the initiation of benthic surveys. As a result, development of a sampling plan often depends upon information generated from other studies and the experience of the investigators. This is to be expected since one of the primary objectives of many surveys is the identification of the fauna.

The objectives of this study were more specific and required a prior understanding and reduction of the variations due to sampling error. Sampling was restricted to a few permanent stations that were maintained and sampled by divers within a locally defined area.

Three major problems should to be solved to develop a quantitative sampling plan for the study area:

(a) Does the sampling device catch all or most of the organisms found in a given volume of sediment?

(b) How many replicates must be taken to be confident, within certain statistical limits, that the parameters used to describe a fauna are adequately estimated?

(c) How should the replicates be distributed over the environment?

II. THE SAMPLING DEVICE

The sampling device is a standard 1.4-kilogram coffee can with both ends removed. Careful placement of corers by divers minimizes bottom disturbance and snap-on plastic lids create a watertight seal that allows transportation of intact sediment cores both in water and air. Depth of penetration can be adjusted by diver operation so the constant surface area (0.018 square meter) is associated with the same volume of sediment. Corers were inserted to maximum penetration which produced an average core height of 15 centimeters.

Quantitative measurements of biomass were not made since they require a sampler that covers a large surface area and penetrates deeper than 15 centimeters into fine sand (Masse, 1968; Oliver, 1973). This is primarily due to the effect of sparsely distributed large animals on the biomass.

A recent comparison of benthic samples taken with the 1.4-kilogram coffee can corer, a diver-operated suction dredge, and a Smith-McIntyre grab at Moss Landing indicated that all three techniques produce similar estimates of the number of species per unit area, number of individuals per unit area, and index of species diversity (personal communication, Hodgson, Moss Landing Marine Laboratories, 1972). The small area sampled by the corers had a significant effect on estimates of the abundance of certain larger and less common species, and on the total number of species in the community. However, the other sampling techniques had disadvantages of equal magnitude. Thus, the use of coffee can corers is adequate for sampling when compared to other conventional sampling techniques. In addition, the hand placement by divers permits good replication and precise control of the area sampled.

III. THE NUMBER OF REPLICATES

A number of parameters were used to describe the benthic infauna: The number of species, total number of individuals, number of individuals per species, and species diversity. To determine the number of replicate corers needed, the precision of estimating as many of these parameters as possible should be maximized.

Twenty-eight cores were taken from an area near the 20-meter control station to examine the relationship between the parameters listed and the number of replicate cores collected. The 28 cores were taken from the three smaller areas in Figure A-1. This number of cores is well above the maximum which would be taken at any one station in a routine sampling program. Although sampling was not strictly random, individual cores were chosen at random from the combined group (28 cores) for the following analyses.

1. Number of Species.

Species were recorded in two ways: The total number of species collected in all cores (species per sample), and the average number per core. Both are sample values which grossly underestimate the actual number of species in the community, but are very useful as relative parameters. Averaging the number per replicate allows a measure of variance. However, a single core collects fewer species than the total sample which covers enough area to include most of the characteristic species though many of these occur in low abundance.

The slopes of the curves in Figure A-2 indicate the rate at which new species are accumulated as the area sampled is increased (Jones, 1961). They are averaged from three random orders of the 28 cores. Considering all 28 cores as 100 percent, 16 cores represent 57 percent of the area and contain 92 percent of the species, 8 cores are 30 percent of the area with 76 percent of the species, and 4 cores are 14 percent of the area and 57 percent of the species. Hodgson (personal communication, 1972) found the corer was compared to two other devices which sample a much larger area; however, almost identical ratios of percent area to percent species were found for all three devices.

To examine the relationship between the number of replicates and the estimation of number of species per core, replicates were drawn at random from the 28 cores; means and confidence limits were computed for

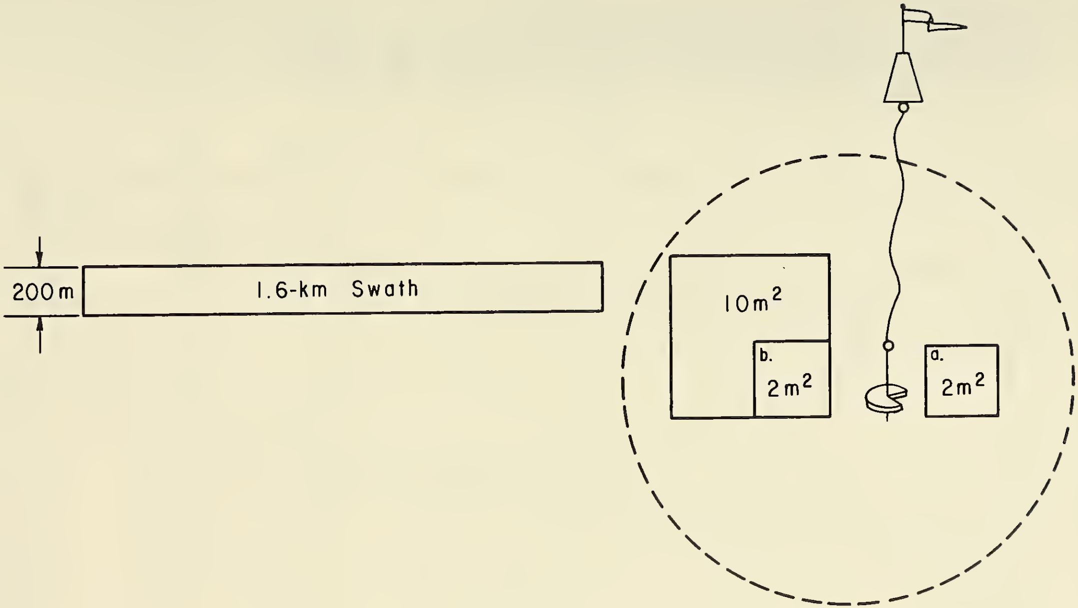


Figure A-1. Schematic diagram (not to scale) of the 20-meter control station (encircled) and vicinity showing the three sampling areas.

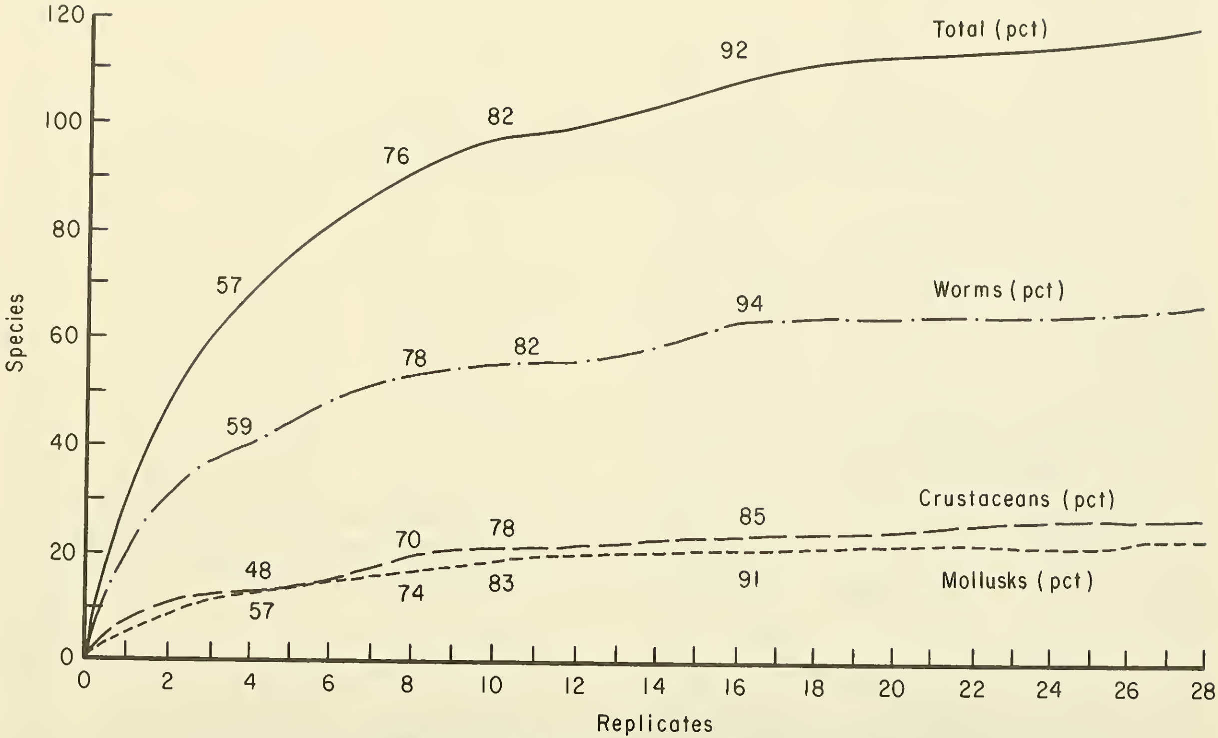


Figure A-2. Accumulation of species of each major group and of total as area sampled increases (mean of three random orders of 28 replicates).

progressively larger sample sizes of 4, 8, 16, and 28 cores. The average number of species per core and the 95-percent confidence limits changed little with increasing sample size (Table A-1).

Thus, within relatively narrow confidence limits, each core is expected to contain about 34 different species. Figure A-2 shows that 8 cores would be necessary to accumulate about 90 species (75 percent of those present in 28 cores).

2. Number of Individuals.

In Table A-1, the common species have been ranked and three main groups delineated on the basis of abundance. Means per core and their 95-percent confidence limits are listed for the four sample sizes. The 20 species are distinguished by the following characteristics: (a) They contain 87 percent of the total number of individuals of all species (by group: 90-percent mollusks, 90-percent crustaceans, and 87-percent worms); (b) variance to mean ratios are greater than 1 in all cases and less than 7 with the exception of *P. cirrifera* and *Mediomastus californiensis;* and (c) the mean abundance per core is greater than 1.5. The lower cutoff point in Table A-1 is somewhat arbitrary, since abundance decreases gradually and there is no clear-cut distinction between the last species included and the first one excluded. Dominance of a few species can be seen by the fact that 90 percent of the individuals are contained in about 20 percent of the species. For most of the species, the confidence limits decrease sharply from 4 to 8 cores and continued to decrease gradually to 28 cores. Exceptions are some of the species with the highest variance to mean ratios.

Table A-1 also shows changes in the estimation of the total number of individuals per core and individuals of major groups per core.

3. Species Diversity and Evenness.

Although this study was not concerned with estimating absolute species diversity of the community (Brillouin, 1965; Pielou, 1966a), the Shannon and Weaver (1963) formula was still used as the measure of diversity and J (Pielou, 1966b) for evenness. The use of the parameters in a strictly relative sense justified using these equations.

Cumulative species diversity and evenness values are plotted in Figure A-3 from an average of five random orders of the 28 cores; diversity and evenness appeared to stabilize between 4 and 8 cores.

4. Choice of the Number of Replicates.

In chosing the number of replicates taken at each station, the practical limitations of time and resources, the nature of the research objectives, and the results of this analysis were considered. Further, as mentioned previously, sampling was confined to permanently marked stations of a limited and well-defined area.

Table A-1. Effect of increasing sample size on means per core ($\bar{X}$) and their confidence limits (CL) of major groups and species.

	N=4		N=8		N=16		N=28	
	$\bar{X}$	CL	$\bar{X}$	CL	$\bar{X}$	CL	$\bar{X}$	CL
Species per core	32.3	4.2	33.6	4.4	33.8	3.6	33.8	2.1
Individuals per core	193.5	44.8	190.3	41.4	195.8	22.5	197.3	16.4
Individuals per core of:								
Worms	99.3	18.8	91.6	18.3	96.3	11.9	100.3	12.0
Crustaceans	39.5	34.0	35.1	6.1	36.7	8.4	34.3	3.4
Mollusks	54.8	33.3	63.5	9.9	62.9	10.9	62.8	8.0
Tellina modesta	44.3	32.1	52.8	20.1	49.7	10.0	51.3	7.4
Magelona sacculata	33.8	14.3	31.8	7.3	34.4	6.5	36.3	6.0
Paraphoxus daboius	21.0	13.7	17.1	6.1	15.6	4.3	16.5	3.0
Prionospio pygmaeus	18.5	19.7	16.0	7.9	14.5	3.9	16.0	3.3
Nothria elegans	7.5	6.7	5.8	3.4	5.9	2.1	6.1	1.4
Lumbrineris luti	6.8	6.9	6.6	2.4	5.3	1.7	5.9	1.3
Prionospio cirrifera	1.8	2.4	1.4	1.4	3.6	2.6	5.6	3.5
Siliqua patula	5.0	4.7	5.5	2.9	5.6	1.9	5.1	1.2
Mediomastus californiensis	8.5	3.8	5.4	2.6	4.4	3.1	4.3	1.9
Hemilamprops californica	4.5	13.2	3.0	4.8	5.6	3.7	3.7	2.2
Haploscoloplos elongatus	2.0	2.9	2.1	1.2	2.9	1.2	3.0	0.8
Euphilomedes oblonga	4.3	2.4	4.0	1.5	3.3	1.0	2.6	0.8
Spiophanes missionensis	2.3	3.5	1.8	1.3	2.2	0.8	2.3	0.6
Pinnixa franciscana	0.0	----	0.1	0.3	1.5	2.5	2.3	2.0
Synchelidium spp.	4.3	9.0	2.3	3.6	2.4	1.8	2.2	1.1
Armandia bioculata	0.8	1.5	1.3	1.7	1.5	1.1	2.0	1.1
Nephtys cornuta	2.0	2.5	2.3	1.3	1.9	0.9	1.9	0.5
Chaetezone setosa	3.0	3.5	2.3	1.5	2.1	0.9	1.6	0.6
Tellina meropsis	1.3	2.0	1.3	1.0	1.4	0.7	1.5	0.5

Based on these considerations, a sample size of eight replicate cores was chosen. The sample size contained 76 percent of the number of species in 28 cores, and only about 20 of these species were important numerically; i.e., they contained 87 percent of the total individuals. The confidence limits for the 20 species indicate how accurately each species' abundance can be estimated with eight cores as compared to more or less; 8 appears to be the optimum number in most cases. In addition, the number of species per core is estimated well with only four cores; eight is satisfactory for the number of individuals per major group. Figure A-3 indicates that eight replicates also provide a good estimate of species diversity and evenness.

IV. SAMPLE DISTRIBUTION

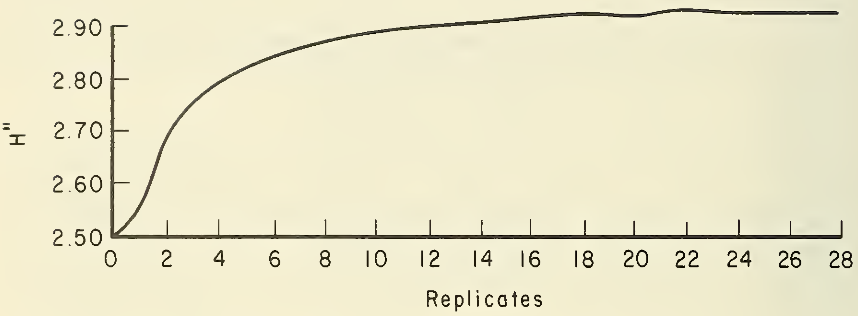
It was beyond the scope of this study to examine the detailed patterns of distribution of the species sampled. However, to construct a quantitative sampling plan it is necessary to have some measure of the gross patchiness of the fauna. Sampling was stratified once by locating stations at different depths, but it was unknown whether the magnitude of spatial variation of the infauna warranted further stratification of sampling within a depth contour.

To determine the gross patchiness of the infauna, four sets of replicate cores were taken randomly from progressively larger areas: 10 from each of the two 2-meter squares, and 8 from a 10-meter square and a 1.6-kilometer swath approximately 200 meters wide. The distribution of the samples at the 20-meter control station is shown in Figure A-1. If any of the major parameters changed significantly from one area to the next, it might be possible to adjust the sampling plan to produce a more accurate representation of the fauna.

Means of individuals per core of the dominant species were calculated for each area and tested with the Kruskal-Wallis test and Wilcoxon-Mann-Whitney *a posteriori* test. The species are listed by abundance in Table A-2; significant differences of means, species, diversity, and evenness are also indicated. Table A-3 is a matrix of the number of significant differences between areas for each species, summed from Table A-2.

Similarity coefficients (Bray and Curtis, 1957) were computed for all the possible pairings of the means of the dominant species (two individuals per core or more) for each of the four areas (Table A-4). The index has no statistical basis so that differences cannot be tested. It equals the sum of the lower relative abundance values for all the species common to both of the samples being compared.

Differences or similarities between the four areas may also be characterized by changes in the rank order of the dominant species as listed in Table A-2. Notable differences between each area and the remaining three are: (a) In area $2M^2$-a, *T. modesta* and *M. sacculata* exchanged rank, and the abundance of *P. cirrifera* and *H. californiensis* was higher; (b) in area $2M^2$-b, the abundance of *N. elegans* was the lowest; (c) in the 1.6-kilometer swath, *M. sacculata* and *P. pygmaeus* exchanged rank, and



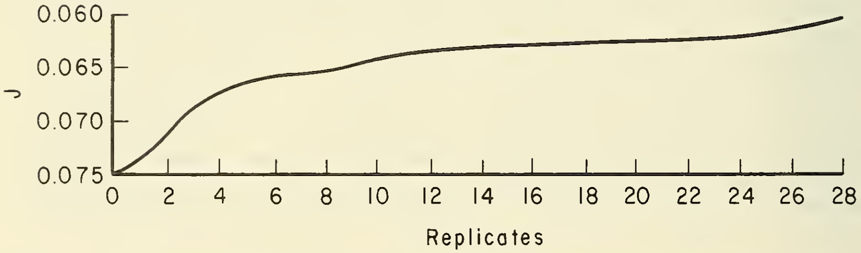


Figure A-3. Cumulative species diversity, H" (Shannon and Weaver, 1963) (upper graph) and evenness, J (Pielou, 1966) (lower graph) with increasing sample size (calculated from mean of five random orders).

Table A-2. Comparison of means per core of major species and groups of the four areas; numbers not connected show significant difference at 5-percent level. (Dotted lines span dissimilar means to connect similar ones.)

Species	$2M^2$a	$2M^2$b	$10M^2$	Mile
Tellina modesta	35.7	58.4	61.8	30.6
Magelona sacculata	45.6	30.2	30.9	14.5
Prionospio pygmaeus	15.5	13.4	19.8	27.9
Paraphoxus daboius	16.8	16.8	15.8	14.4
Nothria elegans	8.0	3.1	7.6	6.6
Lumbrineris luti	4.8	5.4	7.9	3.8
Prionospio cirrifera	10.3	3.3	2.6	0.0
Siliqua patula	4.2	5.8	5.5	1.6
Mediomastus californiensis	6.1	2.6	4.0	2.1
Hemilamprops californica	7.3	2.7	0.4	1.1
Euphilomedes oblonga	2.0	2.0	4.3	5.9
Chaetezone setosa	1.3	1.6	2.5	6.3
Haploscoloplos elongatus	3.4	2.3	4.0	1.5
Protothaca staminea	0.7	0.3	0.9	8.8
Synchelidium spp.	3.9	1.5	1.0	2.5
Euphilomedes caracharodonta	1.8	2.2	1.6	3.4
Anthozoa	0.1	1.6	1.9	8.3

Table A-3. Matrix of the number of significant differences in species abundance between areas derived from Table A-2.

	2M^{2}a	2M^{2}B	10M^2	Mile
2M^{2}a	-	2	2	6
2M^{2}b	-	-	1	8
10M^2	-	-	-	5
Mile	-	-	-	-

Table A-4. Matrix of similarity coefficients of the four areas.

	2M^{2}a	2M^{2}b	10M^2	Mile
2M^{2}a	----	0.78	0.72	0.61
2M^{2}b	----	----	0.78	0.64
10M^2	----	----	----	0.67
Mile	----	----	----	----

P. cirrifera was absent; the abundance of *C. setosa*, anthozoa, and *P. staminea* (bivalve) was higher, and the density of the other bivalves, *T. modesta* and *S. patual*, was lower.

In summary, Tables A-3 and A-4 show that the 1.6-kilometer swath area is the least similar of the four areas sampled. The quantitative and qualitative information in Table A-2 supports this conclusion. Samples from the three smaller areas which were closer together are similar. Thus, the fauna appears to be homogeneous on a smaller scale within the 20-meter depth contour. Since the permanent stations were restricted to an equally small area, stratification of sampling was not necessary.

V. SUMMARY

1. Diver-operated coffee can corers (area, 0.018 square meter; penetration, 15 centimeters) permit good replication and precise control of the area sampled.

2. Eight cores sampled had 76 percent of the species present in 28 cores.

3. The effect of increasing sample size on the means and 95-percent confidence limits was examined for various parameters. In most cases, the confidence limits decreased sharply from 4 to 8 cores and continued to decrease gradually to the largest sample size (28 cores).

4. Cumulative species diversity and evenness values appeared to stabilize between four and eight cores.

5. A comparison of samples from four progressively larger areas indicated a general similarity among the three smaller areas; the largest deviated from these.

6. It was concluded that a sample size of eight replicate cores was sufficient to estimate most of the important parameters and that the fauna appeared homogeneous within the 20-meter depth contour for an area equal to that of the permanent stations.

APPENDIX B

SPECIES LIST

POLYCHAETES

Aedicira nr. *pacifica*
Amaeana occidentalis
Ampharete nr. *labrops*
Anaitides groenlandica
Anaitides williamsi
Ancistrosyllis namata
Aricidia suecica
Aricidea nr. *suecica*
Aricidea sp.
Arabella pectinata (nr. *geniculata*)
Armandia bioculata
Asychis disparidentata
Axiothella rubrocincta
Boccardia basilaria
Capitella capitata
Chaetozone setosa
Chone ecaudata
Chone gracilis
Cossura sp.
Decamastus sp.
Dispio uncinata
Diopatra ornata
Eteone nr. *alba*
Eteone nr. *californica* (nr. *longa*)
Eteone nr. *spetsbergensis*
Eteone sp. (juvenile *californica*?)
? *Euclymene* sp.
Eumida tubiformis
Eusyllis - *Typosyllis*
Glycera americana
Glycera capitata
Glycera convoluta
Glycera robusta
Glycera spp. (juveniles)
Glycinde sp.
Goniada ? *maculata*
Gyptis brevipalpa
Haploscoloplos pugettensis
Harmothoe lunulata
Harmothoe priops
Hesionella sp.
Hesperone laevis (nr. *complanata*)
Hesperone sp. (juvenile *laevis*)
Heteromastus filobranchus

SPECIES LIST-Continued

POLYCHAETES-Continued

Heteromastus nr. *filoformis*
Laonice cirrata
Lepidasthenia longicirrata
Lumbrineris californiensis
Lumbrineris limicola
Lumbrineris nr. *luti*
Lumbrineris tetraura
Magelona nr. *pitelkai*
Magelona sacculata
Magelona sp. *a*
Magelona spp. (mostly juveniles)
Mediomastus californiensis
Nephtys caecoides (including *N. parva*)
Nephtys californiensis
Nepthys cornuta
Nepthys sp.
Nereis zonata
Nerine sp.
Nerinides acuta
Nerinides sp.
Nothria elegans
Notomastus ? *lineatus*
Notomastus magnus
Notomastus tenuis
Onuphus eremita
? *Orbinia* sp.
Oriopsis sp.
Owenia collaris
Paranaitis polynoides
Parandalia sp.
Paraonides platybranchia
Pectinaria californiensis
Phyllodoce sp.
Phyllodocidae
Pherusa inflata
Pholoe glabra
Phylo felix
Pilargis berkeleyae
Pista cristata
Platynereis bicanaliculata
Poecilochaetus johnsoni
Polydora neocardalia (or *brachycephala*)
Polydora sp.
Prionospio cirrifera

SPECIES LIST-Continued

POLYCHAETES-Continued

Prionospio malmgreni
Prionospio pinnata
Prionospio pygmaeus
Pseudopolydora sp.
Rhynchospio sp.
Scoloplos armiger
Sigambra tentaculata
Spiophanes bombyx
Spiophanes missionensis
Sthenelais verriculosa
Telepsavus costarum
Thalenessa spinosa
Tharyx monilaris
Travisia gigas
Typosyllis armillaris
Typosyllis sp.

MISCELLANEOUS WORMS

Anthoza
Echiuroidea
Enteropneusta
Holothuroidea
Nematoda
Nemertinea
Oligochaeta
Phoronopsis viridis
Sipunculida

MOLLUSKS

Snails
Acteocina spp.
Aglaja spp.
Cylichna spp.
Epitonium bellastriatum
Kurtzia sp.
Mangelia barbarensis
Mitrella sp.
Nassarius fossatus
Nassarius mendicus
Nassarius ? perpinguis
Nassarius rhinetes
Odostomia spp.
Olivella biplicata

SPECIES LIST-Continued

MOLLUSKS-Continued

- *Olivella pycna*
- *Polinices draconis*
- *Rictaxis* spp.
- *Turbonilla* spp.

Bivalves

- *Clinocardium nuttallii*
- ? *Cooperella* sp.
- *Cryptomya californica*
- *Lyonsia californica*
- *Macoma acolasta*
- *Macoma indentata*
- *Macoma inquinata*
- *Macoma nasuta*
- *Macoma secta*
- *Macoma yoldiformis*
- ? *Mactra* sp.
- *Modiolus* sp.
- *Mya arenaria*
- *Mysella aleutica*
- *Mytilus* sp.
- ? *Nemocardium* sp.
- *Nuculana* cf. *minuta*
- *Nuculana taphria*
- *Protothaca staminea*
- *Siliqua patula*
- *Siliqua lucida*
- *Solen sicarius*
- *Tellina bodegensis*
- *Tellina* ? *meropsis*
- *Tellina modesta*
- *Tellina nuculoides*
- ? *Transennella* sp.
- *Tresus nuttallii*

CRUSTACEANS

Ostracods

- *Bathyleberis* sp.
- *Euphilomedes carachrodonta*
- *Euphilomedes longiseta*
- *Euphilomedes oblonga*
- *Podocopid ostracoda*

Amphipods

- *Allorchestes* sp.
- *Ampelisca cristata*

APPENDIX B

SPECIES LIST-Continued

CRUSTACEANS-Continued

- *Aoroides columbiae*
- *Argissa hamatipes*
- *Atylus* sp.
- *Bathymedon roquedo*
- *Caprella angusta*
- *Caprella californica*
- *Corophium ? californianum*
- *Corophium ? acherusicum*
- *Dulichia* sp.
- *Eohaustorius sencillus*
- *Isaeidae*
- *Ischyroceridae*
- *Listriella diffusa*
- *Lysianassidae*
- *Megaluropus longimerus*
- *Metaphoxus fultoni*
- *Monoculodes spinipes*
- *Pachynus barnardi*
- *Paraphoxus daboius*
- *Paraphoxus epistomus*
- *Paraphoxus lucubrans*
- *Paraphoxus obtusidens*
- *Paraphoxus variatus*
- *Photidae*
- *Photis californica*
- *Pleustidae*
- *Protomedeia ? penates*
- *Synchelidium* spp.
- *Tiron biocellata*

Isopoda and Tanaidacea

- *Austrosignum tillerae*
- *Bathycopea daltonae*
- *Edotea sublittoralis*
- *Leptochelia* sp.
- *Munna ubiquita*

Mysidaceans

- *Acanthomysis davisi*
- *Archaeomysis maculata*

Cumaceans

- *Anchicolurus occidentalis*
- *Cyclaspis nubila*
- *Diastylis* spp.
- *Diastylopsis tenuis*
- *Hemilamprops californica*

SPECIES LIST-Continued

CRUSTACEANS-Continued

Lamprops spp.
Mesolamprops sp.
Decapods
Blepharipoda occidentalis
Callianassa spp.
Cancer gracilis
Cancer jordani
Cancer magister
Holopagurus pilosus
Opisthus transversus
Pagurus granoimanus
Pinnixa franciscana
Scleroplax granulata

ECHINODERMS

Amphiodia urtica
Amphiura arcystata
Dendraster excentricus

Oliver, John S.

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81 p. : ill. (Technical paper - Coastal Engineering Research Center ; no. 76-15) Also (Contract - Coastal Engineering Research Center ; DACW72-73-C-0010)

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