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Title: HARBOR DREDGING AND BENTHIC INFAUNA: A CASE STUDY

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This study of the immediate, localized effects of a small dredging operation on the benthic invertebrate community in the shipping channel of Coos Bay, Oregon, was designed: 1) to measure the extent of the physical removal of benthic macro- and meiofauna by hopper dredging; 2) to record the subsequent benthic effects of mid-channel spoiling; and 3) to monitor the rate and pattern of biological re-adjustment in the affected areas. Replicate Shipek grab samples before and after dredge operations were restricted spatially and temporally to delineate rapid and localized biological responses. Faunal abundance, taxa composition, species diversity and qualitative sediment characteristics were studied.

Immediate declines in faunal abundance at the dredge and spoil sites were temporary and re-adjusted to pre-dredging abundance levels within 28 days. Temporary increases in diversity reflected

changes in the relative abundance of taxa arising from siltation and burial of organisms.

Following re-adjustment, populations increased in all areas except the dredge channel. Localized population declines are hypothesized to result from the unsuitability of newly exposed sediment for settlement of pelagic larvae.

Although most taxa were adversely affected by dredging activity, *Capitella ovincola* was relatively unaffected and increased dramatically within the dredge channel within 28 days after dredging.

Qualitative sediment characteristics were generally the same before and after dredge operations except for localized increases in wood debris at both dredge and spoil sites.

The effects of dredging activity are thought to be dependent on: 1) the size and duration of the dredge operation, 2) pre-dredging history and frequency of dredging, 3) the type of benthic community, 4) depth of water and sediment type, 5) draft and size of the dredging vessel and 6) shipping and related harbor activities. The direct, benthic effects of this dredging operation were short term. The temporary nature of these changes was linked to the small scope of the dredging operation and the adaptability of the benthic community. It is hypothesized that periodic disruption of the sediment surface by small scale maintenance operations may have less effect on the benthic community than the daily presence of heavy shipping and industrial and domestic pollution.

Harbor Dredging and Benthic Infauna: A Case Study

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HARBOR DREDGING AND BENTHIC INFAUNA: A CASE STUDY

INTRODUCTION

A small dredging operation in Coos Bay, Oregon on October 4, 1972 provided an opportunity to study the effects of dredging and spoiling on the benthic community in the shipping channel of a previously dredged estuary. Although the study was done on short notice, it was possible to compare conditions immediately before dredge operations with conditions immediately afterward to delineate the direct consequences of dredge operations on the benthic environment.

In the natural environment estuaries function as areas of intense biological growth and reproduction for both brackish water and marine organisms. Estuaries serve further as pathways for the migration of anadromous fish. Wet lands surrounding the estuary are nesting areas for waterfowl and the home of aquatic and terrestrial mammals.

An industrial society views estuaries as an area for port development. Protected waters of bays serve as ideal places for the mooring and loading of large ships, while adjacent wet lands are easily filled to provide necessary shore facilities. Large population centers develop close by, tied to the economic stability of the port.

An efficient port requires periodic dredging to maintain navigable waters. Shoaling areas form bottlenecks which delay the passage of deep-drafted ships until the appropriate tide. In severe cases, loading of ships to maximum capacity is restricted, resulting in loss of economic potential for the port and added congestion as a multitude of smaller ships attempt to take up the slack cargo.

Coos Bay is a multi-purpose estuary. Its long history of economic development competes with the importance of the estuary to the natural environment. In recent years extensive dredging and spoiling within certain areas of the bay has altered the natural environment. Environmental groups have argued that further dredging should be prohibited. Considering the economic position of Coos Bay as one of the major shipping ports on the West Coast and the limited scientific knowledge available to regulate dredging operations, a certain amount of damage to the natural environment may be unavoidable. As research into the effects of dredging operations continues, dredging practices will evolve which are more compatible with efficient shipping and the estuarine environment.

The benthic community consists of animals and plants which live on or within the sediment surface. Due to their habitat and limited mobility, these organisms are directly affected by dredging practices to a greater degree than any other segment of the estuarine ecosystem. Delineating the direct effects of maintenance dredging on the benthic community should provide information which will be valuable in assessing the effects of future operations on the environment and may eventually lead to the development of less destructive dredge practices.

This study was undertaken to investigate the influence of dredging operations on benthic macro- and meiofauna. Specifically, the study was designed 1) to measure the extent of the physical removal of benthic fauna by hopper dredging; 2) to record the subsequent benthic effects of mid-channel spoiling; and 3) to monitor the rate and pattern of biological re-adjustment in the affected areas. This investigation differs from previous dredging studies by examining the immediate, mechanical effects of small scale maintenance dredging on benthic communities. Sampling was restricted spatially and temporally to allow the delineation of localized biological responses to dredge-induced disturbances.

Previous Studies

Early investigations concerning the effects of dredging activities on benthic fauna were concerned with the direct effects of siltation on commercial oyster beds. Lunz (1938) conducted extensive field studies during dredging of the Intracoastal Waterway in South Carolina and concluded that unless actual burial took place, no deleterious effects on adult growth or setting of spat would be expected. Wilson (1950) confirmed this conclusion during studies in Copano Bay, Texas.

Combining laboratory bioassay experiments and field observations he observed that turbidity levels very close to dredging activity were detrimental to oysters, but that at distances greater than 300 years no deleterious effects were apparent. Two hundred yards was considered adequate distance from working dredges to prevent oyster damage in Mobile Bay, Alabama (Ingle, 1952).

St. Amant (1956) linked dredge-induced alterations in estuarine circulation to detrimental salinity changes resulting in production declines. Waldo (1956) found that while direct siltation by active dredging was not a problem, the alteration of currents in some cases allowed the natural burial of oyster beds during ensuing years.

A transition in priorities followed these early studies and limited, single-species investigations were replaced by wide ranging, environmental studies. The response of benthic infaunal communities to the dredging of a new boat harbor in Alamito Bay, California was examined by Reish (1961). Quantitative and periodic samples of the benthic macrofauna were studied during the four-year investigation. Although large population changes were reported, no regular pattern of succession was delineated.

A comprehensive study of the benthic environment before and after dredging and spoiling was undertaken by Harrison, Lynch, and Altschaeffl (1964) in lower Chesapeake Bay. The study included extensive investigations of sediment changes resulting from dredging and spoiling 1.3×10^6 cu. yards of sand and silt. Control stations were sampled to monitor seasonal patterns of infaunal abundances. They concluded that "dredging temporarily destroys the infaunal population of an area but that resettlement and recovery are fairly rapid" (p. 752). Declines in abundances were also seen following spoiling but "extensive" sampling a year later indicated successful recovery of the infaunal population.

Flemer, Dovel, Pfitzenmeyer, and Ritchie (1968) made an in-depth study of dredging and spoiling in Upper Chesapeake Bay. Year-round observations of phytoplankton, zooplankton, fish eggs and larvae, and benthic infauna were made to determine the effect of spoiling 1.1×10^6 cu. yards of sediment. Benthic samples collected one month prior to and four weeks after dredge operations detected no gross effects on plankton, fish, or fish larva. Although significant declines in benthic infaunal abundances were detected in the spoils area, repopulation of a part of the population began soon after deposition.

The long term effects of hydraulic dredging in Boca Ciega Bay, Florida were studied by Taylor and Saloman (1969). Benthic abundances before dredging and 10 years later showed that the number of infaunal species within dredged channels was greatly reduced compared to both predredged conditions and present conditions in undredged areas. The abundance of fish in the vicinity of dredge channels was also lower than in surrounding areas. Demersal fish were absent. Turtle grass which was once abundant throughout the area no longer existed.

Reish and Kauwling (1971) reported that within dredged areas of Anaheim Bay, California the number of species of polychaetes was slightly higher than in undisturbed areas. The number of individual organisms, however, was markedly reduced in dredge areas.

Perhaps the most extensive and detailed study of the benthic effects of dredging operations was carried out by Saila, Pratt, and Polgar (1972). They were interested in the consequences of spoiling 8.2×10^6 cu. yards of Providence River sediment in Rhode Island Sound. Combining physical investigations of spoil stability, short term tolerance studies of important marine species, and extensive infaunal sampling, they were able to conclude that transport of species within the spoil was minimal.

The National Marine Fisheries Service (1972) reviewed the effects of sewage sludge and dredge spoil on the marine benthos of the New York Bight. The multi-agency study was conducted over a period of several years with over 307 stations being sampled. Benthic diversity and biomass were found to be reduced throughout the disposal area.

The diversity of benthic infauna within Moriches Bay, New York was investigated by O'Connor (1972). Benthic diversity in dredged channels was significantly less than in other biotopes within the bay.

Servizi, Gordon, and Martens (1969) investigated toxicity levels of sediment dredged from Bellingham Harbor, Washington. Bioassays performed on salmon fry in water containing 1% harbor sediment resulted in 100% mortality in 30 minutes. This high mortality was attributed to the combined presence of hydrogen sulfide and wood fiber. This toxicity level was likely to be experienced in the spoiling of an intended 131,600 cu. yards of sediment from the harbor.

In a similar study in Olympia Harbor, Washington, Westly, Schink, Scholz et al. (1972) performed bioassays on Pacific oyster larvae, phytoplankton, and salmon fry with prospective dredge sediments. Inconclusive results were obtained and the sediment was judged to be far less polluted than sediment from Bellingham Harbor.

An excellent summary of dredging literature from 1938 to the present was given by May (1973). Forty-three papers were reviewed concerning biological, physical, and chemical effects of various types of dredging operations on the aquatic environment.

It is evident that many different approaches are possible for studying the effects of dredge operations on benthic fauna. Widespread disruption or covering of the sediment surface initiates countless direct and indirect physical, chemical, and biological reactions which may have a synergistic effect in the estuarine environment. It is not the intent of this study to relate the direct, immediate effects of maintenance dredging to widespread changes of the total estuarine environment. Understanding the complex temporal and spatial interrelationships between organisms and the estuarine environment is necessary before the widespread effects of dredging can be placed in perspective. This understanding lies in the future. It is hoped that the information presented here may add to the base knowledge of estuarine science by direct input or by stimulating future investigations.

Description of Study Area

Detailed descriptions of the Coos Bay estuary have recently been published (U. S. D. I., 1971; Percy, Bella, and Klingeman, 1973). Situated among forest-covered slopes, Coos Bay has an approximate surface area of 10,000 acres. The primary tributary is the Coos River (Figure 1). Annual precipitation ranges between 180-250 cm falling primarily during the winter, November through April.

Mean tidal range is 1.6 m (Johnson, 1972). Average tidal current velocity at the mouth is 1.0 m/sec (Bourke, Glenne, and Adams, 1971). The bay ranges from a well-mixed estuary during periods of low runoff to a partially-mixed estuary during periods of maximum runoff (McAlister and Blanton, 1963). Tidal flushing is normally more important than stream inflow (Rudy, 1970).

The study area is located in the upper estuary between mile 13.00 and 14.00. The dredge site is at the mouth of Isthmus Slough,

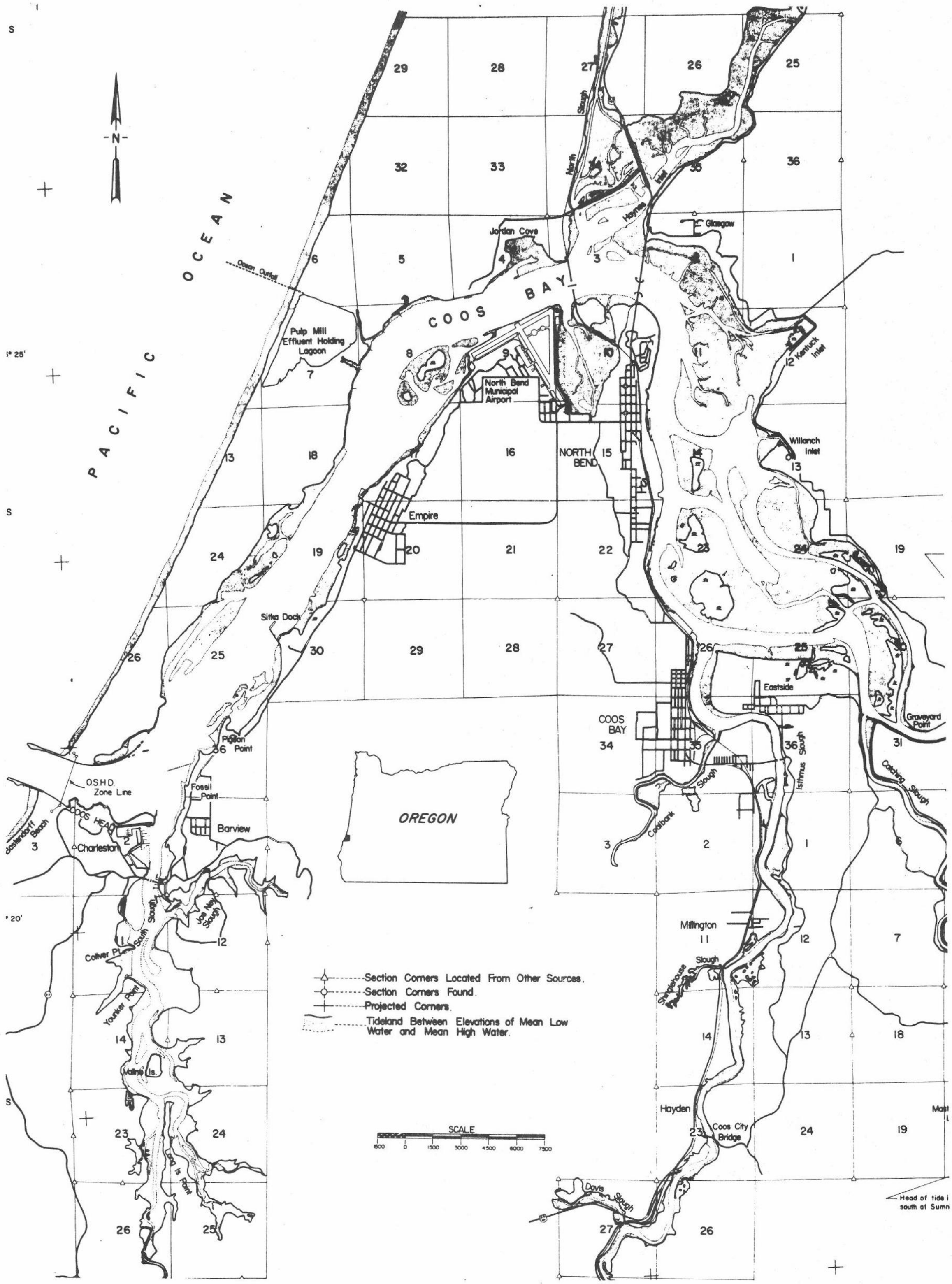

Figure 1. The Coos Bay Estuary.

while the spoil site is one-half km downstream in mid-channel. Both sites are located within the port facilities of the city of Coos Bay and experience extensive shipping activity. The area is also utilized for log rafting and storage. The water quality of Isthmus Slough is poor due to industrial, domestic, and shipping wastes. Leachates and dislodged bark from thousands of logs stored in the area are also important in degrading water quality (U. S. D. I., 1971).

Salinity and temperature measurements were recorded at the dredge and spoil sites (Table 1). Short term fluctuations in bottom salinity are attributed to differences in tidal cycle between sampling periods. Sanders, Mangelsdorf, and Hampson (1965) reported that in the Pocasset River, Massachusetts, salinities on the sediment surface and immediately below were relatively constant and unvariable compared to water salinity. The relative uniformity of interstitial salinities for areas of Coos Bay surrounding the study site was confirmed by McConnaughey (1971).

Dissolved oxygen measurements 1.0 m from the sediment surface were taken several hours before and during dredge operations (Table 2). Dredge operations had no drastic widespread effect on the amount of dissolved oxygen available to the benthic community. The well-mixed structure of the estuary, nearby influx of the Coos River, and presence of tidal currents are possible reasons for the lack of localized depletions in dissolved oxygen.

Table 1. Salinity-Temperature Data from Dredge and Spoil Sites.

Date	Station	Depth (m)	Salinity (‰)	Temperature (°C)	Time
Sept. 28, 1972	1	0	27.48	15.40	1210
		5	28.08	14.70	
		9	28.50	14.60	
	2	0	27.70	15.40	1215
		5	28.24	14.76	
		7	28.68	14.66	
	3	0	28.14	15.02	1225
		5	28.54	14.76	
		10	28.83	14.54	
	4	0	28.36	15.22	1235
		5	28.34	14.66	
		12	29.42	14.34	
	5	0	28.28	15.26	1245
		5	28.44	14.80	
		10	29.06	14.42	
	6	0	28.56	14.90	1240
		3	28.30	14.80	
Oct. 1, 1972	10	0	28.70	15.80	1705
		10	29.25	15.51	
	11	0	29.08	16.26	1710
		10	29.10	15.44	
	12	0	29.21	15.91	1715
		7	29.44	15.58	
Oct. 2, 1972	2	0	28.24	15.84	1115
		5	30.12	15.18	
		11	30.47	14.90	
	10	0	30.30	15.20	1020
		5	30.33	15.34	
		11	30.43	14.92	
	11	0	30.28	15.58	1035
		5	30.48	15.05	
		11	30.48	14.80	
	12	0	30.34	15.05	1047
		5	30.74	14.84	
		7	30.60	14.84	

(Continued on next page)

Table 1. (Continued)

Date	Station	Depth (m)	Salinity ($^{o}/_{oo}$)	Temperature (°C)	Time
Oct. 12, 1972	1	0	29.78	13.30	1456
		9	30.46	12.82	
	2	0	29.84	13.42	1453
		10	30.68	12.60	
	3	0	29.98	13.29	1450
		11	30.68	12.54	
	4	0	29.89	13.18	1446
		12	30.78	12.68	
	5	0	30.32	12.78	1440
		12	30.62	12.74	
	6	0	30.40	12.68	1438
		4	30.49	12.66	
Oct. 12, 1972	10	0	29.24	13.38	1033
		11	29.80	13.18	
	11	0	29.24	13.38	1038
		11	29.62	13.20	
	12	0	29.30	13.56	1025
		7	29.52	13.20	

Table 2. Dissolved Oxygen Measurements Taken One Meter from the Sediment Surface on October 4, 1972.

Dissolved Oxygen (mg/l)	Station	Time
6.5	2	0930
6.7	4	1020
6.9	11	1048
	Start of Dredge Operations	
6.3	5	1135
6.2	2	1210
6.8	4	1220
6.6	4	1700
6.7	11	1715

Source: Slotta, Sollit, Bella _et al._ (1973)

The mouth of Isthmus Slough is a point of deposition for fine sediment. The narrow channel is a major shipping route and the continual buildup of silt necessitates periodic maintenance dredging. The dredge site has been dredged five times in the last 10 years, the last operation being completed two years before the present study (Slotta _et al._,, 1973).

METHODS

This study includes a comparison of the benthic infauna before and after hopper dredge operations at dredge and spoil sites. Approximately 8023 cu. yards of silt and wood debris were removed from the dredge area on October 4, 1972 by the U. S. Army Corps of Engineers' hopper dredge, Chester Harding. Resulting spoil was dumped mid-channel one-half km downstream at a depth of 12 m.

Six stations (1-6) were established on a cross-channel transect, perpendicular to the proposed dredging channel (Figure 2). Each station was marked with a buoy, located on a chart, and its location was recorded with respect to permanent landmarks. The stations were approximately 33 m apart.

The dredge passed over two of the stations (2 and 3) but did not pass over the other four (1, 4, 5 and 6).

Three stations (10, 11 and 12) in the spoil area were established on a cross-channel transect, and positions were defined in a similar manner (Figure 2). Two stations (10 and 11) had spoil material dropped directly over them, but the third (12) did not.

A Shipek grab sampler (1/25 m^2) was used to collect all samples. The sampler is designed to sample the top 10 cm of sediment.

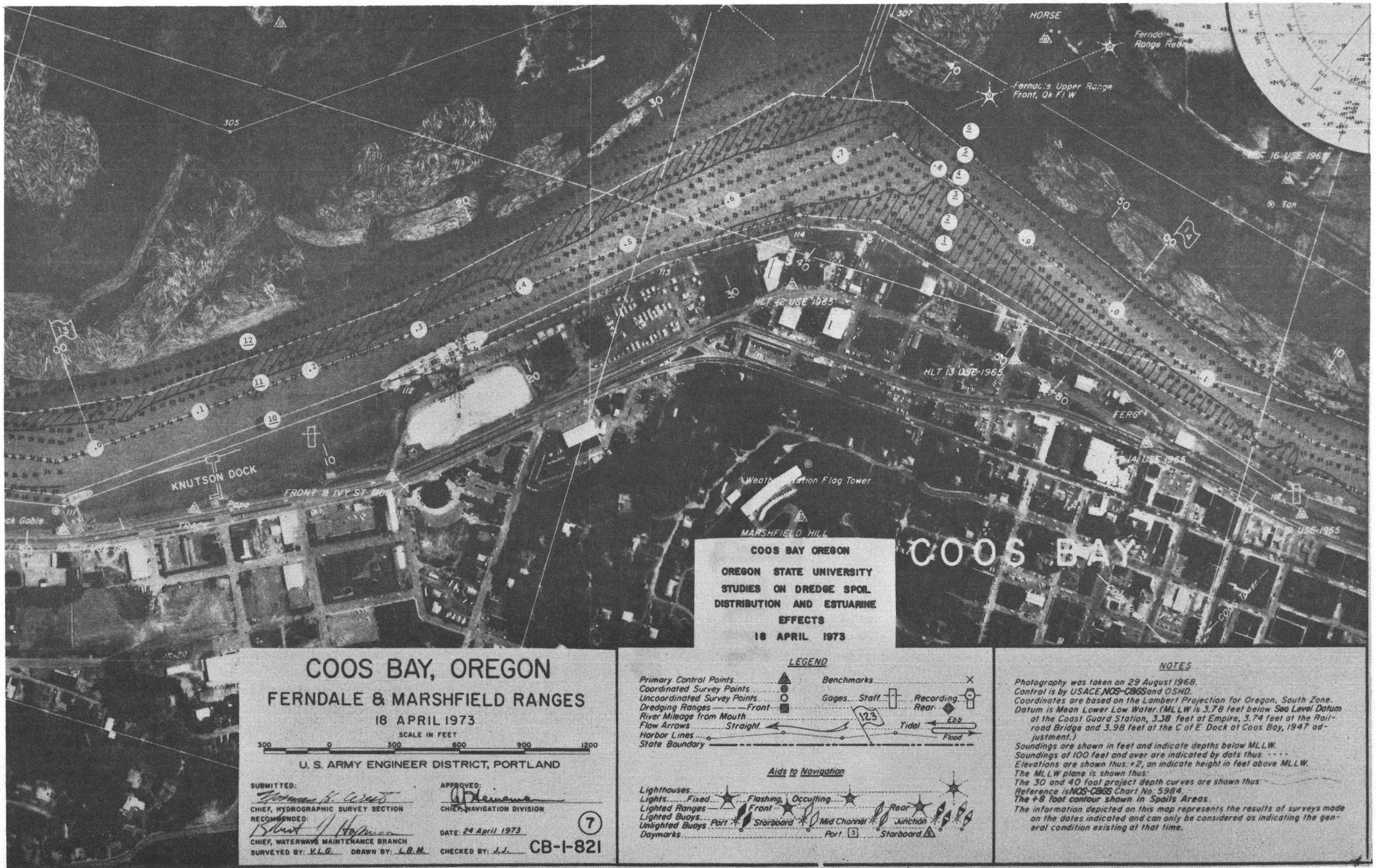

Figure 2. Aerial photograph of the Port of Coos Bay. Dredge stations marked 1-6; Spoil stations, 10-12.

The study consisted of two phases. Phase I was designed to measure the immediate extent of the physical removal of benthic fauna at the dredge site and the degree of burial at the spoil site; Phase II to study early benthic re-adjustment. In Phase I small, well defined areas were sampled at frequent intervals, over a relatively short time period (seven days) to ensure that changes in faunal abundance and community composition would reflect the direct mechanical effect of dredging operations rather than seasonally occurring physical and biological variations. At the dredge site 36 samples were collected before dredging: paired samples from each of the six stations on three consecutive days (September 28, 29, and 30). After dredging, 36 additional samples were collected within 24 hours. At the spoil site 12 samples were collected: paired samples from each three stations on September 30 and October 1. Six additional samples were collected within 24 hours after spoiling (see Appendix 1 and 2). A total of 90 grab samples were collected during Phase I.

Phase II was designed to delineate early biological re-adjustment to dredging disturbances. Replicate samples were taken at each station 7, 14, 28, and 56 days after dredging and spoiling (see Appendix 3). Stations which were not directly dredged over or spoiled upon (1, 4, 5, 6, and 12) were intended to serve as control stations allowing a differentiation between natural and dredge induced population changes. A total of 72 grab samples were taken during Phase II.

All grab samples were measured volumetrically, preserved in formalin, and returned to the laboratory.

Grab samples consisted of a mixture of inorganic silt and sand, benthic organisms, wood chips and fibers, other vegetation, and shell fragments. Samples were placed in a fluidizing chamber which set the material in suspension using water and compressed air. Immediate sieving followed. Sieving frees the sediment from the sample retaining organisms, extraneous debris, and, in Coos Bay, wood chips. The importance of using the appropriate mesh size in sieving quantitative benthic samples cannot be understated since mesh size directly determines the abundance and types of organisms recorded from each sample (Reish, 1959). Previous dredge studies have generally been sieved using mesh sizes > 0.75 mm (Reish, 1961; Harrison _et al._, 1964; Flemer _et al._, 1968). The dredge site samples from the first day (September 28th) were randomly scanned under a dissecting microscope prior to the sieving. Multitudes of organisms were observed of which only a fraction would be retained in the 0.75 mm mesh. To retain a significant portion of the sample community it was necessary to use a reduced mesh size. The 12 samples were sieved using a 0.29 mm mesh. Since the amount of debris retained and sieving time increase in direct proportion to decreasing mesh size, it soon became apparent that time and man-power considerations prohibited continued use of the 0.29 mm mesh.

The samples were re-sieved with a 0.50 mm mesh, compromising between the 0.75 mm mesh which would retain fewer animals and the 0.29 mm mesh which would retain large quantities of wood chips and debris. A 0.50 mm mesh was used for the rest of the study. Although, theoretically, re-sieving the first day's samples should not have resulted in loss of animals, from practical experience it was felt that the double sieving may have unnecessarily biased these collections. The samples were not included in future analysis.

Most Oregon estuaries have bottom sediments that contain large amounts of wood chips. Unfortunately, many wood chips remain after sieving at 0.50 mm. The high numerical density of minute organisms and abundance of wood chips makes the direct enumeration of organisms within the entire sample unfeasible. To solve this problem a large Folsom plankton sample splitter was used to subsample each collection. McEwen, Johnson, and Folsom (1954) gave a detailed description of the splitter and its use. Briefly, the sample is placed in fluid suspension within the device and the sample volume is halved each time the cylinder is rotated. The sample is successively halved until a workable aliquot is obtained. An intensive statistical study concerning the operation of the Folsom sample splitter was carried out by McEwen et al. (1954). The device and procedure were found to obtain unbiased, representative, random aliquots of the original sample. Longhurst and Seibert (1967) warned that experience and careful technique are necessary to ensure reliability. Coos Bay samples were usually split to 1/8 aliquots. The aliquots were preserved in 70% isopropanol and stained with Rose Bengal to differentially color organisms from wood chips and vegetable matter (Wigley and McIntyre, 1964; Saila *et al.*, 1972).

Organisms were hand picked under a stereo microscope and identified. Identification was carried to family, genus, or species level depending on the information or experience available. Taxonomic references utilized included: Polychaetes (Hartman, 1969); Bivalves (Keen, 1963; Dunnil and Ellis, 1969); Pycnogonids (Hedgpeth, 1941); Amphipods (Shoemaker, 1949); Cumaceans (Sars, 1900).

Counts from each aliquot were divided by the aliquot factor (e.g., 1/8) to obtain the number of individuals in the original sample. Results were normalized to a 1000 cc sediment sample calculated from the initial grab volume (Appendix 1, 2, and 3). Volumetric reporting in this situation is thought to be more realistic than the usual areal reporting (number/m^2) because of the high numerical density of meiofauna (organisms < 1.0 mm) encountered in relatively small volumes of sediment and the variability in the volumes of sediment taken by the Shipek grab on different sediment types.

RESULTS

Phase I

Sediment Trends

Inspection of the grab samples before sieving suggested basic sediment trends within the study area. Black silt predominated at Stations 1, 2, 3, 4, 10, and 12; sand at Stations 6 and 11. Station 5 had a transitional sediment type between black silt and sand. This general sediment pattern was not changed by dredging and samples taken immediately after dredging operations were similar to those taken before.

After sieving, the fraction > 0.50 mm consisted of organisms, vegetation, shells, wood debris, and wood chips. Prior to dredging operations, assorted vegetation and wood chips were found at Stations 1 and 2; wood chips at Stations 3, 5, 10, 11, and 12; large wood chips and wood debris at Station 4; and shell and wood chips at Station 6. It appears that Station 4 is a natural area for the accumulation of large amounts of wood debris. The fact that this debris is found on the sediment surface indicates that either a persistent influx of wood debris is occurring or that the environment is not conducive to the deposition of fine silt which would cover the material. In either case, current activity is suggested. Since Isthmus Slough has no large tributaries leading into it, current activity is probably the result of tidal oscillations of the water within the Slough (U. S. D. I., 1971). These qualitative trends persisted 24 hours following dredging activities except at Stations 5, 10, and 11 where varying amounts of wood debris were introduced (see Appendix 1 and 2).

Quantitative changes before and after dredging activity in the 0.50 mm sieve fraction are shown in Figures 3 and 4. Sieve volumes are recorded as percentages of original grab volume to correct for the grab volume variability. Higher percentages indicate proportionally larger volumes of material > 0.50 mm within each sample. At the dredge site before dredging, the general trend was for increasing percentages outward from Station 1, reaching a maximum at Station 4 and declining towards Station 6. These findings coincide with the presence of large amounts of wood debris and lack of deposition of fine material in the central channel. After dredging, percentages of material > 0.50 mm were generally the same as before dredging at all stations except Stations 4 and 5 where increases in this fraction were recorded (Figure 3). At the spoil site before spoiling the percentage of material > 0.50 was lowest at Stations 10 and 11 and increased at Station 12. After spoiling increases in this fraction were recorded at Stations 10 and 11 (Figure 4).

Differences in mean percentage of material > 0.50 mm before and after dredging activity were examined by t-test. Significant (5%)

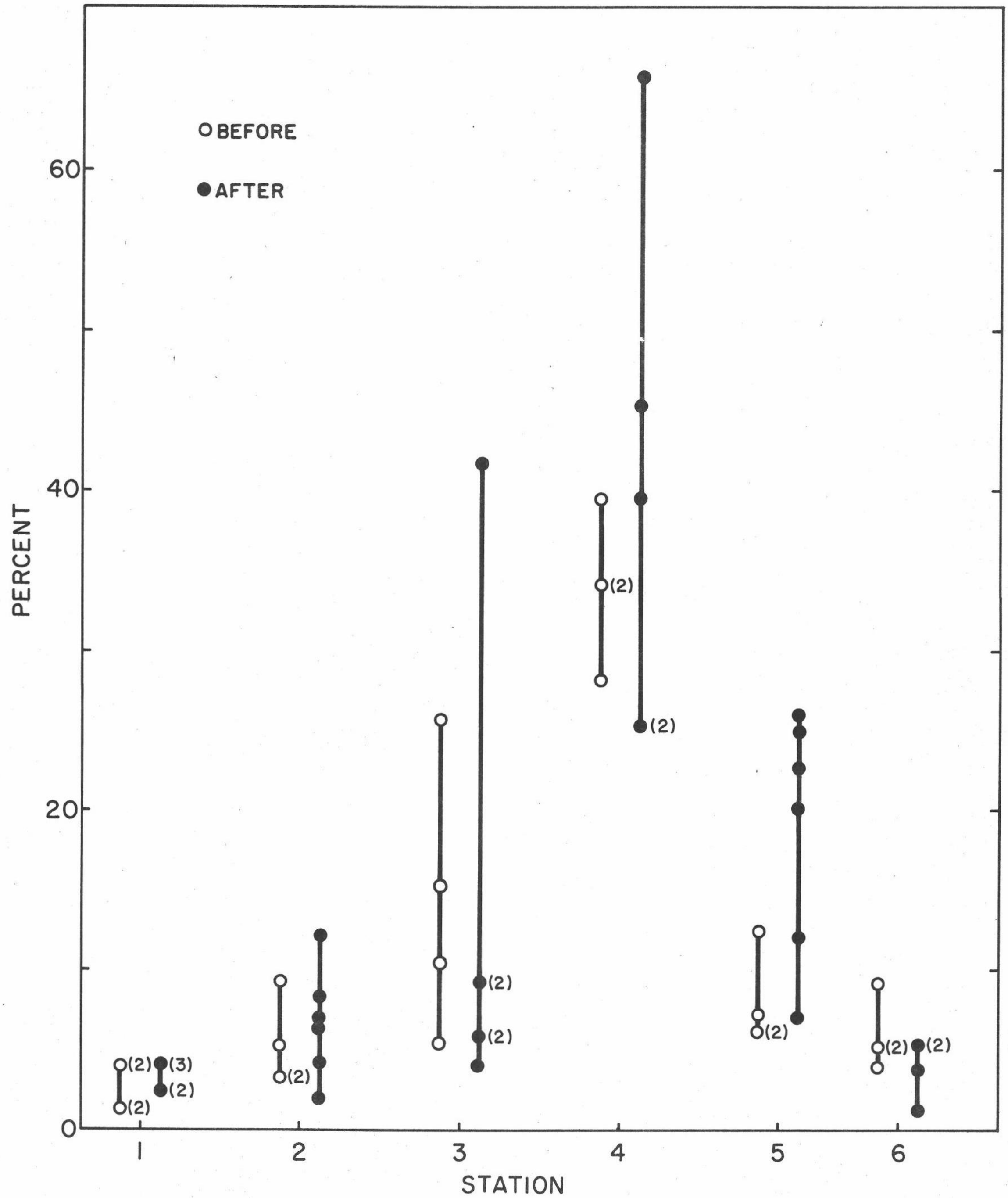

Figure 3. Percentage of material > 0.50 mm in grab samples from dredge site. Open circles denote samples taken before dredging; closed circles afterward. Numbers in parentheses to right of observations indicate multiple observations of same relative value. Vertical lines delineate range of observations for given period.

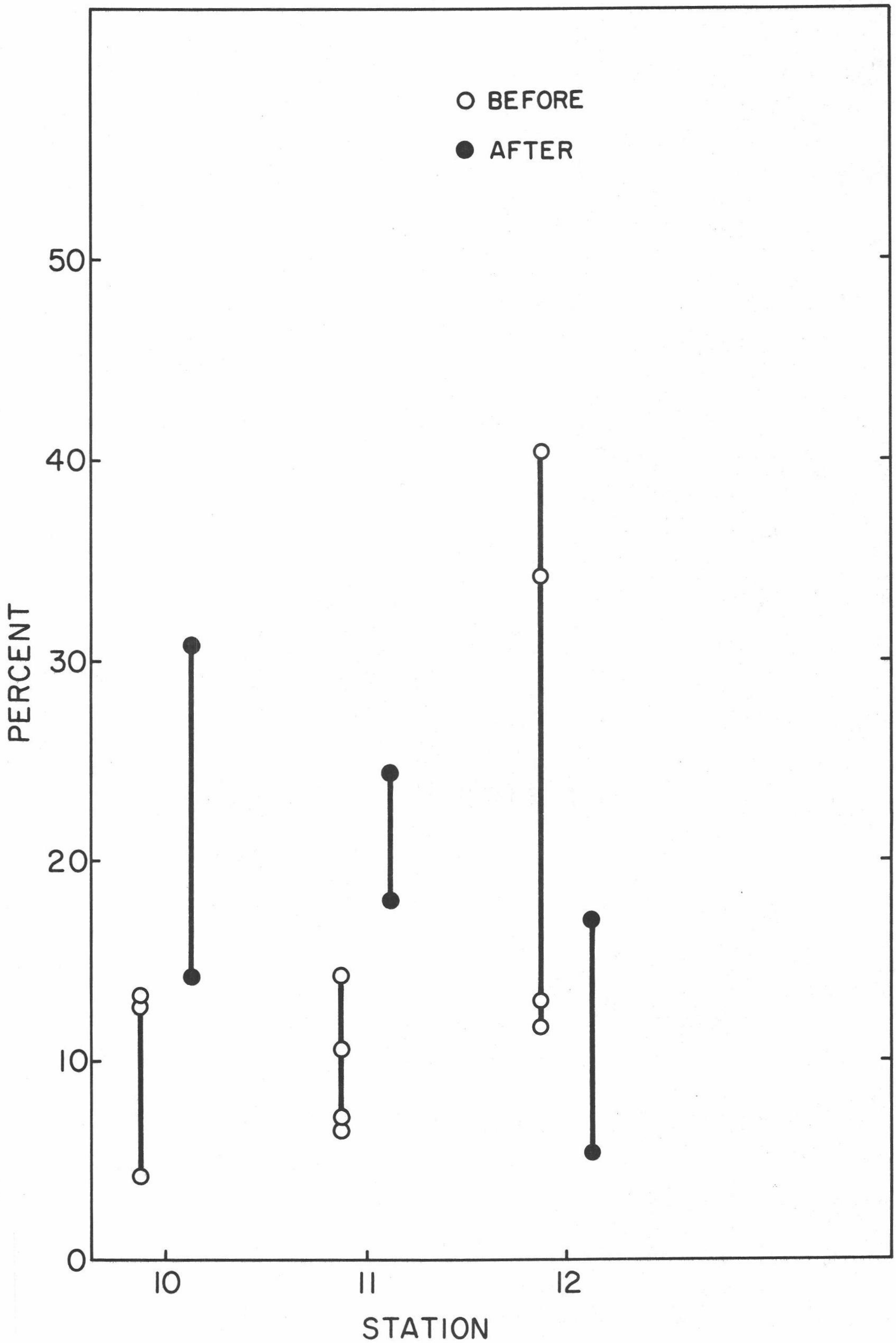

Figure 4. Percentage of material > 0.50 mm in grab samples from spoil site. Graphing pattern explained in caption of Figure 3.

increases were recorded at Stations 5 and 11 (Table 3). The introduction of wood debris at Station 5 after dredging may indicate a dredge-induced change in current patterns at the dredge site. The increase in coarse material at Station 11 reflects the presence of spoil material.

Benthic Fauna

Both the dredge and spoil sites contained a wide variety of benthic invertebrates before and after dredging operations (see Appendix 4 and 5). Similar types of taxa were found at both sites. The most frequently encountered organisms were the small polychaetous annelids, Streblospio benedicti, Pseudopolydora kempi, Polydora ligni, Eteone lighti, Capitella (Capitata) ovincola, Notomastus (Clistomastus) tenuis, and Glycinde armigera. Bivalves were Macoma inconspicua, Clinocardium nuttallii, Mya arenaria, and Modiolus sp. Pycnogonids were Achelia nudiuscula and Achelia chelata. Identified amphipods included Corophium salmonis, Corophium spinicorne and Anisogammarus ramellus.

Cumaceans and oligochaetes were also present at both sites. The abundance and distribution of these taxa was never as persistent as that of the polychaetes or bivalves. Inexperience regarding the taxonomy of these groups and the lack of available literature describing Oregon species has so far delayed species identification. The cumacea were represented primarily by the families Leuconidae and

Table 3. Descriptive Statistics of Percentage of Material > 0.50 mm in Bottom Sediment Before and After Dredge Operations.

	Dredge Site Stations					
	1	2	3	4	5	6
Before Dredging						
Observations	4	4	4	4	4	4
Mean	3.4	5.3	14.4	33.9	8.1	5.7
Variance	0.5	9.2	77.5	19.8	9.0	5.3
Standard Deviation	0.7	3.0	8.8	4.4	3.0	2.3
After Dredging						
Observations	6	6	6	6	6	6
Mean	3.4	6.7	12.6	38.6	18.9	4.4
Variance	0.4	12.2	206.1	271.6	61.3	1.3
Standard Deviation	0.6	3.5	14.4	16.5	7.8	1.1
Significance level difference in means (t-test)	> 40%	30%	> 40%	30%	5%	20%

	Spoil Site Stations		
	10	11	12
Before Spoiling			
Observations	4	4	4
Mean	10.3	9.9	25.2
Variance	27.1	12.7	233.1
Standard Deviation	5.2	3.5	15.2
After Spoiling			
Observations	2	2	2
Mean	22.7	21.6	11.1
Variance	129.6	21.1	70.9
Standard Deviation	11.4	4.6	8.4
Significance level sifference in means (t-test)	> 20%	5%	20%

Nannastracidae. Members of the families Diastylidae and Cumidae were also present in reduced numbers. The taxonomy of marine oligochaetes is extremely difficult. Previous authors (Jones, 1961; Sanders et al., 1965) have approached the problem by setting up personal catgories within the oligochaetes sampled. These categories are inadequate in comparison to specific determinations but they make it possible to count and differentiate types. The Coos Bay samples included two types of marine oligochaetes. Type "A" had a relatively short body (< 4 mm). The anterior body region was only slightly wider than the rest of the body and terminated in a nose-like protrusion. Posteriorly, the body terminated in a flattened disk. Type "B" had a relatively long (> 4 mm) body which was distinctly wider at the anterior end. Posteriorly, the body was elongated and progressively tapered.

Harpacticoid copepods, nematodes, and ostracods were also collected in the samples but many passed through the 0.50 mm sieve. Although individuals of these taxa were counted, their numbers were not included in any of the following discussion or graphs because they were not considered to be quantitative.

Dredge Site (Stations 1-6)

The abundance of total organisms refers to the total number of individual animals of all taxa. This abundance varied from station to station. Station 6 showed the highest mean abundance of total organisms before dredging (2043 organisms/1000 cc sediment), while Station 1 had the lowest (560 organisms/1000 cc sediment) (Figure 5). The course of the Chester Harding through the dredge site resulted in repeated dredging of Station 2. Station 3 was also heavily dredged although to a lesser extent. Station 1 was not in the direct path of the dredge but was narrowly missed repeatedly. Stations 4, 5 and 6 were progressively removed from the vicinity of active dredging. Significant (5%) decreases in mean abundance of total organisms were seen at Stations 1, 2, 3, 5, and 6 (Figure 6; Table 4). Station 4 did not show a significant (5%) change in mean total abundance after dredging. The percent change in mean total abundance (Figure 5) was greatest at Station 2, -88%; Station 3 showed -74%; Station 1, -70%; Station 5, -65%; Station 6, -45%; and Station 4, -34%. The percent change in mean total abundance suggests that the immediate effects of dredging are not confined to the dredge channel alone. With the exception of Station 4 and one collection from Station 6, every grab sample taken after dredging showed fewer organisms (Figure 6). As expected, Station 2 which experienced the most intensive dredging, recorded the largest decline in mean total abundance, followed by Station 3. Large declines in mean total abundance in adjacent areas suggest that the mechanical removal of benthic organisms is not the only disruptive process associated with dredging operations.

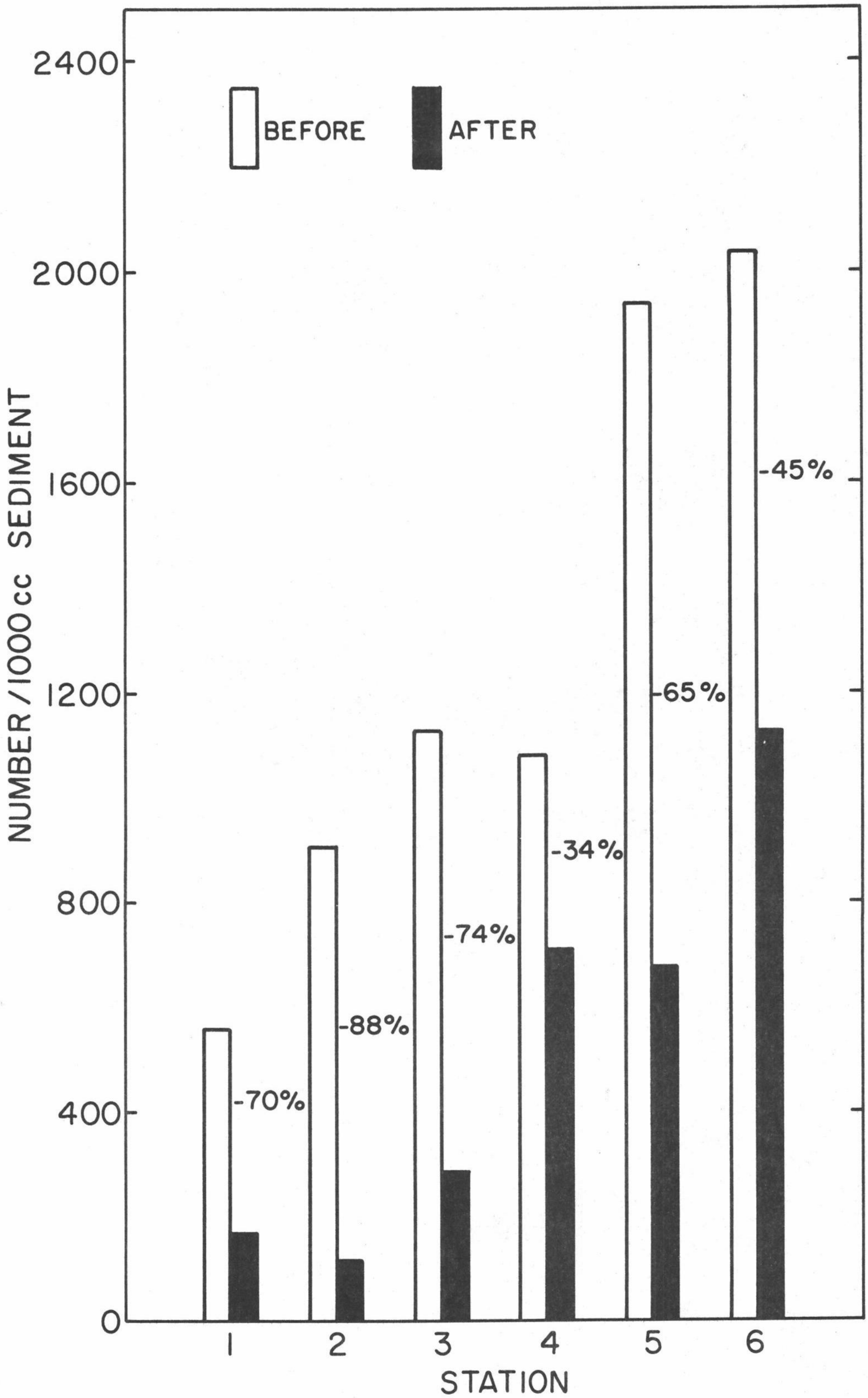

Figure 5. Mean total abundance before and after dredging at dredge site. Percentage change indicated to right of columns.

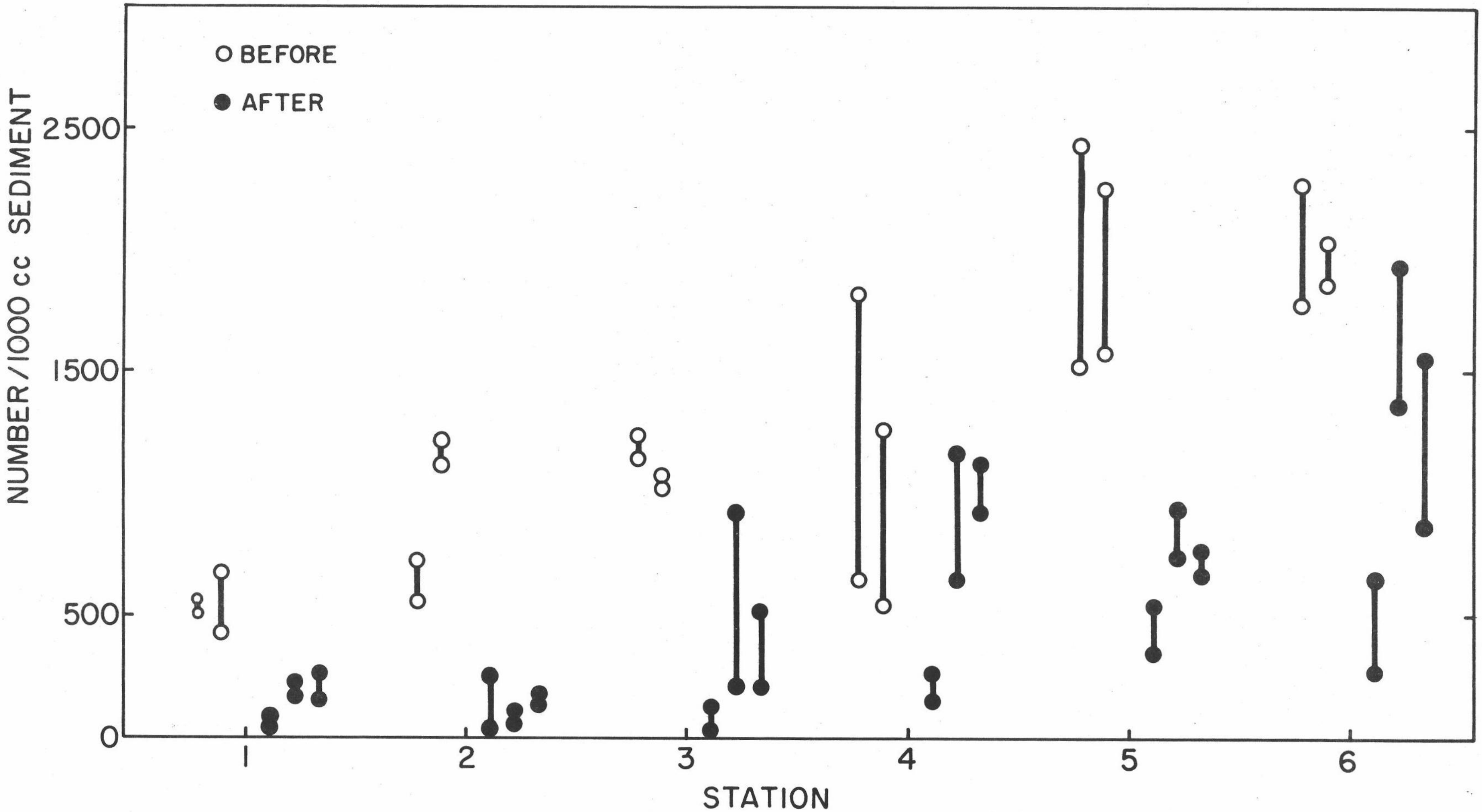

Figure 6. Total organisms in individual grab samples before and after dredging at dredge site. Circles indicate individual observations connected by range of replicate sample.

Table 4. Descriptive Statistics of Total Abundance Before and After Dredge Operations.

	Dredge Site Stations					
	1	2	3	4	5	6
Before Dredging						
Observations	4	4	4	4	4	4
Mean	560	910	1136	1087	1949	2043
Variance	13938	82208	2744	341389	216723	39874
Standard Deviation	118	287	52	584	466	199
After Dredging						
Observations	6	6	6	6	6	6
Mean	165	106	294	714	677	1119
Variance	5490	9757	66453	178139	38435	384631
Standard Deviation	74	99	258	422	196	620
Significance level difference in means (t-test)	< 5%	5%	5%	20%	5%	5%

	Spoil Site Stations		
	10	11	12
Before Spoiling			
Observations	4	4	4
Mean	330	37	1638
Variance	35010	1043	285664
Standard Deviation	187	32	534
After Spoiling			
Observations	2	2	2
Mean	75	16	598
Variance	3200	8	540800
Standard Deviation	56	2.8	735
Significance level difference in means (t-test)	10%	30%	10%

Table 4 shows the variation in total abundance between replicates before and after dredging. Examination of the standard deviation reveals that variation decreases at Stations 2 and 5 and increases at Stations 3 and 6 after dredging.

The number of taxa represented before and after dredging is somewhat variable and no uniform increases or decreases could be seen (Table 5). These data should be viewed with the realization that the number of taxa recorded is equally affected by the presence of one rare organism or 500 or more individuals of a dominant taxa. Small changes in taxa number, hence, may not be directly related to dredging activity.

Figure 7 shows the percentage change in mean abundance of selected taxa before and after dredging. Most taxa declined following dredging at all stations. Polychaetes and oligochaetes showed maximum declines at Station 2. The greatest decline in amphipods occurred at Station 3, followed closely by Station 2. Cumaceans declined at Station 5 to the greatest extent, followed by Stations 2 and 3 respectively.

Several taxa increased in relative numbers followed dredging. Bivalves increased at Station 1 and showed minimum decreases at Stations 2, 3, 5, and 6. Pycnogonids increased at Stations 1 and 2. Amphipods were represented at Station 4 only after dredging.

Table 5. Number of Taxa Before and After Dredging and Spoiling - Phase I.

Sample	Dredge Site Stations 1	2	3	4	5	6
Before Dredging						
2-A	16	11	13	8	11	15
2-B	12	11	12	12	11	17
3-A	13	13	14	10	14	17
3-B	15	14	10	14	13	14
After Dredging						
4-A	14	11	14	8	13	14
4-B	11	13	2	12	11	12
5-A	14	8	14	9	8	16
5-B	14	8	10	12	10	15
6-A	14	9	9	11	8	15
6-B	13	12	13	11	10	14

Sample	Spoil Site Stations 10	11	12
Before Spoiling			
1-A	7	6	13
1-B	7	9	14
2-A	13	8	12
2-B	15	3	12
After Spoiling			
3-A	6	3	9
3-B	10	7	12

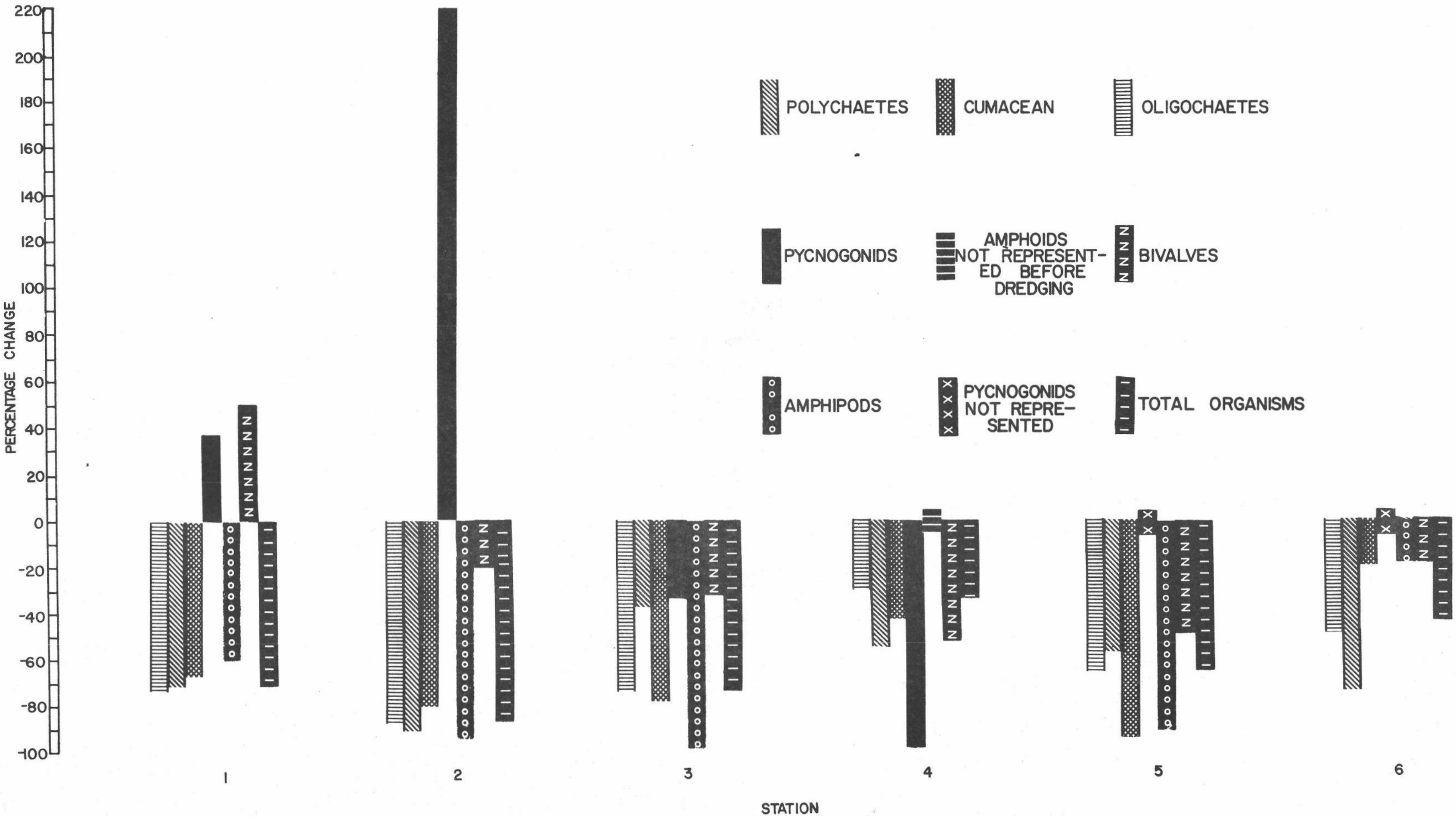

Figure 7. Percentage of change in mean abundance of selected taxa before and after dredging at the dredge site. Percentage change calculated from the formula:

$$\frac{\text{taxon abundance before - taxon abundance after}}{\text{taxon abundance before}} \times 100$$

The number of taxa and relative abundance of each taxa are important characteristics of benthic communities (Saila, 1972). The delineation of dredge-induced changes within the benthic community requires a method of summarizing large amounts of information. Diversity, expressed as the degree of uncertainty attached to the specific identity of any randomly selected individual (Pielou, 1966), is a measure of community structure; changes in diversity reflect changes in structure. Numerous indices have been formulated to measure diversity. The most widely used diversity index is that developed from the Shannon-Weiner function (Shannon and Weaver, 1963). Based on information theory, the index is calculated from the following formula:

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_i$$

where:

H' = diversity in bits of information/individual

s = total number of species

p_i = observed proportion of individuals belonging to the i^{th} species

The Coos Bay H' values must be viewed with caution since we are dealing with relatively instantaneous changes in the benthic community rather than long term, biological adaptations. The use of taxa in place of species does not affect H' if consistently recognizable taxa are compared within a given station (Wilhm and Dorris, 1965).

For Coos Bay the Shannon index was used to ascertain changes in community structure following the mechanical removal of a portion of the benthic community. Boesch (1971) contended that the dependence of H' on sample size indicates that its distribution is not normal. He recommends avoiding parametric statistics and relying on comparison of the range of H' to indicate dissimilarities. (Ranges which overlap are considered similar, while ranges exclusive of each other indicate a marked change in diversity.) Figure 8 gives ranges of H' before and after dredging at each station. Ranges of H' are similar at all stations except 1 and 2. Every sample collected at Stations 1 and 2 after dredging recorded higher diversity.

Values for H' have been shown by Lloyd and Ghelardi (1964) to be sensitive to both species (taxa) richness and equitability (relative abundance of taxa). The Shannon index for an existing benthic community might be increased in two ways: by the addition of more taxa which did not seem to occur (Table 5); or for the relative abundance of taxa to become more evenly distributed. Dredging activities could affect equitability in several ways. Discriminate removal of taxa (selectively removing taxa from near the sediment surface rather than taxa found deeper in the sediment) is the most obvious way. Widespread disruption of the sediment habitat or covering the sediment surface with spoil could also affect the relative abundance of collected taxa. In these cases the spatial distributions

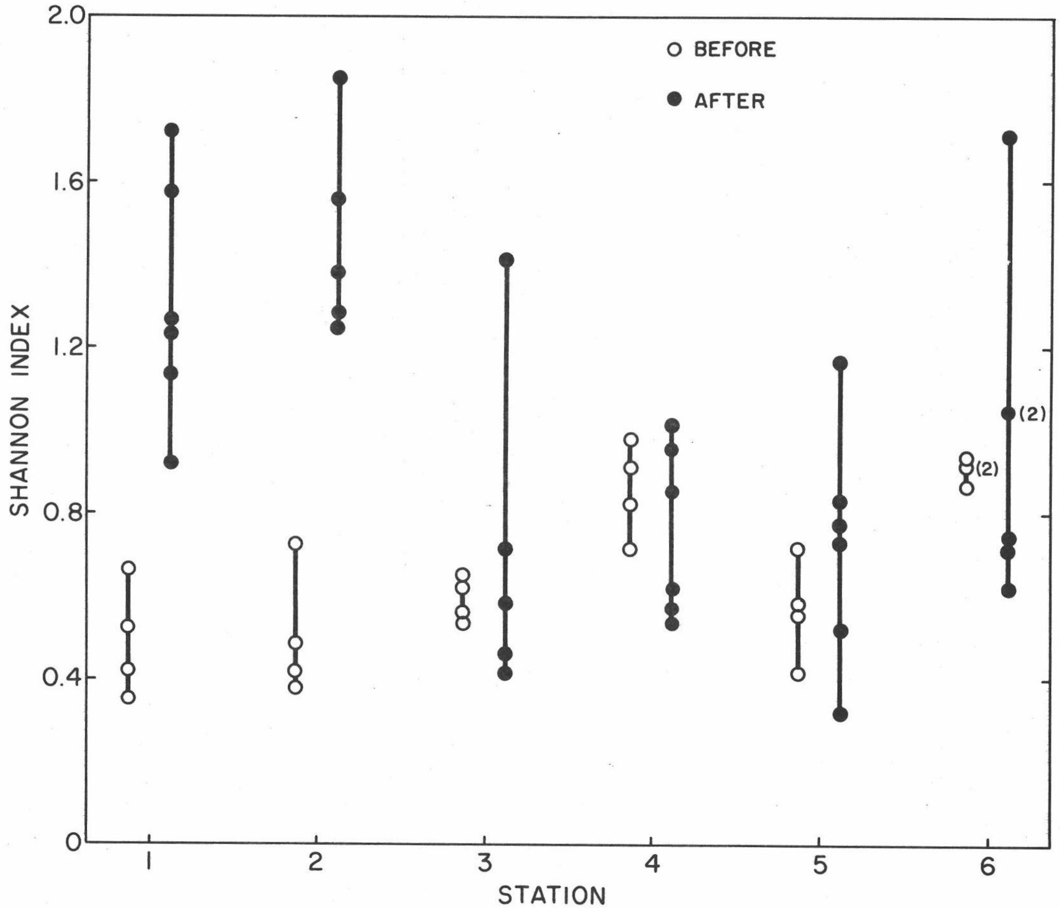

Figure 8. Diversity values before and after dredging at dredge site. Vertical lines indicate range of observations in each period.

of taxa within the sediment (lateral and vertical) would not be the same after dredging activity as before. Since the Shipek grab collects from the sediment surface downward, the relationship of taxa to the sediment surface is important in the efficiency of sampling each taxa.

Using a table developed by Lloyd and Ghelardi (1964) it was possible to calculate equitability from H'. Like H', values of equitability were similar before and after dredging at all stations except 1 and 2 (Table 6). This information indicates that the increase in diversity at Stations 1 and 2 was related to changes in the relative abundance of taxa associated with dredging disturbances.

Spoil Site (Stations 10, 11, and 12)

Severe time and manpower limitations prevented thorough sampling of the spoil area. Replicate grabs were taken twice at each station before spoiling and only once afterward.

The uptake of fine sediment with the suction heads of the *Chester Harding* resulted in a heavy slurry of mud, debris and water in the hopper bins. The bins were emptied by opening the bottom and allowing the material to fall out as the ship moved over the spoil site. The operation took only a few minutes and the surrounding water became quite turbid. Spoil was dumped on the site six times, primarily over Station 11. Station 10 also received some spoil, but Station 12 was outside of the direct spoil area.

Table 6. Equitability Component of Calculated H' Values - Phase I.

Sample	Dredge Site Stations					
	1	2	3	4	5	6
Before Dredging						
2-A	.1031	.1363	.1383	.2762	.1727	.1406
2-B	.1191	.1736	.1250	.1550	.1536	.1329
3-A	.1176	.1123	.1285	.2050	.1085	.1317
3-B	.1220	.1164	.1680	.1678	.1330	.1578
After Dredging						
4-A	.2692	.4281	.2171	.2637	.1584	.1785
4-B	.3800	.2384	*	.1965	.2481	.3500
5-A	.1964	.3625	.1242	.2666	.1750	.1106
5-B	.2035	.4687	.1530	.1466	.1650	.1220
6-A	.1592	.3322	.1744	.1518	.2450	.1273
6-B	.2192	.2716	.1430	.1554	.1910	.1771

Sample	Spoil Site Stations		
	10	11	12
Before Spoiling			
1-A	.2571	.5583	.1076
1-B	.2642	.4577	.1228
2-A	.1330	.4087	.1441
2-B	.1770	.4833	.2150
After Spoiling			
3-A	.3450	.8000	.2466
3-B	.2760	.5314	.1691

*Insufficient data

Before spoiling, Station 12 had the highest mean total abundance with 1638 organisms/1000 cc sediment. Station 10 followed with 330 organisms/1000 cc sediment, while Station 11 had only 37 organisms/1000 cc sediment (Figure 9). Following spoiling, significant (10%) decreases in mean abundance were seen at Stations 10 and 12 (Table 4; Figure 10). The percent change in mean total abundance at these stations was -77% and -64% respectively. Data from Station 11 were somewhat confusing because no significant (10%) change in mean total abundance was seen even though the station experienced extensive spoiling.

All taxa except bivalves declined following spoiling (Figure 11). Bivalves increased after spoiling at Station 11 and showed minimum decreases at Stations 10 and 12. Oligochaetes and cumaceans declined most at Station 10; amphipods at Station 11; and pycnogonids at Station 12. Polychaetes declined relatively evenly at each station to moderate degree.

Following spoiling there was no major change in number of taxa (Table 5). Ranges of H' overlapped before and after spoiling (Figure 12). Maximum equitability values at each station occurred only after spoiling (Table 6) suggesting changes in the relative abundance of taxa due to spoiling activity.

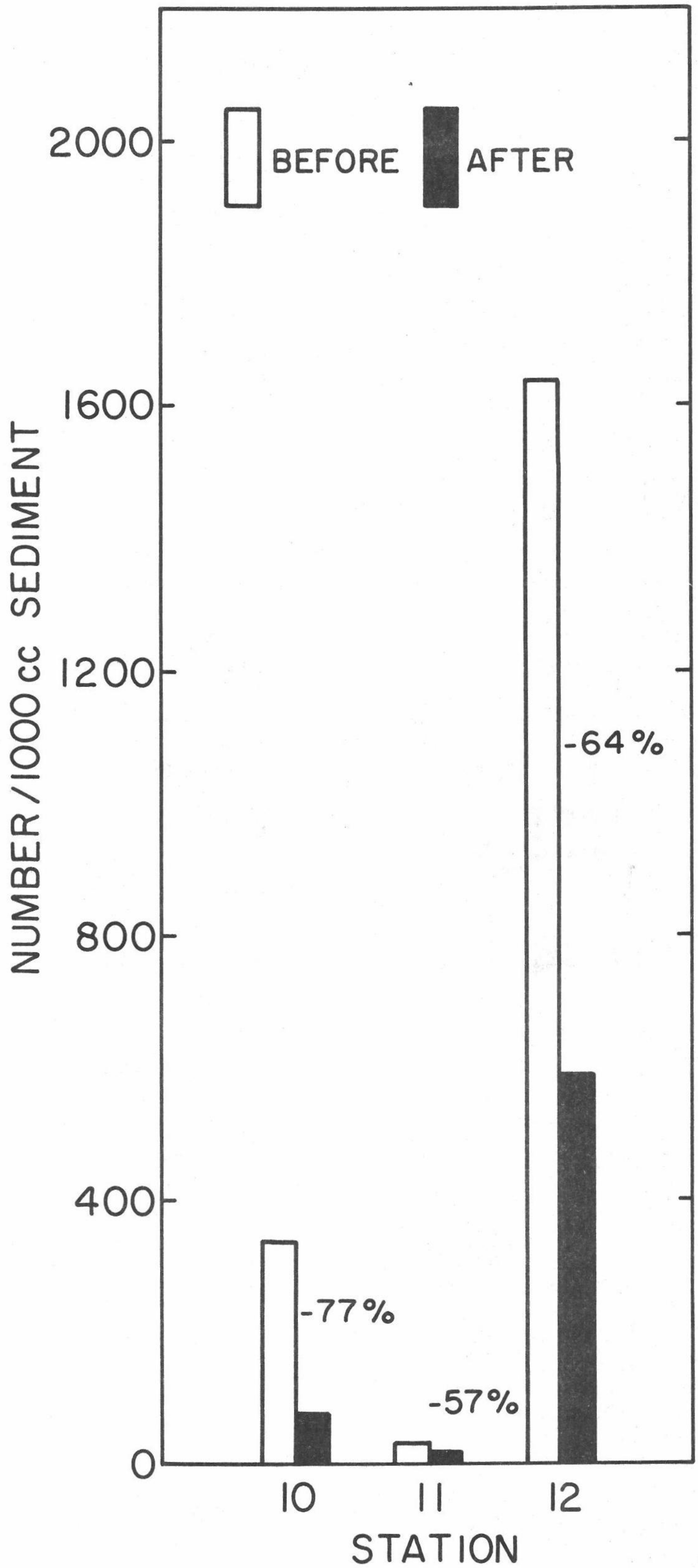

Figure 9. Mean total abundance before and after spoiling at spoil site. Percentage change indicated to right of column.

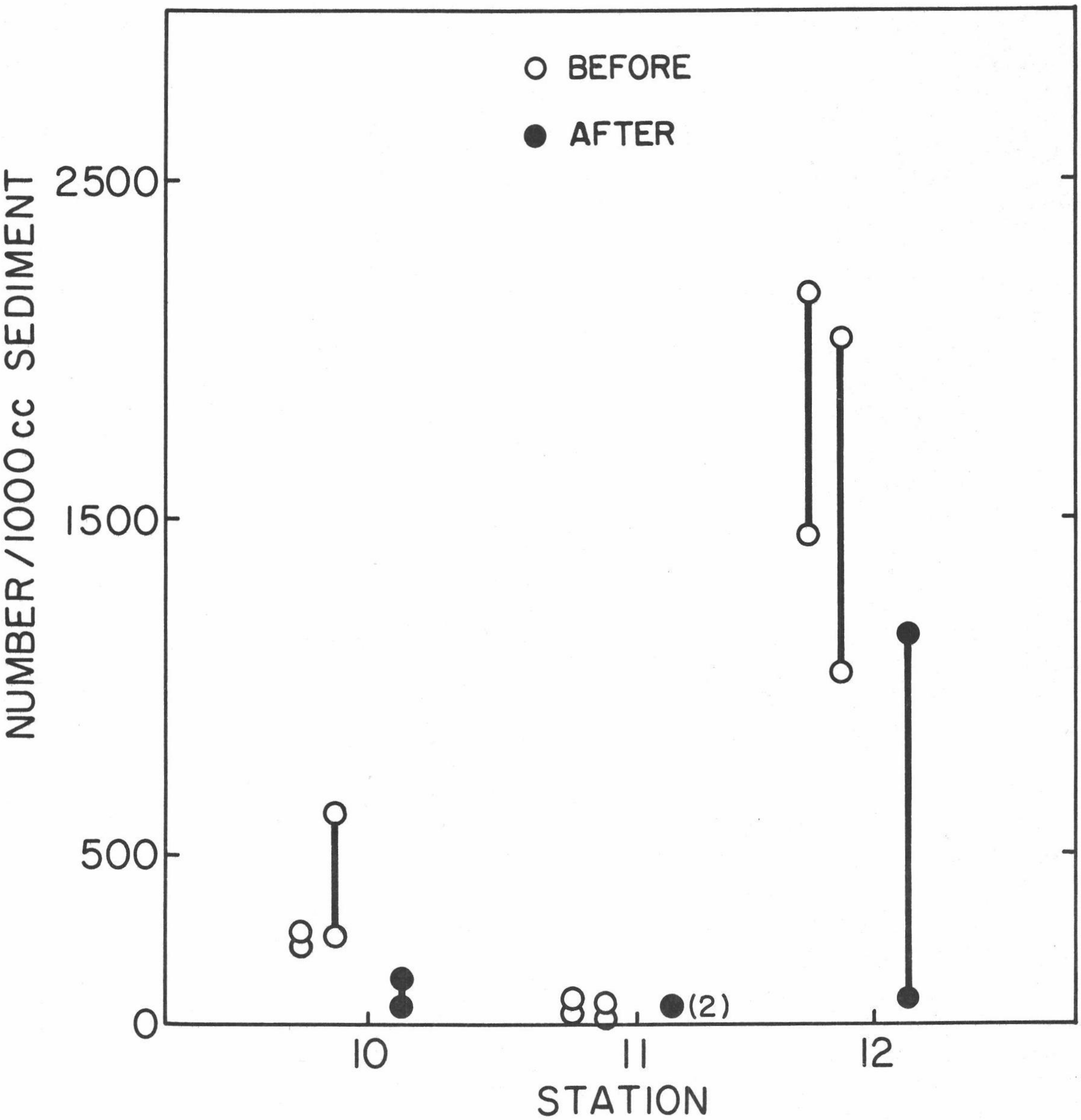

Figure 10. Total organisms in individual grab samples before and after spoiling at spoil site. Circles indicate individual observations connected by range of replicate sample.

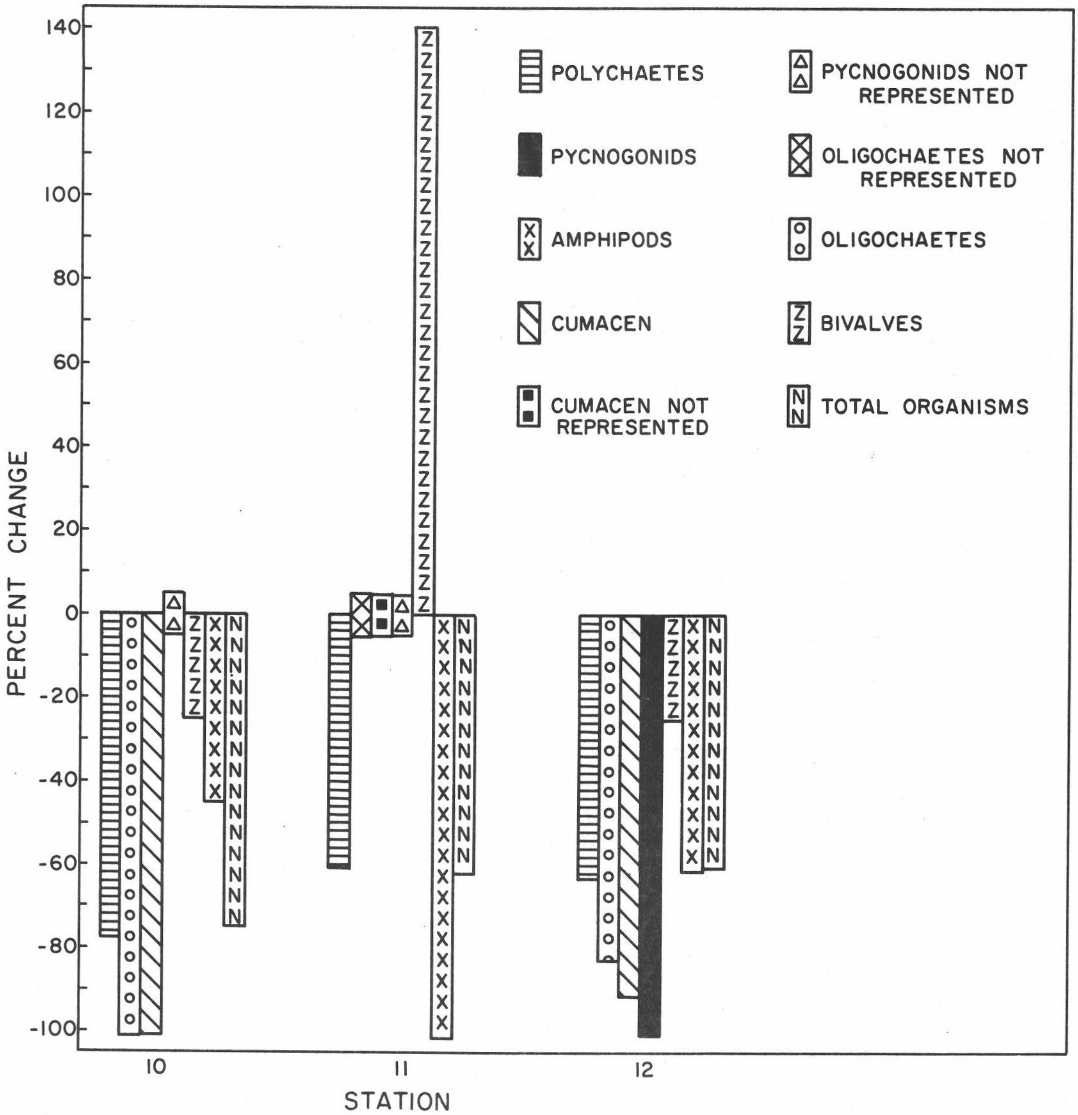

Figure 11. Percentage of change in mean abundance of select taxa before and after spoiling at the spoil site.

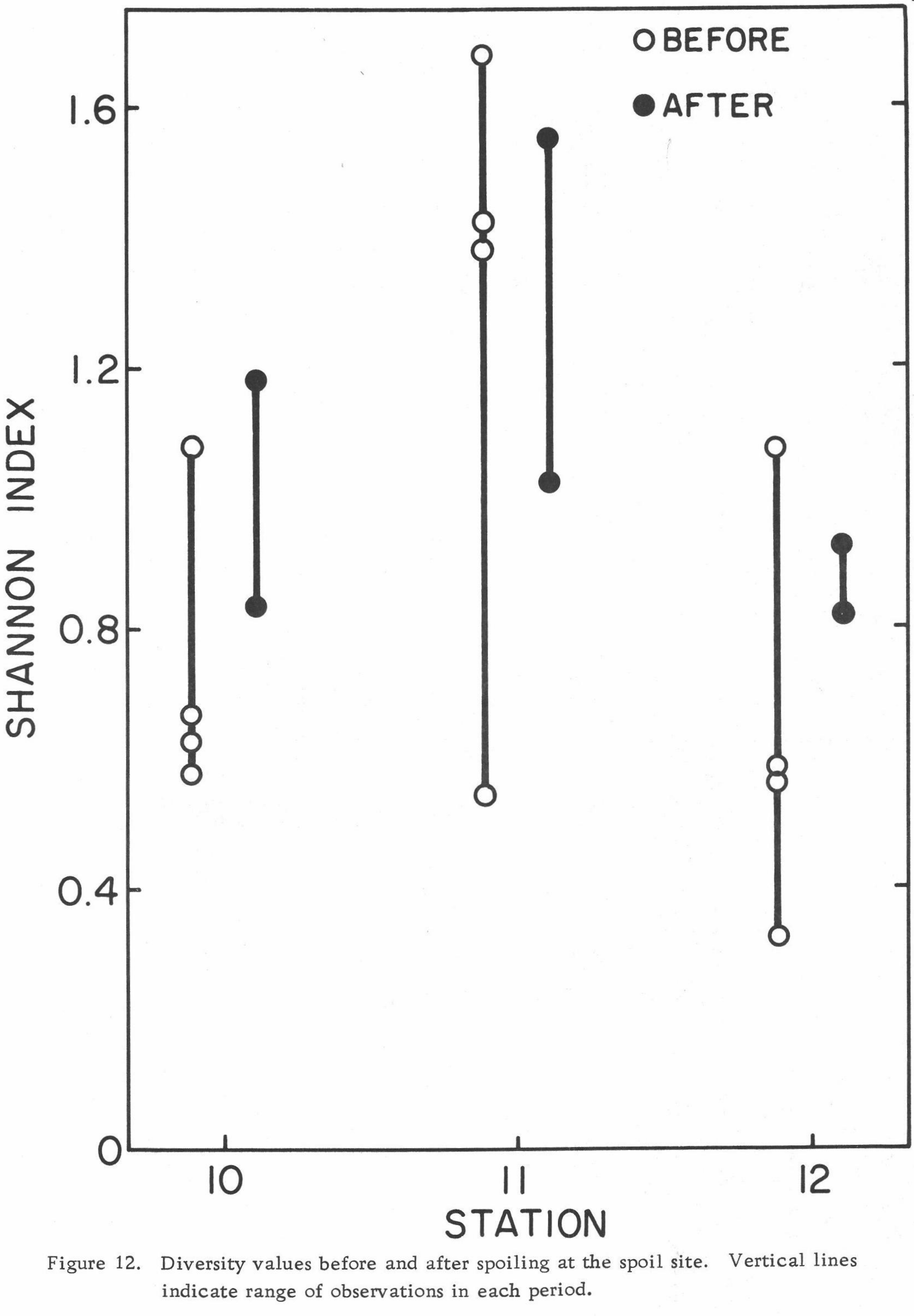

Figure 12. Diversity values before and after spoiling at the spoil site. Vertical lines indicate range of observations in each period.

Phase II

Faunal abundances generally decline immediately after dredging operations (Harrison et al., 1964; Flemer et al., 1968). In the present study the return of faunal abundance to previous levels is termed re-adjustment. Re-establishment is not used to describe this phenomena because it infers a return to pre-dredging stability and community structure which may not be the case.

The sampling program of Phase II was limited in the number of replicates taken at each station. One replicate sample (two grabs) was taken at each station, 7, 14, 28, and 56 days after dredge operations. Because the limited number of replicates prevents a meaningful statistical analysis of the data, only general trends regarding sediment characteristics and biological re-adjustment will be discussed.

Sediment Trends

The qualitative sediment characteristics of Phase I persisted throughout Phase II. With few exceptions, the sieved material > 0.50 mm was similar. Wood debris (sticks and large pieces of bark) sampled at Stations 10 and 11 immediately after spoiling, however, was replaced by small wood chips one week later.

Table 7 lists the percentage of material > 0.50 mm at each station during Phase II. Mean values before dredging and spoiling are

Table 7. Percentage of Material > 0.50 mm from Phase II. Mean Percentage > 0.50 mm from Phase I Included for Comparison.

	Dredge Site Stations					
	1	2	3	4	5	6
			Phase I			
Mean Before	3.4	5.3	14.3	33.9	8.1	5.7
Mean After	3.4	6.7	12.6	38.6	16.9	4.3
			Phase II			
Sample						
7-A	4.8	4.7	4.9	36.2	16.6	3.9
7-B	3.4	6.6	17.5	15.9	20.1	4.5
8-A	2.4	4.4	8.5	28.1	20.8	2.4
8-B	2.8	7.3	29.4	26.7	9.5	3.7
9-A	4.0	8.3	8.2	34.2	43.0	5.8
9-B	5.0	5.2	6.6	22.5	22.6	10.0
10-A	5.7	25.8	16.7	15.7	24.7	9.6
10-B	3.8	13.3	9.9	46.9	21.3	10.0

	Spoil Site Stations		
	10	11	12
		Phase I	
Mean Before	10.3	9.9	24.9
Mean After	22.7	21.5	*
		Phase II	
Sample			
4-A	9.1	20.5	25.6
4-B	29.4	24.3	12.7
5-A	14.5	14.6	21.3
5-B	20.0	9.1	26.2
6-A	28.0	10.8	24.4
6-B	*	14.5	22.8
7-A	4.3	14.3	47.4
7-B	8.5	11.8	23.1

*Insufficient data

included for comparative purposes. Increased amounts of coarse material persisted at Station 5 following dredging suggesting the continued presence of dredge-induced alterations of the hydrographic environment. The initial buildup of material > 0.50 mm at Station 10 and 11 after spoiling declined with time suggesting that some of the spoil material was naturally removed from the area. Considering the high energy environment of the spoil site, this result would be expected.

Benthic Fauna

Both dredge and spoil sites contained the same basic types of benthic fauna after dredging operations as before (Appendices 4, 5 and 6). Polychaetes remained the overwhelmingly abundant taxon. The small polychaete *Streblospio benedicti* continued to be numerically dominant at all stations.

Several taxa were collected only after dredge operations; the polychaetes *Armandia bioculata*, *Arenicola pusilla*, and *Scoloplos* sp. were sampled infrequently. Unidentified marine mites (order Acarina) were found in low numbers primarily associated with vegetative debris at Stations 1 and 2. Several mechanisms are possible to account for the occurrence of these taxa only during Phase II. Their relatively low abundances may indicate that they are normally rare organisms at the study site, and extending the sampling program into

Phase II would be expected to turn up several unsampled taxa. It is also possible that population increases or migrations of these taxa into the study site increased chances of collecting them.

The primary goal of Phase II was to observe changes in benthic faunal abundance following dredging activity. A review of changing abundance for important taxa follows.

Individual points on Figures 13 through 21 indicate abundance levels at progressive times relative to dredge operations. Numbers in parentheses beside observation points indicate multiple observations having the same relative value. Vertical lines connecting individual abundances represent the range of observations for a given collecting period. The attainment of re-adjustment will be marked by the first collection at which both observations fall within or above the range of the pre-dredging collections. Vertical dashed lines marked "D" and "S" indicate dredging or spoiling respectively. Days to the left of the dashed lines are before dredge operations.

Total Abundance

Dredging resulted in immediate decreases in total abundance at all stations except 4 (Figure 13). Re-adjustment to former abundance took seven days at Station 1, 14 days at Stations 3 and 6, and 28 days at Station 2. After 56 days, Station 5 had not regained pre-dredging abundance. The data represent maximum re-adjustment rates since

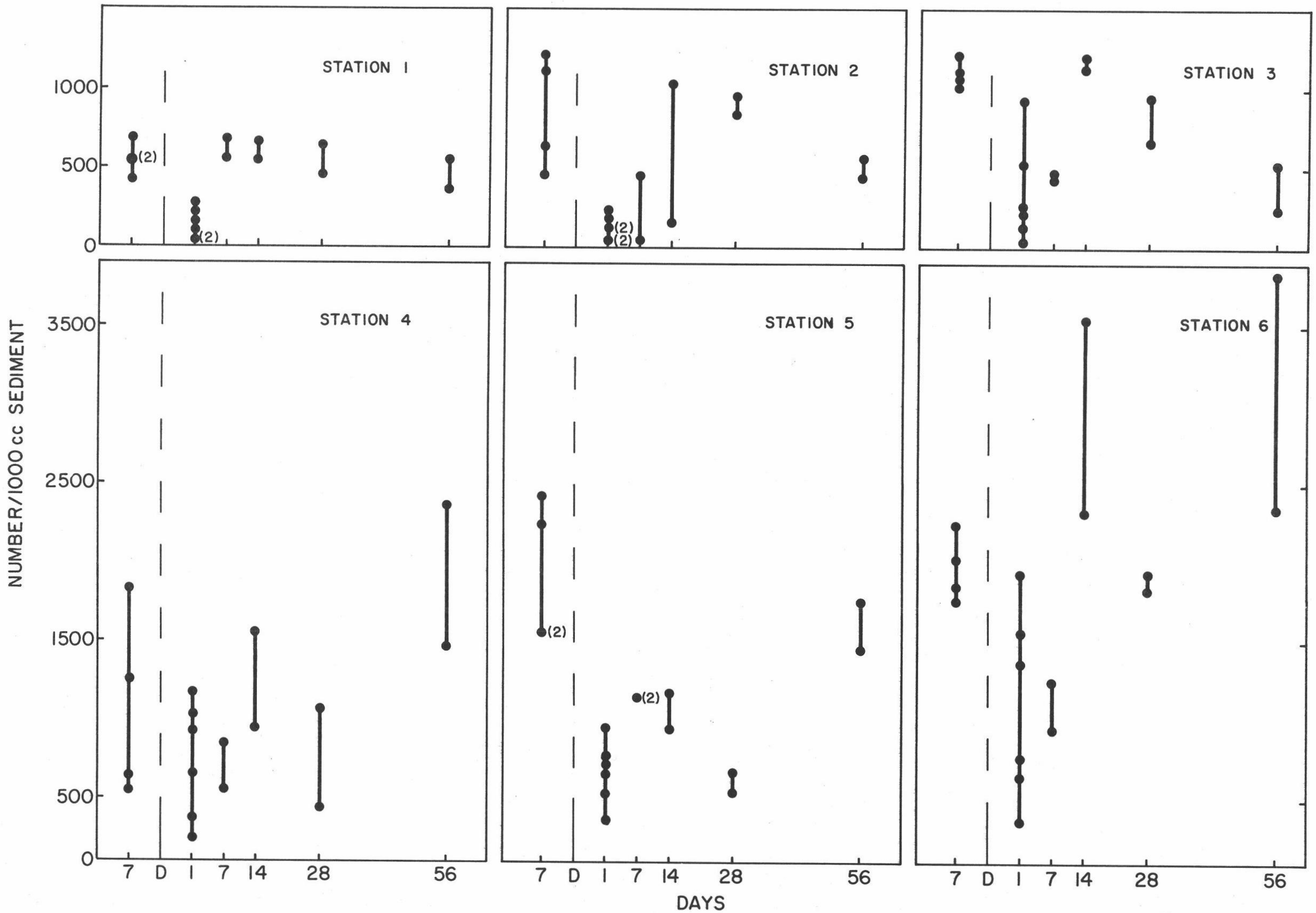

Figure 13. Total abundance at dredge site.

re-attainment of pre-dredged abundance between sampling periods would not be recorded until the following collection.

Spoiling resulted in decreases in total abundance at Stations 10 and 12 (Figure 14). Re-adjustment took no longer than seven days.

Ranges of total abundance at each station change between sampling periods. When progressive ranges of total abundance exclude each other or are markedly dissimilar it may be concluded that a change in total abundance has occurred between sampling periods. It is not feasible nor realistic to follow each of these changes. Concurrent changes at several stations, however, are more easily observed and may delineate broad biological processes within the study site.

Dredge site Stations 4, 5, and 6 increased in total abundance between 28 and 56 days. During this same period Stations 2 and 3 declined. Station 1 also appeared to decline somewhat, although this decline was evident in only one of the grab samples. At the spoil site, Stations 10 and 11 increased during this period. Station 12 increased in only one of the grab samples taken. Considering the entire study area, declining abundances were localized at Stations 1, 2, and 3.

Changes in total abundance reflect variations in the number of organisms at each station but do not give information concerning the relative changes of individuals within each taxa. Since different taxa

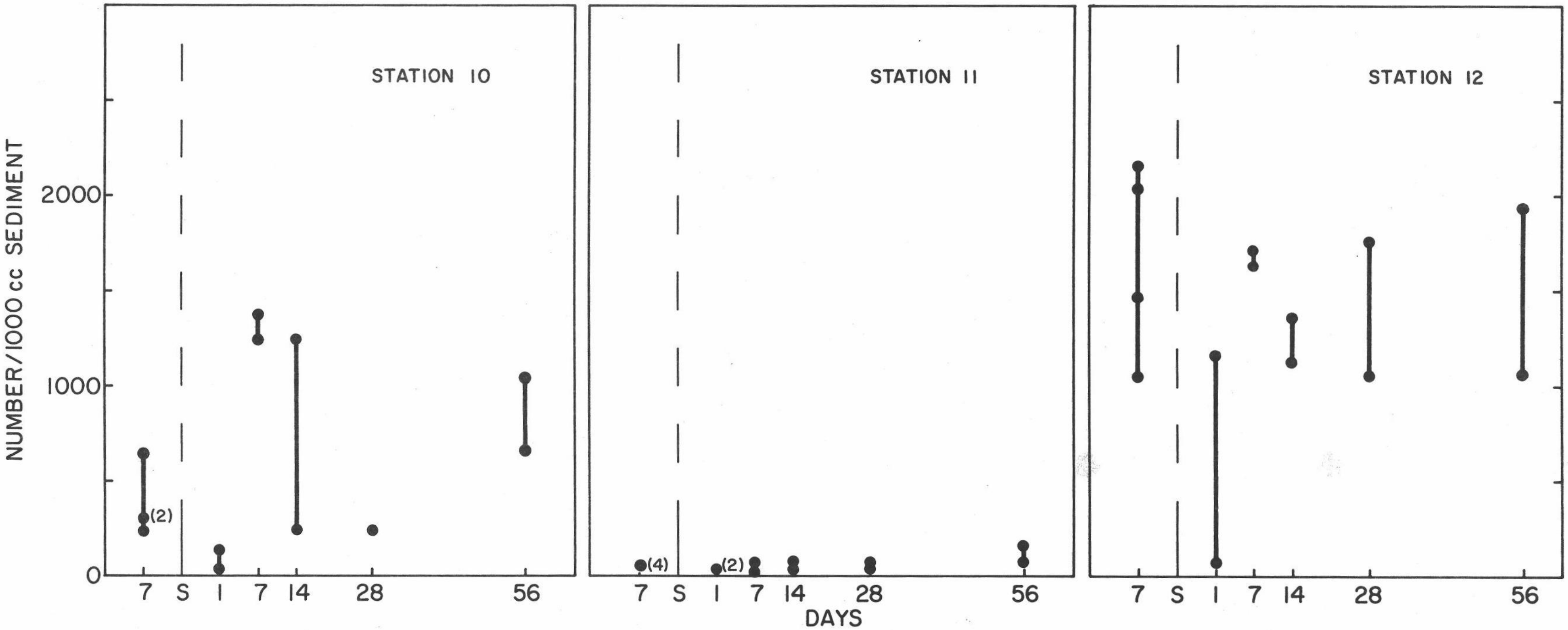

Figure 14. Total abundance at spoil site.

may have different tolerances to dredging disturbances it is important to follow the abundance of separate taxa through the study period. The following taxa are dominant organisms within the study area.

Streblospio benedicti

This polychaete usually constituted >85% of the individuals taken in each grab. This overwhelming numerical dominance is seen in Figures 15 and 16 and essentially mirrors changes in total abundance already mentioned.

Capitella (C) ovincola

The abundance of this large polychaete did not decrease at any station immediately after dredging, but immediate increases were recorded at Stations 1 and 2 (Figure 17). Dramatic population increases were recorded at Stations 1, 2 and 3 after 28 days. Numerous juvenile *C. ovincola* were noted in samples from this period suggesting recruitment from the pelagic realm. *C. ovincola* was not abundant at either Stations 4, 5, 6, or at the spoil site.

Type "A" Oligochaete

The wide range of abundance before dredging made it difficult to determine immediate changes in Oligochaete "A" following dredging (Figure 18). During the period between 28 and 56 days, abundances

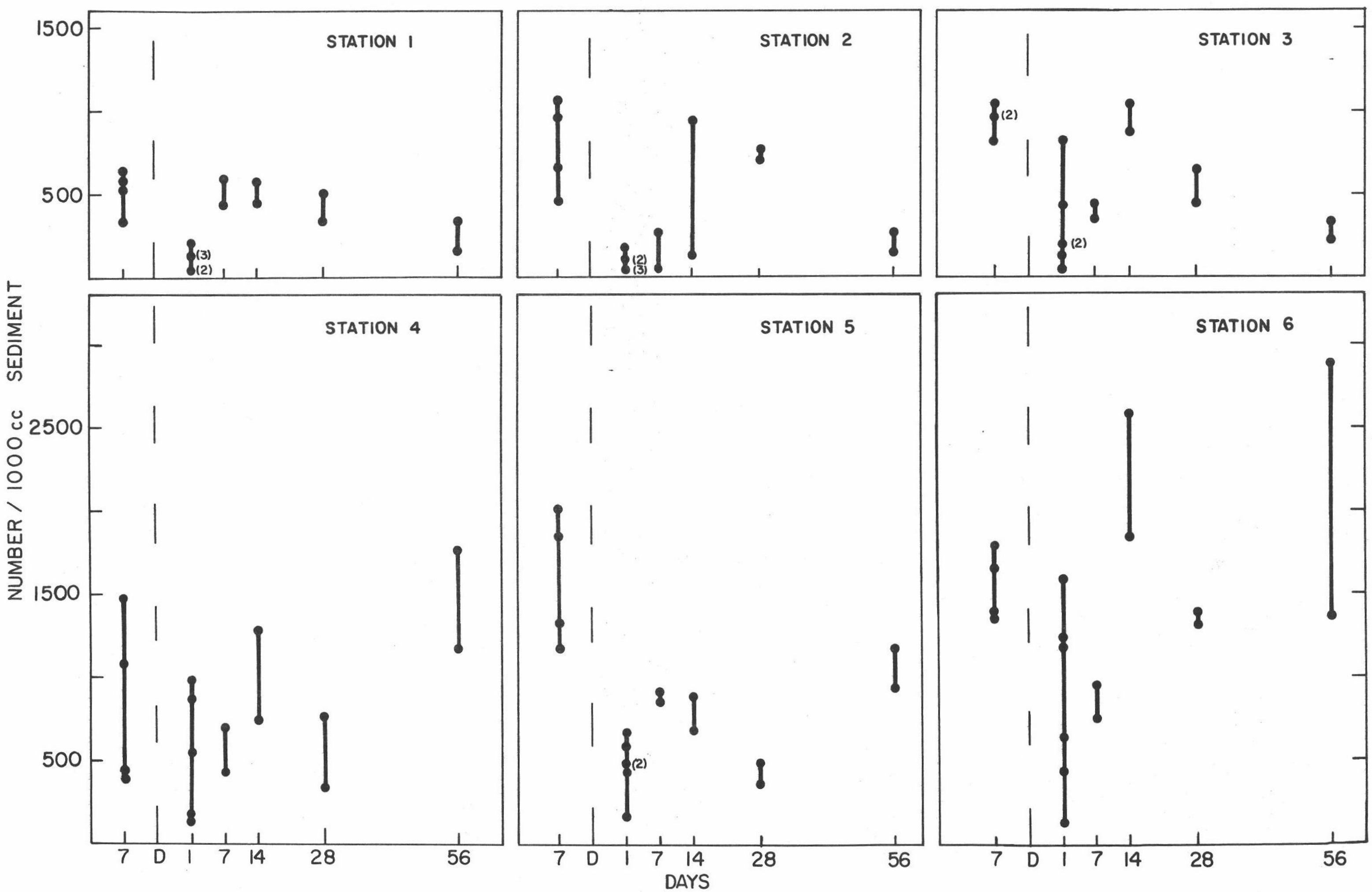

Figure 15. Streblospio benedicti abundance at dredge site.

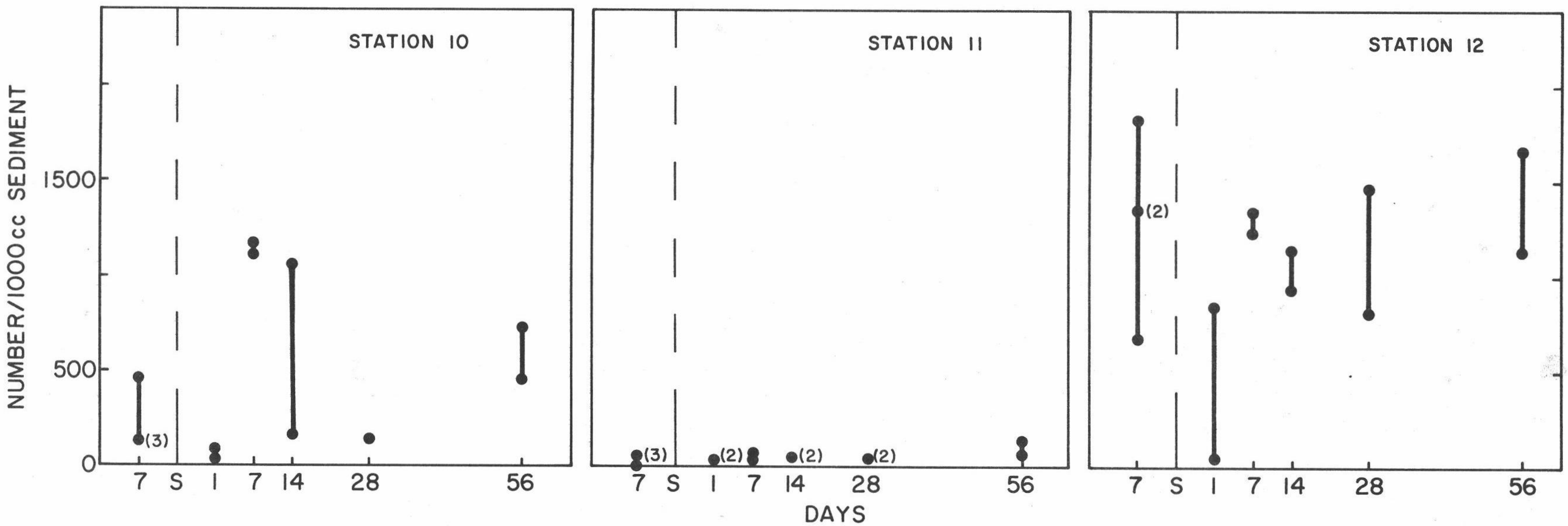

Figure 16. Streblospio benedicti abundance at spoil site.

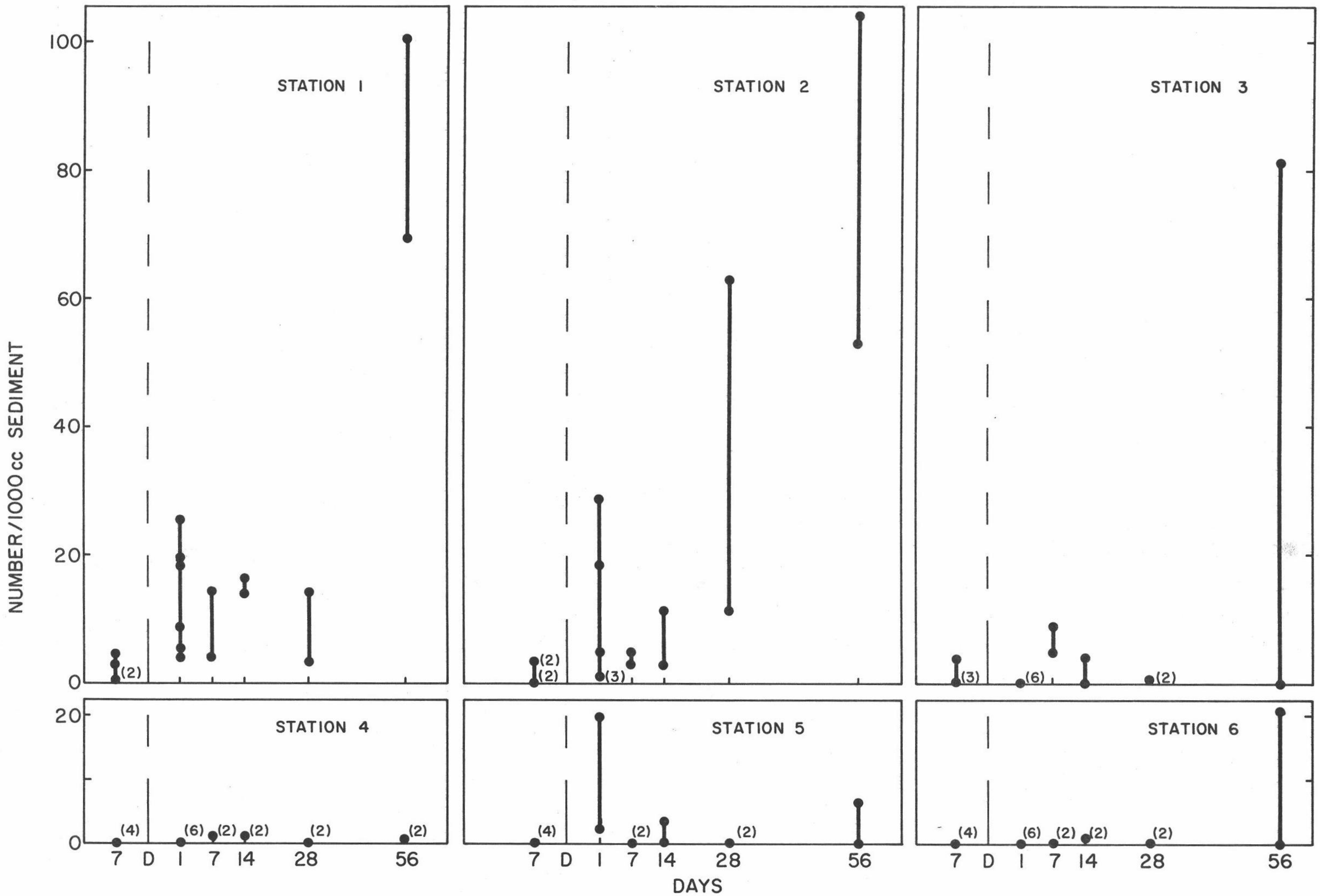

Figure 17. Capitella ovincola abundance at dredge site.

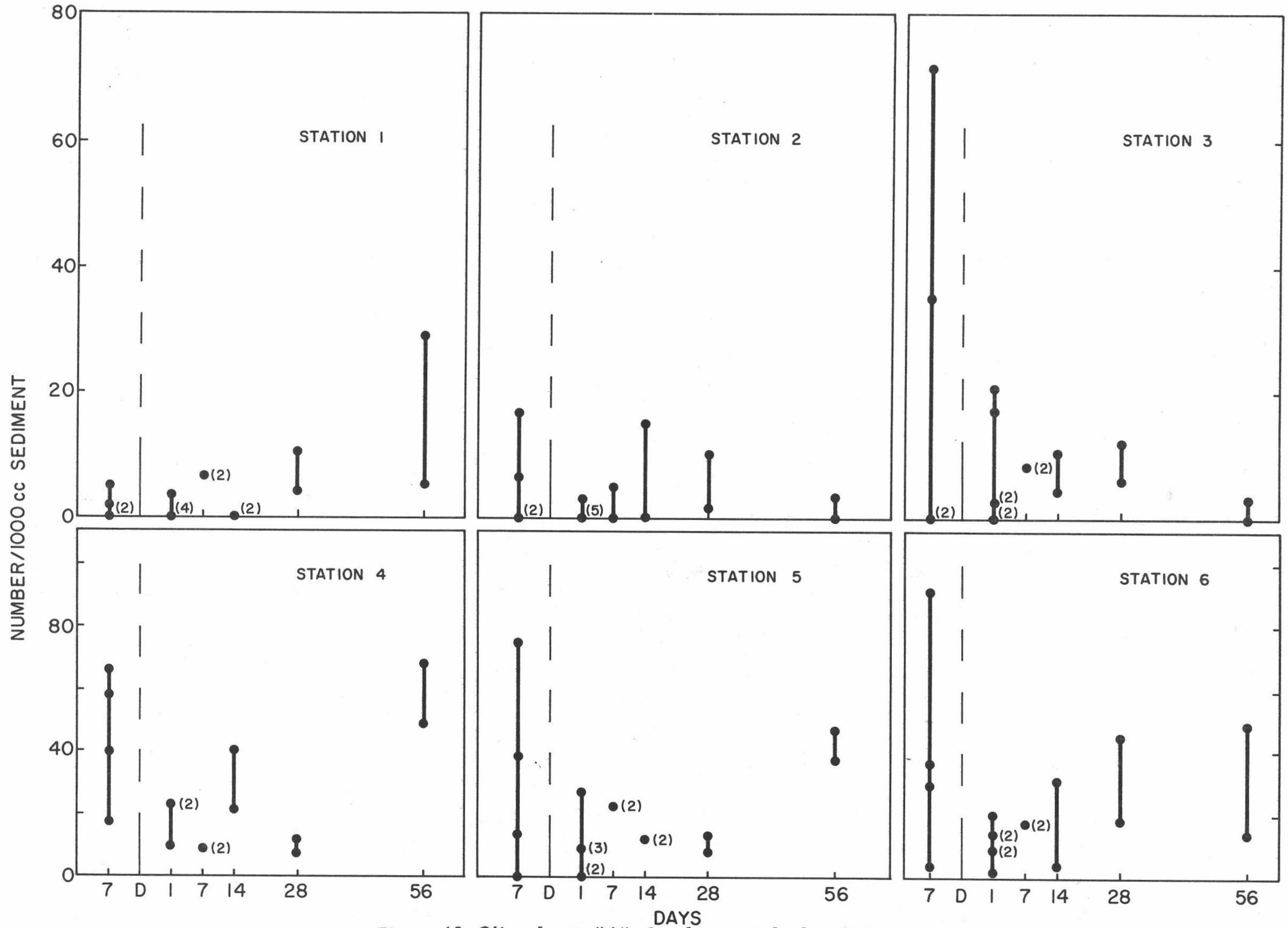

Figure 18. Oligochaete "A" abundance at dredge site.

decreased at Stations 2 and 3 while they increased or remained constant at Stations 1, 4, 5, and 6.

Type "B" Oligochaete

Wide ranges of abundance before dredging made it difficult to determine immediate changes (Figure 19). Oligochaete "B" was never abundant at the spoil site. Decreases in abundance at Stations 2 and 3 after 28 days were in sharp contrast to increases at Stations 1, 4, 5, and 6.

Bivalves

Initial abundances of the four types of bivalves encountered were so low that the groups were combined under one heading. At the dredge site immediately after dredging abundances were essentially unchanged except at Station 1 where a slight increase was detected (Figures 20 and 21). Following 28 days large increases in abundance were seen at Stations 4, 5, and 6. Bivalves were not one of the dominant taxa at the spoil site.

Changes in Number of Taxa

Throughout the study, no radical differences from pre-dredging taxa levels were apparent, but small increases in the number of taxa are seen at all stations during Phase II (Table 8) indicative of the

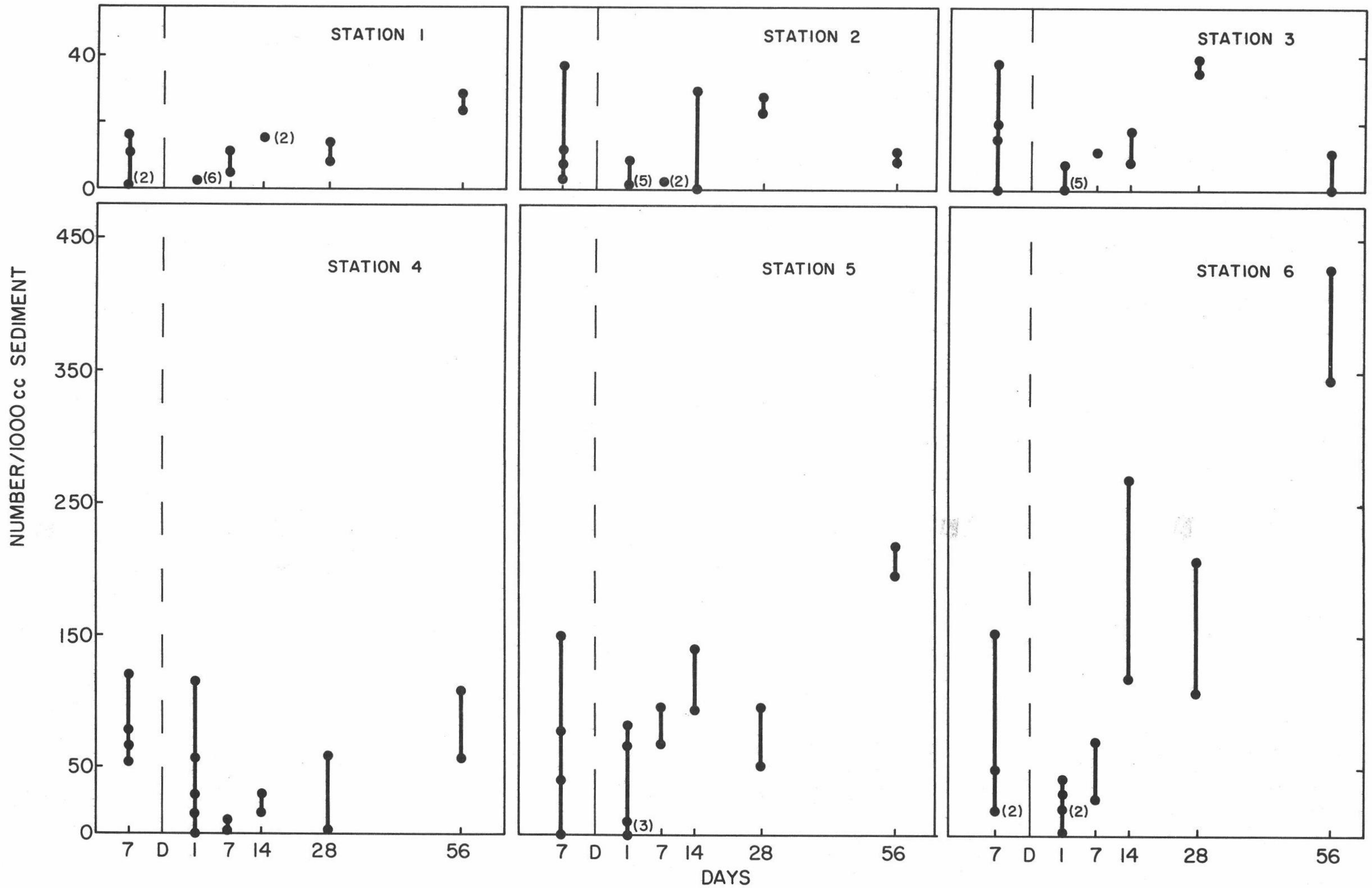

Figure 19. Oligochaete "B" abundance at dredge site.

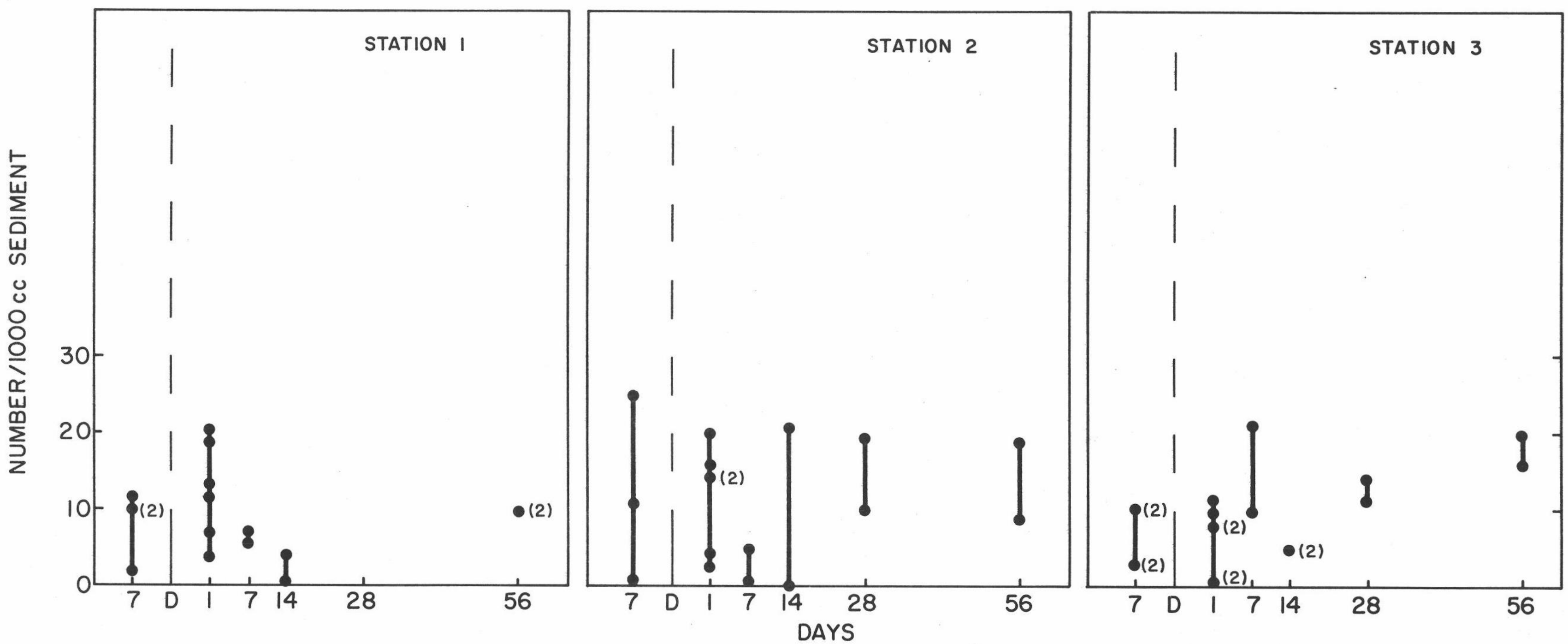

Figure 20. Bivalve abundance at Stations 1, 2, and 3.

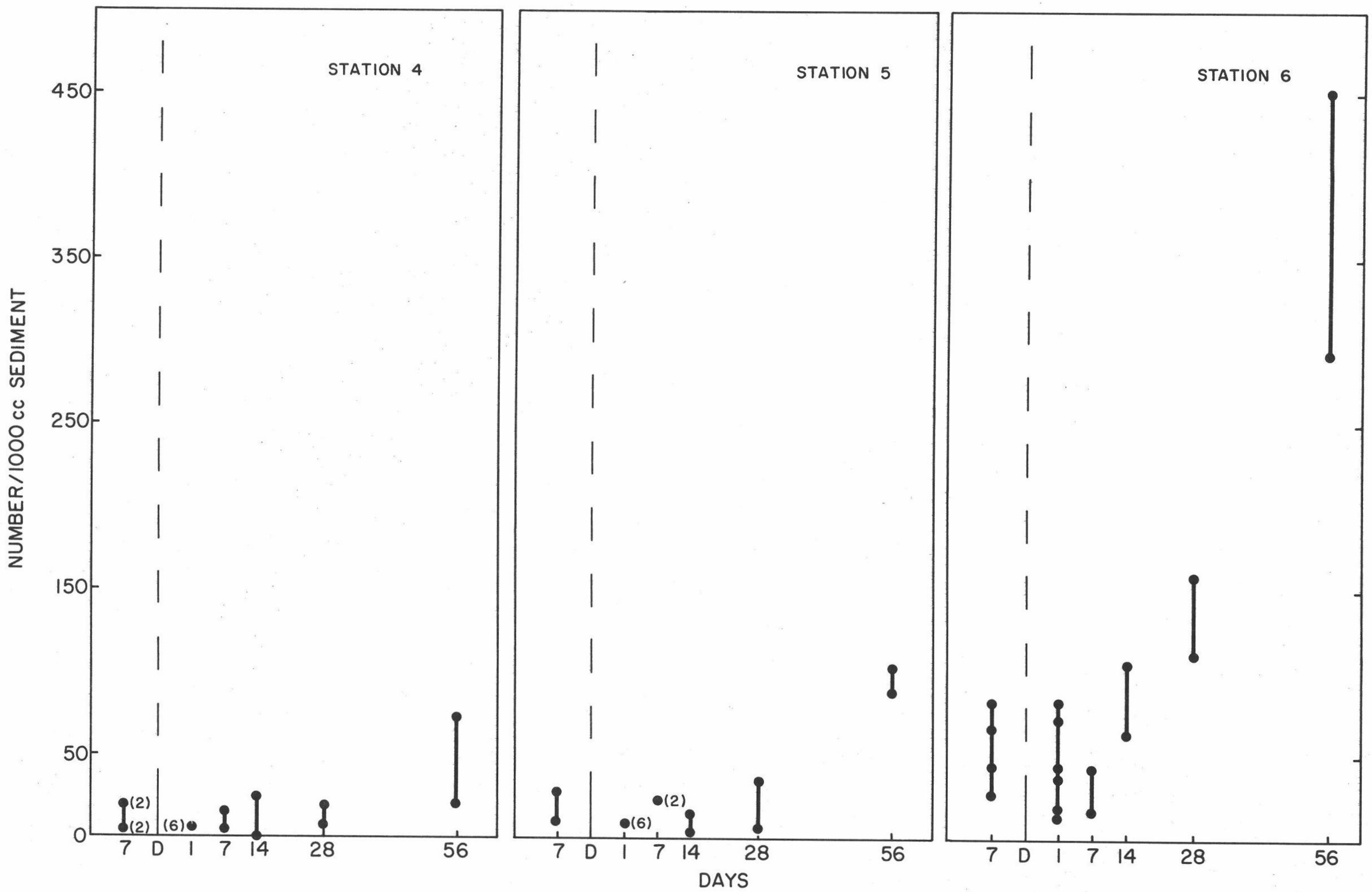

Figure 21. Bivalve abundance at Stations 4, 5, and 6.

Table 8. Number of Taxa from Phase II. Mean Number of Taxa from Phase I Included for Comparison.

	Dredge Site Stations					
	1	2	3	4	5	6
			Phase I			
Mean Before	14	12	12	11	12	16
Mean After	13	10	10	11	10	14
			Phase II			
Sample						
7-A	17	14	12	14	13	17
7-B	19	7	15	12	10	17
8-A	14	9	12	15	15	23
8-B	11	14	12	12	15	18
9-A	14	19	14	14	16	16
9-B	13	12	15	14	12	12
10-A	13	15	15	16	16	13
10-B	10	12	13	13	14	16

	Spoil Site Stations		
	10	11	12
		Phase I	
Mean Before	11	7	13
Mean After	8	5	11
		Phase II	
Sample			
4-A	11	4	15
4-B	9	4	15
5-A	10	7	13
5-B	10	9	14
6-A	9	7	15
6-B	*	6	13
7-A	9	5	12
7-B	12	7	16

*Insufficient data

presence of _Armandia bioculata_, _Arenicola pusilla_, _Scoloplos_ sp., and the unidentified marine mites.

Changes in Shannon Diversity

Initial increases in diversity experienced immediately after dredging at Stations 1 and 2 were temporary and returned to pre-dredging levels within seven days. Ranges of diversity at all other stations overlapped pre-dredging and spoiling values (Figures 22 and 23).

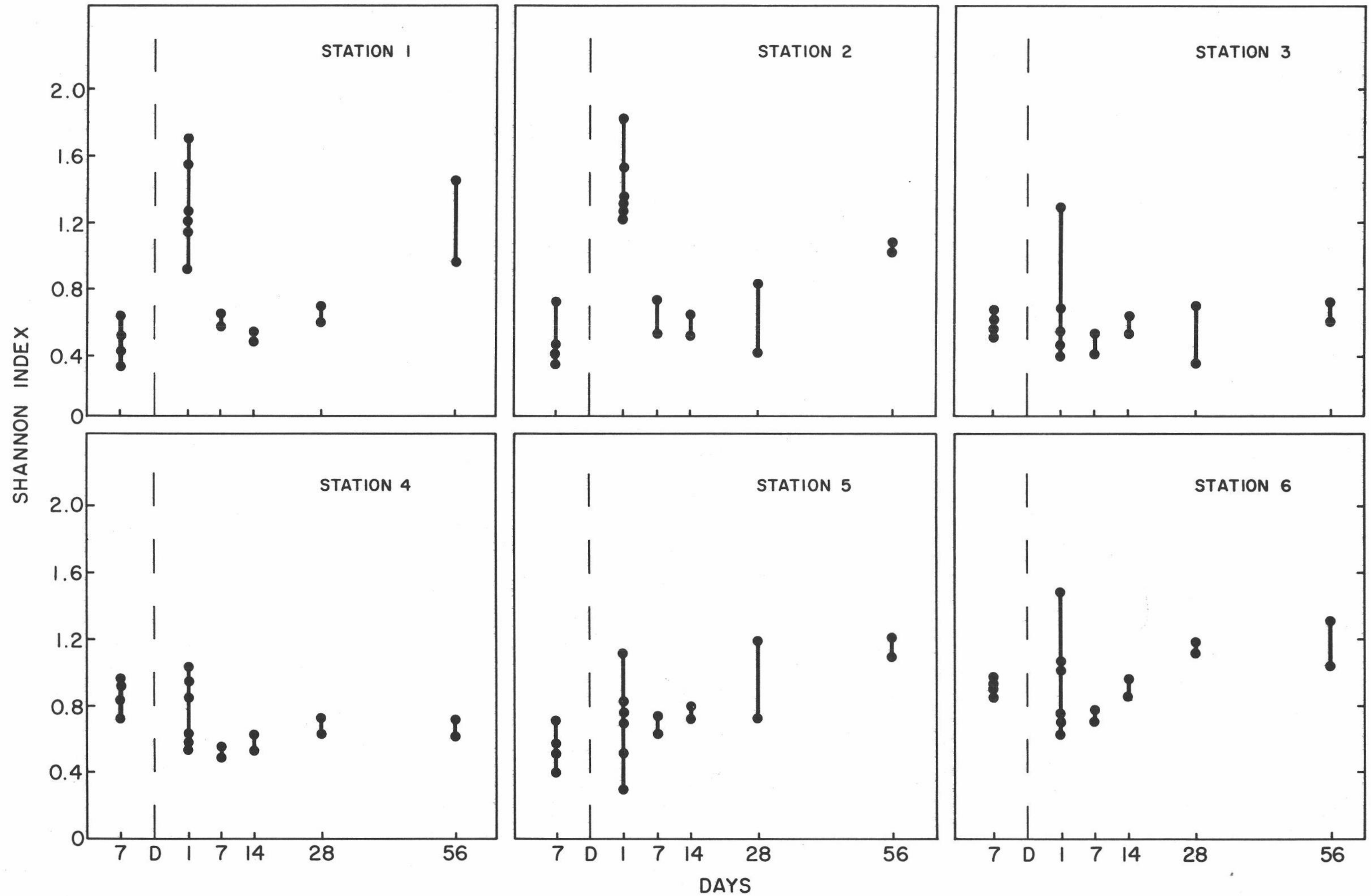

Figure 22. Diversity values for dredge site.

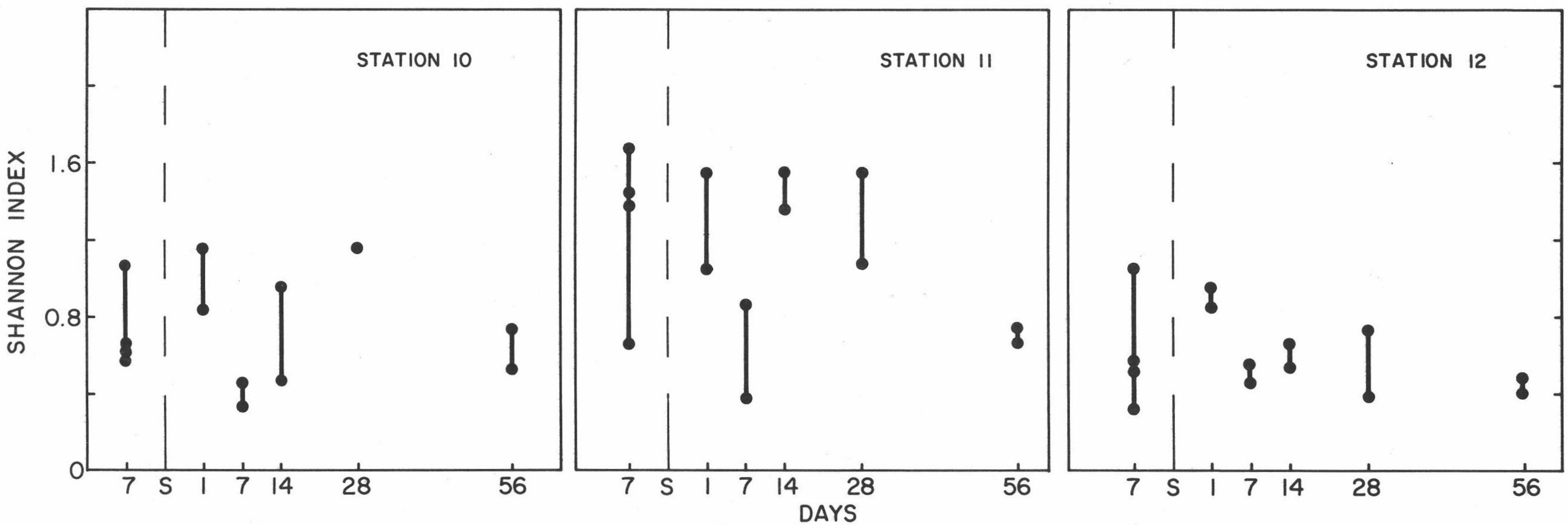

Figure 23. Diversity values for spoil site.

DISCUSSION

Although the benthic invertebrates sampled in this study are not directly exploited by man, they serve crucial roles in the estuarine ecosystem. Benthic invertebrates function in the recycling of organic detritus from within the sediment and are also major components of the estuarine food chain. Each generation, countless gametes and larvae provide a vast supply of food for juvenile fish in estuary nursery grounds. In addition, adult invertebrates form a substantial part of the diet of demersal fish and diving birds. Valuable migratory fish such as salmon also feed heavily on these organisms (McConnaughey, 1971).

Benthic invertebrates have frequently been used as indicators of water quality because they are omnipresent and have low mobility (Reish, 1960; Wass, 1967; McNulty, 1970). Gaufin and Tarzwell (1952) suggested that benthic invertebrates indicate the water quality at the time of sampling as well as past conditions during their life spans.

Infaunal invertebrates may serve further as indicators of sediment quality. Selective consumption of organic debris or the indiscriminant devouring of large quantities of sediment tightly binds adult organisms to physical and chemical sediment properties. The pelagic larval stage of most infaunal organisms is physically dependent on prevailing currents for widespread dispersal. After an indeterminant period, larvae settle to the sediment surface and metamorphose to the adult stage. Wilson (1952, 1958) and Thorson (1958) have shown that if biological criteria of the sediment are not met, larvae can delay metamorphosis and allow themselves to be carried elsewhere. Bio-selectivity of sediment types by larvae is obviously fundamental to the distribution of the adult organism.

Most benthic infauna are found within 7 cm of the sediment surface (Mare, 1942; Wieser, 1960). Each taxon distributes itself at preferential depths within this zone. Jones (1961) has delineated the vertical distribution of several of the Coos Bay taxa. Streblospio benedicti, Polydora kempi and Capitella C. ovincola inhabit the upper 2 cm of the sediment. Oligochaetes and Glyciande sp. may be found at depths to 6 cm. Bivalves are usually distributed somewhat deeper depending on the species and length of siphon (Trueman, Brand, and Davis, 1966).

It is evident that the effects of dredging and spoiling will have an immediate impact on benthic fauna. Changes in abundance and distribution are to be expected.

Before the impact of a particular dredging operation can be assessed it is necessary to mention certain factors: biological characteristics of the dredge and spoil sites, history and frequency of dredging, harbor activities such as frequency and magnitude of shipping operations and industrial pollution, size and duration of the dredge operation, size of the shipping channel, and draft and size of the dredge vessel.

The bottom fauna of the Coos Bay dredge and spoil sites contained many species which have been reported in the literature to be indicators of pollution: Streblospio benedicti, Capitella (C.) ovincola, Polydora ligni, Nereis sp., Scoloplos sp. and Mya arenaria (Reish, 1960; Richardson, 1971; Boesch, 1971). Streblospio benedicti, Capitella (C.) ovincola and Polydora ligni have been compared to "certain weeds which proliferate over broad areas of man's disclimaxes (Wass, 1967, p. 275). Other Coos Bay taxa, Macoma inconspicua and Achelia nudiuscula, have been associated with areas of low water quality (Felice, 1959; Ricketts, Calvin, and Hedgpeth, 1968). Different taxa have different ranges of tolerance to pollution. Although the Coos Bay taxa are sometimes present in unpolluted environments, their high tolerance to domestic and industrial pollution and their great reproductive potential allows them to flourish in the stressed environment of the Port of Coos Bay. In the polluted environment these taxa are less exposed to the pressures of biological competition and predation from less tolerant taxa (McNulty, 1970; Boesch, 1971).

Periodic dredging and heavy ship traffic within the study site are environmental factors to which the benthic community must adapt.

The study site was dredged two years before the present study. During 1970, 175 vessels having drafts exceeding 28 feet put in at the Port of Coos Bay (Slotta et al., 1973). Taking into account the water depth of the study site (pre-dredging mean for all stations equaled 27 feet) it is evident that the sediment surface experienced extensive prop wash from the passage of these vessels. Also, the practice of dragging large anchors for stability during mooring was common at the study site and further disturbed the sediment surface.

Extensive log rafting and storage within Coos Bay places additional stress on the biotic community. Leachates from the logs and large amounts of sunken wood debris are possible sources of pollution. Rudy (1970) observed that the thousands of logs stored in the estuary pound and roll over the mudflats twice a day as the tide rises and falls. It can be assumed that this action is influential in preventing the establishment of a diverse fauna on the mudflats, and further, that it results in increased turbidity within the rest of the bay. Before dredging operations, turbidity was measured at 80 Jackson Turbidity Units (Slotta et al., 1973). Turbidity levels in this range are reflected in murky waters with low visibility. Although most estuarine animals have relatively wide tolerances to turbidity, increased turbidity levels may limit the establishment of more sensitive fauna. Turbidity may also be responsible for the lack of extensive rooted vegetation in the study area due to reduced light levels near the sediment surface.

Unstable sediment surfaces may also inhibit the establishment of rooted vegetation. Sediment instability was pronounced in the study area (Slotta et al., 1973). Frequent re-suspension of surface sediments was indicated by coarse material overlying fine substrates, and by the lack of free sulphides in interstitial environments conducive to their formation. While some of this overturning is the result of natural processes, the man-made disturbances mentioned above undoubtedly contribute to the situation. Only taxa capable of adjusting to these frequent disruptions of the sediment surface will be abundant.

The relatively small volume (8023 cu. yards) of sediment removed and the one-day duration of the dredging operation are undoubtedly reflected in the degree of biotic disruption measured. The narrow width of Isthmus Slough (215 m at the dredge site) and the site of the Chester Harding (94 m length, 17 m width and 4-6 m draft range) are other important factors affecting the study.

Immediate Effects at the Dredge Site - Phase I

Hopper dredging, described by O'Neal and Sceva (1971), involves a self-propelled vessel designed for hydraulic dredging and transportation of spoil to a disposal area. Dredging is by two large suction pipes which are hinged on the sides of the ship and lowered or raised by cables. Each is equipped with a broad scraper which directs bottom material into the pipe as it drags along the sediment surface. As the ship moves down the dredge course, the top layer of sediment is drawn up through the pipe and discharged into hopper bins onboard. When the bins are full, the suction pipes are raised and the ship moves to the disposal site. The limited size of the scraper head (approximately 2 m across) necessitates that many trips be made over the same course to attain desired depth and width of the channel.

This study was designed to monitor changes in benthic abundance and taxa composition. The following station-by-station analysis and discussion deals with the immediate effects of hopper dredging and spoiling, i. e., those evident 24 hours after dredging operations. Hypotheses are suggested as possible explanations for the observed changes. While the study was not designed to provide proof of these hypotheses, the author feels that based on the available data, they provide the most accurate and realistic explanation for the observations recorded.

Station 1

Although not directly dredged over, Station 1 was within 33 m of heavy dredging at Station 2. Station 2 was located in shallow water (7. 6 m) and widespread disruption of the silt bottom resulted from the suction heads of the dredge and more importantly from the propellers of the *Chester Harding*. When loaded the large propellers of the dredge were no more than 2 m from the sediment surface. Whereas disruption by the suction heads is somewhat localized due to their small surface area and accumulating nature, silt placed in suspension by violent prop wash could be transported outward on both sides of the moving ship. The effect of prop wash in scouring bottom sediments has been reported by MacPhail (1961) and Godcharles (1971) who recommended propeller guards for small boats working in shallow water clam beds.

Fine silt remains in suspension until turbulence decreases allowing deposition. Suspended silt from Station 2 could be transported outward and begin to settle upon reaching the relatively undisturbed waters of Station 1. Repeated dredging of Station 2 resulted in siltation of the sediment surface at Station 1.

The fact that only a thin surface layer (7 cm) of the sediment harbors appreciable life (Wieser, 1960) has two important consequences: 1) as Station 2 was progressively dredged removing the surface sediments, the suspended silt would be progressively more abiotic; 2) organisms which were buried at Station 1 would begin burrowing upward to regain positions near the sediment surface. Rates of burrowing vary. Saila (1972) found that *Streblospio benedicti* could regain the surface in 24 hours after being buried 6 cm. Other small polychaetes and oligochaetes can be expected to have similar rates of burrowing. Infaunal bivalves must be able to move rapidly toward the surface as sediment is deposited over them to prevent their life supporting siphons from being covered (Reineck, 1967). Their rate of burrowing may appreciably exceed that of small annelids which do not have to maintain surface contact. In the Coos Bay samples, bivalves were usually > 12 mm in length while annelids were < 5 mm. It is obvious from this size difference that bivalves would be able to burrow through deposited silt at a rate exceeding that of annelids. In addition, bivalves can detect the need to start burrowing upward as soon as silt covers their siphons, while annelids living below the sediment surface might take longer to realize that burial was taking place.

If grab samples were taken before all taxa have regained former depth habitats, it would appear that: 1) the faster burrowing bivalves had increased in relative abundance, and 2) the slower burrowing annelids had decreased in relative abundance. A partial sampling before former depths were reached would tend to increase diversity and equitability by equalizing the relative abundance of taxa. After all taxa had completed burrowing, spatial distributions with depth would be re-established and successive grab samples would record total abundance, diversity, and equitability values highly comparable to pre-dredging levels. Predictably, these results were obtained in sampling one week later. If the decline in abundance at Station 1 had resulted from the gross displacement or death of organisms it would not be reasonable to expect abundance, diversity and equitability values to closely match pre-dredging values after only one week since these parameters are long term adapted characteristics of the benthic community.

The percent change in select taxa before and after dredging indicates that bivalves and pycnogonids increased immediately after dredging. While differing rates of burrowing might increase the relative abundance of bivalves with respect to other taxa, it would not necessarily increase the actual number of bivalves collected. Since the abundance of bivalves before dredging was low, the percent increase in abundance could be realized by the addition of relatively few individuals. Modiolus sp., one of the four types of bivalves encountered at Station 1, increased from 4 individuals/1000 cc sediment to 8.6 individuals/1000 cc sediment and accounted for all of the increase in total bivalve abundance. All specimens of Modiolus sp. were recently settled spat suggesting that settlement may have intervened between the cessation of dredging and sample collection the next day.

The change in pycnogonids before and after dredging also suggests an increase in abundance immediately following dredging. Low abundance before dredging makes it evident that the addition of less than 2 individuals/1000 cc sediment after dredging would give this result. Even this small increase is difficult to explain. It may be that pycnogonids, which are one of the most motile organisms sampled, migrated into the station from undisturbed areas shoreward of Station 1 to scavenge on freshly deposited material. These small increases would also tend to increase diversity and equitability.

Station 2

Hopper dredging does not remove sediment uniformly. Each suction head of the dredge cuts a furrow about 2 m wide. The area is repeatedly passed over until a large portion of the sediment has been removed. Owing to the relatively small area of the suction heads and imprecision of ship navigation, patches of sediment are left behind which have not been dredged. These patches contain organisms which may be important in the short term re-adjustment and eventual re-establishment of the benthic community in dredged areas by serving as source areas for adult organisms.

Benthic fauna were removed by active dredging. Violent prop wash was produced with the passage of the dredge. Although dredging probably resulted in a mosaic pattern of dredged and undredged sections, prop wash and slumping of the fine sediment were thought to obliterate this pattern quickly.

Results obtained immediately after dredging seem to confirm this hypothesis. Large decreases in total abundance were recorded, but unlike Station 1 they required several weeks to return to pre-dredging levels. Since organisms were physically removed from the area, re-adjustment through active migration of organisms into the area, passive transport with moving sediments from nearby areas, or reproductive increase would be necessary to re-build the population.

The percent change in taxa after dredging indicates that pycnogonids increased as at Station 1. The minimum decline noted in bivalves may reflect two processes: 1) the intervening settlement of Modiolus sp. which increased from 7 to 9 individuals / 1000 cc sediment, and 2) the reduced efficiency of removing bivalves by dredging. While all other taxa decreased 80%, bivalves (excluding Modiolus) decreased only 59%. The suction heads may discriminate slightly in collecting these deeper living organisms. Also, of the organisms remaining in the undredged areas, bivalves, because of their need to remain in contact with open water by means of their siphons, would be quick to recover from burial caused by slumping and homogenization of the sediment. Their relative abundance would not appear to decline as much as other taxa.

Diversity and equitability values were affected by changes in the numerical distribution of the remaining taxa. There are two possible sources of these changes: 1) selective removal of some taxa by the dredge leaving an altered community, and 2) the alteration of depth distributions of the remaining taxa. Although there is evidence that dredging is somewhat discriminatory with regard to bivalves, the numerically dominant polychaetes and oligochaetes are removed approximately equally. Further, if selective dredging were the primary cause for enhanced diversity and equitability, it would be expected that this enhancement would continue until re-adjustment had occurred. This was not the case at Station 2 where these parameters returned to previous levels one week later. The temporary quality of this enhancement is very similar to Station 1 where changes in depth distributions were believed responsible. It appears that temporary changes in depth distributions caused by slumping and homogenization of the sediment surface are the primary cause for enhanced diversity and equitability.

The variation in total abundance among replicate samples is lower after dredging than before (standard deviations before 286.7; after 98.7). After dredging the organisms remaining are more evenly distributed horizontally within the station and are sampled more evenly. This result would logically follow homogenization of the sediment surface.

Station 3

Total abundance decreased at Station 3 but to less degree than at Station 2. Re-adjustment to former abundance was observed within 14 days rather than 28 days as at Station 2. Less dredging and increased water depth may have been responsible for these results.

Greater water depth and fewer passes of the dredge would create less turbulence. Without homogenizing the sediment surface, the mosaic of dredged and undredged sections would be more persistent. Marked increase in the variation of total abundance among replicates (standard deviation before 52.4; after 257.8) suggests that the horizontal distribution of organisms has been changed and that faunal distributions are more patchy than before dredging. Limited dredging of an area in water of sufficient depth to prevent prop wash appears to leave hummocks of undredged sediment which may serve as important sources of adult organisms for the re-colonization of the dredged channel.

Station 4

The distribution of sediments within an estuary is the final result of complicated processes of erosion, transportation, and deposition (Postma, 1967). The deposition of fine materials necessitates a low current, low energy environment. Station 4 located in 10.6 m of water in the natural channel bed of Isthmus Slough was generally covered on the bottom with large wood debris. The lack of substantial amounts of fine silt and small wood chips suggests current velocities greater than those at Stations 1, 2 or 3. The current regime of Isthmus Slough is controlled almost entirely by tidal forces (U. S. D. I., 1971), and the semi-diel movement of tidal water appears to generate enough current along the bottom to prevent the deposition of fine debris and sediments.

The lack of a significant reduction in total abundance at Station 4 and the lack of uniform changes in diversity suggests that the station was not greatly affected by dredging operations. A number of factors may be responsible for these results. Greater distance from extensive dredging and deeper water are the most apparent. A stronger bottom current may have prevented the deposition of dredge-induced turbidity also.

Station 5

Although Station 5 was at least 60 m from active dredging, immediate declines in total abundance were observed. A significant increase in coarse material (> 0.50 mm), recorded after dredging, persisted for the rest of the study.

The Army Corps of Engineers (1969, cited in U.S.D.I., 1971) lists the modification of current patterns as one of the possible problems resulting from channel maintenance. The persistent presence of wood debris at Station 5 suggests that the hydrographic environment may have been somewhat altered. Before dredging the only area with wood debris was the central channel at Station 4. The introduction of wood debris to Station 5 suggests changes in current patterns from altered bathymetry of the channel.

The introduction of wood debris into the station coincides with large declines in total abundance. Station 5 was the only station which did not return to former abundance levels during the course of the study. While the immediate removal of organisms by dredging appears to be temporary at the other stations, possible changes in current patterns resulting in different sediment characteristics may have longer lasting effects at Station 5.

Station 6

Station 6 was approximately 100 m from active dredging. Immediate declines in faunal abundance were observed. Re-adjustment to former abundance levels was rapid. No hypothesis for these changes is offered at this time. It appears that widespread disturbance to the benthic community results even in areas not physically approached by the dredge.

The immediate effects of dredging appear to be related to: 1) siltation in adjacent areas; 2) removal of benthic organisms in the spoil; and 3) possible alterations of current patterns. The effect of prop wash from the Chester Harding produced effects at Station 1 similar to effects seen at Stations 2 and 3 which were dredged. While dredging is a periodic disturbance to the benthic environment, prop wash from passing ships may be an almost daily occurrence. Godcharles (1971) reported that prop wash from small boats in shallow water was responsible for violent disruptions to seed clams leading to their eventual death by crowding and smothering. The effects on the benthic community of bottom scour by passing ships have not been delineated in the literature but it is logical that daily disruptions of the surface layers of sediment would have a substantial effect on the type of community which could survive. Successful taxa would have to cope with sediment instability and other pollution stresses related to a commercial shipping port.

Immediate Effects at the Spoil Site - Phase I

Strong bottom currents within the spoil site are implied by the presence of sand and lack of deposition of fine material. The natural configuration of the channel and prevailing current regime prevent shoaling within the area, a prime reason for selecting the site for spoil dispersal. The force of prevailing currents declines outward from the main channel (Station 11) as indicated by the deposition of silt and small wood chips at Stations 10 and 12.

Six hopper loads of spoil were dumped on the site, three loads primarily over Station 11 and three loads midway between Stations 10 and 11. Station 12 was not directly spoiled upon but was less than 50 m from active spoiling.

The spoil within the dredge hoppers was a concentrated slurry of fine silt mixed with smaller amounts of wood debris. Material released from the surface will not fall directly to the bottom but will be transported horizontally by water movements as it falls through the water column (Postma, 1967). Dense spoil material (wood debris) will settle relatively fast and be deposited closer to the point of discharge than will lighter material.

Station 10

The immediate decline in abundance following spoiling reflects burial of the native benthic populations, but the re-adjustment of total abundance within one week suggests that the majority of individuals were not grossly impaired by spoiling. Bivalves appear to decline least, perhaps due to their rapid burrowing upward following burial (Reineck, 1967).

Station 11

The direct effects of spoiling on the benthic community at Station 11 are lost amid disturbances from other sources. The presence of strong bottom currents and heavy shipping activity combined to limit the initial abundance of organisms at this station. Although the water was deep enough (12 m) to prevent violent sediment disturbances by prop wash, maneuvering of ships in the narrow channel is done by tug boats and it is common practice for large ships to drag anchors for added control of momentum. This practice was performed over Station 11 several days prior to spoiling and collections taken immediately afterward revealed lower total abundances than immediately following spoiling. The increase in wood debris immediately after spoiling is reflected in a significant rise in the percentage of material > 0.50 mm. Since spoil was composed primarily of fine silt, the percentage increase in heavy material at Station 11 suggests that the fine fraction of the spoil was carried away.

Station 12

Station 12 was located in shallow water (4 m) and was not exposed to the strong bottom currents of mid-channel. The station was an area of deposition as indicated by the natural accumulations of small wood chips and fine silt.

Although not immediately spoiled over, significant declines in total abundance were recorded at this station after spoiling. The re-adjustment of total abundance one week later to very near pre-spoiling levels suggests that some burial may have taken place. Some siltation of Station 12 would be expected when silt and light material from nearby spoiling (< 50 m away) reached the lower energy environment of this station. The lack of wood debris from spoiling agrees with the idea that heavier material would be found close to the point of discharge and was not carried over Station 12.

The question of transport of organisms from the dredge site to the spoil site within the spoil is difficult to answer. Both sites have similar fauna so that direct comparison of introduced taxa is impossible. A cursory examination of the spoil from the dredge hoppers revealed very low abundances of organisms. This was expected since the dredge cut well into the abiotic region and most spoil came from that segment of the sediment profile.

Although diversity and equitability values at the spoil site did not rise as markedly as at Stations 1 and 2 where burial was hypothesized, samples taken immediately after spoiling included near maximum values for each station. The lack of uniform enhancement of these values may be related to the non-uniform distribution of spoil material on the bottom. Slotta et al. (1973) found that the deposition of spoil material over the spoil site was very irregular, with closely located sampling points receiving widely different types and amounts of spoil. Uneven burial of organisms within stations therefore would contribute to disparate changes in diversity and equitability after spoiling.

The range of pre-spoiling total abundance and diversity within stations at the spoil site was relatively large (Figures 10 and 12) suggesting uneven distributions of organisms before spoiling. Intensive shipping activity in the area undoubtedly contributed partially to this condition. A large ship docked within 20 m of Station 10 immediately before spoiling. Disruption of the sediment surface resulting from ship maneuvering would be expected. Combined with the anchor dragging activity observed at Station 11 it is probable that shipping has a substantial and almost daily effect upon the benthic community of the spoil site.

Extended Effects of Dredging Activity - Phase II

Capitella ovincola increased dramatically in abundance shortly after dredging. Maximum increases occurred in the zone of heavy dredging. Juvenile individuals in the samples suggest that the population increase was reproductive rather than migratory. Reproduction of *C. ovincola* usually occurs from August to November (Jones, 1961). It appears that the Coos Bay increase was part of a normal population cycle unrelated to dredging. This organism did not show immediate declines after dredging and experienced normal population growth suggesting that it is affected little by dredging. O'Conner (1970) and Reish (1971) found *C. ovincola* to be the numerically dominant organism in dredge channels on both East and West coasts implying that the tolerance of this polychaete to dredging is a widespread phenomenon. By being able to survive and flourish in environments where other taxa are limited, *C. ovincola* escapes many of the pressures of predation and competition. In Coos Bay, *C. ovincola* increased in numbers during periods when Streblospio benedicti, Oligochaete "A", and Oligochaete "B" (three possible competitors) were decreasing. Although the timing of this increase falls within their yearly reproductive cycle (Jones, 1961), the dramatic nature and scope of this increase may have been influenced by reduced competition from other annelids.

In Coos Bay S. benedicti is the numerically dominant organism, exceeding C. ovincola in total numbers and range of distribution. Although at the end of the study C. ovincola was increasing rapidly in abundance while S. benedicti was declining in the same areas, it is unlikely that C. ovincola will eventually replace S. benedicti as the dominant organism for several reasons: S. benedicti owes its dominance in part to its ability to thrive in varying types of substrates; it is prevalent in fine silt, wood chips, wood debris, and sand, while C. ovincola is abundant only in fine silt; and its dominance may be linked to its uninterrupted period of reproduction which extends throughout the year (Jones, 1961). Streblospio benedicti's reproductive potential, which is not restricted seasonally, allows it to take quick advantage of favorable environmental conditions for population growth while other taxa which reproduce more periodically are between periods of reproduction.

After 28 days, populations of Oligochaete "A" and Oligochaete "B" decreased in the area of actual dredging while increasing at less disturbed stations. Streblospio benedicti decreased at Stations 1, 2, and 3, while maintaining populations or increasing at all other stations. The localized decline of these taxa within the dredged channel or in immediately adjacent areas suggests some problem related to dredging. The role of the upper sediment layer is important during the early life stage of benthic organisms. The settlement of pelagic larvae is not random but is related to the presence of the right quantities of living microorganisms (Wilson, 1958). Wilson further states,

> The larvae most sensitive in their reactions at settlement time to the quantity and quality of the microorganisms present in a substratum will be those of species that, when adult, not only live in a restricted range of bottom soils but also feed by swallowing the substratum. They are, in fact, choosing their food at settlement time (Wilson, 1958, p. 92).

Zobell and Allen (1935) have shown the importance of a bacterial film in favoring the attachment of certain sedentary species. It appears that a microfaunal succession must occur on surfaces before larvae will settle. Newly dredged channels and areas immediately adjacent to them may consist of sediment in which the normal microfaunal succession has been disrupted. If immature individuals of S. benedicti and Oligochaetes "A" and "B" were repelled by recently disturbed sediments, the recruitment of new members into the population would cease and as adults died off the population would decrease. The possibility that dredged channels may be repelling to immature benthic organisms was also considered by Taylor and Saloman (1969).

If the newly dredged areas of Stations 2 and 3 are indeed repellant to pelagic larvae it is probable that this condition will not persist. The small surface area of the dredged zone combined with the daily presence of shipping disturbances and natural siltation will eventually mask over distinctions in the sediment surface.

After 28 days large increases in juvenile bivalves were evident at Stations 4, 5, and 6, although similar increases were not seen at Stations 1, 2, and 3. It is not possible to determine if this polarity was the result of dredging activity. Bivalves were somewhat more abundant at Stations 4, 5, and 6 before dredging, and the localized settlement of young bivalves may be related to environmental factors which are unrelated to dredging effects. The large increase in bivalve abundance, especially at Stations 5 and 6, suggests that although stations in the vicinity of dredging may experience immediate, temporary declines in abundance, the area is still attractive to the settlement of juvenile organisms a short time later.

The direct effects of this dredging operation appear to be temporary with regard to the benthic environment. Total abundances re-adjusted quickly to pre-dredge and spoil levels. Changes in the abundance of select taxa were observed but the overall structure of the benthic community returned quickly to pre-dredge conditions as indicated by diversity levels and types of taxa present. As mentioned previously, the taxa of the study site have been associated with pollution and generally are abundant only in stressed environments. The rapid re-adjustment of the community to pre-dredging and spoiling conditions suggests that the community is relatively stable within the given environment.

SUMMARY AND CONCLUSIONS

This study suggests that for this particular section of the Coos Bay Estuary (miles 13.00 to 14.00) the benthic fauna represents a community that has become adapted to stresses associated with a large commercial shipping port. These stresses include periodic dredging and daily ship traffic causing widespread disruption of the sediment surface. The benthic infaunal community depicted in pre-dredge sampling represents the culmination of biological adaptations to former physical and chemical disturbances. Although the community is lacking in economically important taxa, it serves an important role in the overall ecology of Coos Bay. Albeit the community consists of organisms associated with pollution and suffers from low diversity, it appears to be relatively stable within the given environment.

Since periodic maintenance dredging is directly responsible for only a portion of the environmental disturbances in the study site, it is clear that cessation of dredging alone will not return the fauna to more desirable levels of quality or diversity. The immediate, direct effects of maintenance dredging of this scale cannot be compared to the long term effects of dredging which open an estuary to commercial ship traffic, industrialization, and urbanization.

Conclusions

1. The benthic infauna community of the Port of Coos Bay (Coos Bay Estuary miles 13.00 to 14.00) appears impoverished and is composed of taxa frequently reported from polluted environments.

2. Factors which are thought to be conducive to the polluted condition of this area are: 1) domestic and industrial wastes; 2) log transport and storage; 3) periodic dredging; and 4) heavy ship traffic.

3. The mechanical effects of dredging activity may depend on: 1) the size and duration of the dredge operation; 2) pre-dredge history and frequency of dredging; 3) the type of benthic community; 4) depth of water and sediment type, 5) draft and size of the dredging vessel; and 6) shipping and related harbor activities.

4. At the dredge site the immediate, mechanical effects of this operation included: 1) physical removal of sediment and benthic organisms; 2) siltation and burial of organisms in adjacent areas; and 3) alterations in prevailing current patterns.

5. Immediately following dredging operations significant declines in faunal abundance were recorded in the dredge channel and adjacent areas not directly passed over by the dredge. Significant declines in abundance were evident 100 m from active dredging.

6. Areas adjacent to the dredged channel returned to prior abundance levels within 14 days, and experienced natural population increases within 28 days.

7. Short term changes in diversity and equitability of the benthic community immediately after dredging suggest homogenization of the sediment surface by prop wash resulting in siltation and burial of organisms. Sampling before the organisms had returned to previous depth habitats within the sediment resulted in temporary increases in both these parameters.

8. Although stations within the dredge channel re-adjusted to former total abundance levels within 28 days, subsequent declines in total abundance were noted while adjacent stations were undergoing population increases. It is hypothesized that biotic properties of the newly exposed sediment forestalled the settlement of juvenile organisms.

9. Hopper dredging in shallow water over fine silt bottoms results in homogenization of the sediment surface by prop wash from the dredge. This homogenization may result in considerable siltation at adjacent stations not directly within the dredge channel.

10. Limited dredging results in hummocks of undredged sediment within the dredged channel. In areas where prop wash homogenizes the sediment surface these hummocks do not persist.

Given deeper water and reduced prop wash, hummocks of undredged sediment may remain which serve as important sources of adult organisms in the re-adjustment of faunal abundances within the dredged channel.

11. Increases in Capitella ovincola within 56 days after dredging, primarily in the dredged channels and immediately adjacent areas, are thought to be natural population increases largely unrelated to dredging. The dramatic nature and scope of these increases may reflect lack of competition from annelids which were adversely affected by dredging.

12. Bivalves experienced the least decline in abundance of any group as the result of dredging. Possible reasons for this include: 1) discriminate dredging; 2) fast upward burrowing rates following siltation; and 3) settlement of young spat between dredging and subsequent sampling. Within 28 days large increases in population occurred in areas adjacent to dredging, suggesting that natural population growth of bivalves continued after dredging.

13. Throughout the entire study at both dredge and spoil site, Streblospio benedicti was the overwhelmingly dominant organism. This dominance is probably related to S. benedicti's ubiquitous sediment preference and extended reproductive potential.

14. At the spoil site, significant declines in faunal abundance were apparent immediately after spoiling at one station receiving direct spoiling and at another station in an adjacent area < 50 m away. Lack of significant declines in abundance at the central spoiling station are related to initially low natural abundances and intensive shipping activity prior to spoiling which masked the direct effects of burial.

15. Dense material within the spoil appears to settle relatively near the point of discharge while fine material is distributed over broader areas, causing siltation in low current areas.

16. Re-adjustment of benthic infauna to former abundance levels occurred within two weeks of spoiling at all stations.

17. The effects of this dredging operation on the benthic infaunal community appear to be temporary. The non-persistence of dredge-induced changes is related to the adaptability of the benthic community rather than the absence of large scale disruptions of the sediment surface.

18. The direct, benthic effects of the October 4th dredging operation are short term. The temporary quality of these effects is linked to the small scope of the dredging operation and the adaptability of the benthic community. Periodic disruption of the sediment surface by small scale maintenance operations may have less effect on the benthic community than the daily presence of heavy shipping and industrial and domestic pollution.

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APPENDICES

Appendix 1. Sampling Schedule and Sediment Data for Dredge Site - Phase I.

Sample No.	Station No.	Date (1972)	Sediment Composition	Volume Sampled (cm^3)	Sieve Volume (cm^3)
1-1-A	1	28 Sept.	Black silt Vegetation	3,980	115
1-1-B	1	"	"	3,980	100
2-1-A	2	"	"	3,980	230
2-1-B	2	"	"	3,980	515
3-1-A	3	"	Black silt Wood chips	5,130	410
3-1-B	3	"	"	4,650	490
4-1-A	4	"	Wood debris Black silt	3,230	840
4-1-B	4	"	"	4,010	1,625
5-1-A	5	"	Black silt Sand, shell	1,170	45
5-1-B	5	"	Wood chips Black silt	3,190	175
6-1-A	6	"	Sand, shell	2,610	80
6-1-B	6	"	"	1,640	55
1-2-A	1	29 Sept.	Black silt Vegetation	3,210	90
1-2-B	1	"	"	3,240	95
2-2-A	2	"	"	4,540	145
2-2-B	2	"	"	2,700	260
3-2-A	3	"	Black silt Wood chips	2,610	145
3-2-B	3	"	"	2,920	765
4-2-A	4	"	Wood debris Black silt	2,750	775
4-2-B	4	"	"	2,680	920
5-2-A	5	"	Wood chips Black silt	2,540	320
5-2-B	5	"	"	2,340	150
6-2-A	6	"	Sand, shell	1,650	75
6-2-B	6	"	"	2,070	80
1-3-A	1	30 Sept.	Black silt Vegetation	2,750	120
1-3-B	1	"	"	2,610	95
2-3-A	2	"	"	2,900	150
2-3-B	2	"	"	2,800	90
3-3-A	3	"	Black silt Wood chips	3,300	350
3-3-B	3	"	"	2,730	415
4-3-A	4	"	Wood debris Black silt	2,600	1,015
4-3-B	4	"	"	2,590	890
5-3-A	5	"	Wood chips Black silt Sand	2,640	170

(Continued on next page)

Sample No.	Station No.	Date (1972)	Sediment Composition	Volume Sampled (cm^3)	Sieve Volume (cm^3)
5-3-B	5	30 Sept.	Wood chips Black silt Sand	2, 440	170
6-3-A	6	"	Sand, shell	2, 160	115
6-3-B	6	"	"	610	55
1-4-A	1	5 Oct.	Black silt Vegetation	3, 730	-
1-4-B	1	"	"	3, 170	120
2-4-A	2	"	"	3, 800	90
2-4-B	2	"	"	2, 860	355
3-4-A	3	"	Black silt Wood chips	3, 730	150
3-4-B	3	"	"	2, 930	270
4-4-A	4	"	Wood debris Black silt	3, 000	770
4-4-B	4	"	"	3, 040	1, 390
5-4-A	5	"	"	2, 200	150
5-4-B	5	"	"	3, 300	750
6-4-A	6	"	Sand, shell	1, 290	60
6-4-B	6	"	"	1, 030	45
1-5-A	1	"	Black silt Vegetation	2, 860	75
1-5-B	1	"	"	2, 850	80
2-5-A	2	"	"	2, 880	125
2-5-B	2	"	"	3, 090	195
3-5-A	3	"	Black silt Wood chips	3, 550	345
3-5-B	3	"	"	3, 100	1, 290
4-5-A	4	"	Wood debris Black silt	2, 950	760
4-5-B	4	"	"	2, 850	790
5-5-A	5	"	"	2, 358	625
5-5-B	5	"	"	2, 500	300
6-5-A	6	"	Sand, shell	2, 360	50
6-5-B	6	"	"	810	40
1-6-A	1	"	Black silt Vegetation	2, 750	110
1-6-B	1	"	"	2, 900	105
2-6-A	2	"	"	3, 140	205
2-6-B	2	"	"	2, 710	235
3-6-A	3	"	Black silt Wood chips	3, 220	170
3-6-B	3	"	"	3, 030	190
4-6-A	4	"	Wood debris Black silt	3, 000	1, 170
4-6-B	4	"	"	2, 350	1, 595
5-6-A	5	"	"	2, 770	565
5-6-B	5	"	"	2, 610	655
6-6-A	6	"	Sand, shell	1, 340	70
6-6-B	6	"	"	1, 000	50

Appendix 2. Sampling Schedule and Sediment Data for the Spoil Site - Phase I.

Sample No.	Station No.	Date (1972)	Sediment Composition	Volume Sampled (cm^3)	Sieve Volume (cm^3)
10-1-A	10	30 Sept.	Black silt Wood chips	2,760	375
10-1-B	10	"	"	2,840	370
11-1-A	11	"	Sand Wood chips	800	85
11-1-B	11	"	"	1,090	160
12-1-A	12	"	"	2,910	1,220
12-1-B	12	"	Black silt	2,700	930
10-2-A	10	1 Oct.	"	3,020	130
10-2-B	10	"	"	1,230	-
11-2-A	11	"	Sand Wood chips	790	55
11-2-B	11	"	"	1,550	115
12-2-A	12	"	Wood chips Black silt	2,840	325
12-2-B	12	"	"	950	125
10-3-A	10	5 Oct.	Wood debris Black silt	3,250	1,000
10-3-B	10	"	"	3,000	440
11-3-A	11	"	Wood debris Sand	2,400	440
11-3-B	11	"	"	1,410	350
12-3-A	12	"	Wood chips Black silt	2,600	135
12-3-B	12	"	"	1,000	-

Appendix 3. Sampling Schedule and Sediment Data for Dredge and Spoil Stations - Phase II.

Sample No.	Station No.	Date (1972)	Sediment Composition	Volume Sampled (cm^3)	Sieve Volume (cm^3)
1-7-A	1	12 Oct.	Black silt	2,800	135
1-7-B	1	"	"	3,210	110
2-7-A	2	"	"	2,950	140
2-7-B	2	"	"	2,850	190
3-7-A	3	"	"	3,125	155
			Wood chips		
3-7-B	3	"	"	2,850	500
4-7-A	4	"	Wood debris	3,175	1,150
			Black silt		
4-7-B	4	"	"	3,600	575
5-7-A	5	"	"	3,000	500
5-7-B	5	"	"	3,250	655
6-7-A	6	"	Sand, shell	3,450	135
			Wood chips		
6-7-B	6	"	"	1,850	85
10-4-A	10	"	Black silt	2,450	225
			Wood chips		
10-4-B	10	"	"	1,530	450
11-4-A	11	"	Sand	1,800	370
			Wood chips		
11-4-B	11	"	"	1,825	445
12-4-A	12	"	Wood chips	2,925	750
			Black silt		
12-4-B	12	"	"	2,425	310
1-8-A	1	21 Oct.	Grey-black silt	4,750	115
1-8-B	1	"	"	3,450	100
2-8-A	2	"	"	2,820	125
2-8-B	2	"	"	2,650	195
3-8-A	3	"	Black silt	4,020	345
			Wood chips		
3-8-B	3	"	"	4,380	1,290
4-8-A	4	"	Wood debris	2,700	760
			Black silt		
4-8-B	4	"	"	2,950	790
5-8-A	5	"	"	3,000	625
5-8-B	5	"	"	3,130	300
6-8-A	6	"	Sand, shell	2,050	50
			Wood chips		
6-8-B	6	"	"	1,075	40
10-5-A	10	"	Black silt	1,480	215
			Wood chips		
10-5-B	10	"	"	1,350	270
11-5-A	11	"	Sand	2,150	315
			Wood chips		
11-5-B	11	"	"	1,200	110
12-5-A	12	"	Fine wood chips	2,550	545
			Black silt		

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Appendix 3. (Continued)

Sample No.	Station No.	Date (1972)	Sediment Composition	Volume Sampled (cm^3)	Sieve Volume (cm^3)
12-5-B	12	21 Oct.	Black silt	2,700	710
1-9-A	1	2 Nov.	Black silt Wood chips	3,370	135
1-9-B	1	"	"	2,900	145
2-9-A	2	"	"	3,280	275
2-9-B	2	"	"	3,360	175
3-9-A	3	"	"	3,290	270
3-9-B	3	"	"	3,300	220
4-9-A	4	"	Wood chips Black silt	3,070	1,050
4-9-B	4	"	"	3,145	710
5-9-A	5	"	"	3,000	1,290
5-9-B	5	"	"	2,760	625
6-9-A	6	"	Sand, shell Black silt	1,450	85
6-9-B	6	"	"	700	70
10-6-A	10	"	Sand Wood chips	875	245
10-6-B	10	"	"	1,750	-
11-6-A	11	"	"	735	80
12-6-B	11	"	"	1,200	175
12-6-A	12	"	Wood chips Black silt	2,900	710
12-6-B	12	"	"	2,950	675
1-10-A	1	29 Nov.	"	3,020	175
1-10-B	1	"	"	3,000	115
2-10-A	2	"	"	2,900	750
2-10-B	2	"	"	3,000	400
3-10-A	3	"	Wood chips Black silt	2,980	500
3-10-B	3	"	"	3,030	300
4-10-A	4	"	"	2,320	365
4-10-B	4	"	"	1,150	540
5-10-A	5	"	"	2,320	575
5-10-A	5	"	"	2,060	440
6-10-A	6	"	Sand, shell Wood chips	570	55
6-10-B	6	"	"	650	65
10-7-A	10	"	Wood chips Black silt	2,520	110
10-7-B	10	"	"	2,215	190
11-7-A	11	"	Sand Wood chips	800	115
11-7-B	11	"	"	2,200	260
12-7-A	12	"	Fine wood chips Black silt	2,120	1,005
12-7-B	12	"	"	2,610	605

Appendix 4: Counts of Organisms Normalized to #/1000 cc Sediment for Dredge Site-Phase I.

	Nematodes	Streblospio benedicti	Pseudopolydora kempi	Polydora ligni	Capitella (C) ovincola	Eteone lighti	Notomastus (C) tenuis	Glycinde armigera	Nephthys californicus	worm fragments	Oligochaeta "A"	Oligochaeta "B"	Total Polychaetes	Total Annelids	Macoma inconspicua	Mya arenaria	Clinocardium nuttalli	Modiolus sp.	Ostracoda	Harpactocoid	Cumacean	Corophium	Pycnogonids	Total bivalves	Total Arthropods	Total Organisms	Total Taxa
STN 1 Before	16	428	64	2	10	4	2	0	0	98	10	8	613	647	5	0	2	6	0	8	2	0	6	7	22	647	15
	30	403	38	2	.8	4	0	0	0	0	0	0	458	488	0	4	0	7	0	51	6	2	6	4	70	473	12
	437	513	19	.3	4	0	0	0	0	0	0	0	539	991	1	0	1	9	0	151	2	0	12	2	170	561	11
	521	530	10	0	0	5	0	0	0	7	5	2	548	1077	2	0	0	0	0	274	5	2	4	2	284	572	11
	700	602	17	0	1	0	0	0	0	36	0	16	663	1379	3	0	3	4	0	256	6	1	1	3	269	690	12
	208	337	25	.4	3	0	0	0	0	12	2	11	383	604	3	2	2	3	0	83	2	2	0	6	89	404	14
STN 1 After	92	26	5	.5	4	0	0	0	0	6	1	0	42	136	.5	.5	0	12	.5	3	0	.5	1	1	21	57	13
	.6	31	16	3	26	0	0	0	0	0	0	0	76	78	3	0	0	15	0	0	0	0	4	3	18	98	8
	60	112	52	0	6	0	0	0	0	14	0	0	183	249	2	3	1	6	1	4	1	0	6	6	17	203	12
	182	107	30	2	8	0	0	0	0	23	3	3	171	355	1	0	0	3	0	1	.7	.7	6	1	11	187	13
	131	199	9	0	18	0	0	0	0	10	1	1	236	370	8	.4	0	12	0	13	1	0	5	8	32	264	12
	124	110	11	1	19	0	0	0	0	7	1	1	154	204	3	0	0	4	0	6	0	1	4	3	15	162	12
STN 2 Before	24	494	15	0	2	2	1	0	0	0	0	0	514	544	3	3	8	8	0	74	2	2	0	15	36	540	13
	332	281	8	0	16	0	0	0	0	0	10	8	306	659	2	0	0	22	10	66	4	2	6	6	110	359	13
	892	656	14	0	0	4	0	0	4	39	7	4	712	1621	1	0	0	0	0	504	0	11	0	1	514	740	10
	1961	492	24	0	0	6	0	0	6	12	0	12	587	2572	.4	6	0	12	0	486	12	0	0	6	510	582	11
	891	996	28	0	3	0	0	0	0	33	17	8	1057	1972	1	0	3	8	14	348	3	0	6	4	378	1103	13
	1180	1069	23	0	3	3	0	0	0	20	0	37	1118	2335	4	3	9	9	0	540	20	3	0	15	571	1203	13
STN 2 After	0	2	.3	.5	0	0	0	0	0	0	0	0	3	4	.7	0	.5	3	0	0	.5	1	1	1	5	10	9
	794	129	3	3	28	3	0	0	0	50	0	6	215	1015	3	0	0	17	8	36	6	0	6	3	72	254	13
	18	13	3	0	.3	0	0	0	0	3	0	0	18	36	1	0	0	6	0	1	0	0	1	1	8	27	8
	28	5	3	0	0	0	0	0	0	5	0	0	13	41	.6	0	3	10	0	8	0	0	3	3	21	30	8
	0	97	20	0	5	0	0	0	0	0	0	0	122	122	3	0	3	13	0	9	0	0	10	6	29	148	8
	221	94	9	0	18	0	0	0	0	18	3	3	139	366	5	0	0	9	9	32	3	0	4	5	62	166	12
STN 3 Before	572	1173	41	0	0	11	0	0	0	37	0	0	1269	1929	8	2	5	5	17	1446	14	3	0	16	1485	1299	12
	1356	657	10	0	0	3	0	0	0	3	24	17	675	2071	6	4	0	0	217	1294	0	0	0	9	1518	724	10
	159	959	52	0	3	3	0	0	0	25	0	37	1045	1241	2	6	0	3	0	423	12	6	0	8	438	1108	12
	137	1025	60	5	0	16	0	0	0	5	71	16	1112	1348	3	.3	0	0	[illegible]	230	0	0	0	3	238	1201	10
	87	953	39	5	2	7	5	0	0	5	36	20	1015	1166	7	3	0	0	[illegible]	385	16	0	0	17	402	1098	13
	53	826	56	0	0	0	0	0	0	164	0	0	1046	1152	3	0	0	0	3	82	15	0	3	5	102	1067	8
STN 3 After	2	71	18	1	.5	0	3	0	0	10	3	.5	108	116	4	3	1	2	.5	17	0	0	0	8	20	117	14
	0	3	0	0	0	0	0	0	0	3	0	0	5	5	0	0	0	0	[illegible]	3	0	0	0	0	3	6	2
	3	177	5	0	0	1	2	0	0	14	1	1	199	205	5	1	0	2	[illegible]	23	3	0	0	8	28	212	12
	124	810	5	0	0	5	5	0	0	83	21	0	655	800	8	.3	0	0	10	52	0	0	0	8	62	937	10
	0	194	5	2	0	2	.3	0	0	0	0	0	204	206	1	0	0	0	0	20	7	0	0	1	27	211	8
	48	403	32	1	0	4	0	0	0	24	17	7	465	572	4	4	3	0	20	172	4	0	0	11	195	503	13
STN 4 Before	698	649	52	5	0	0	5	.3	0	27	17	74	738	1541	2	0	2	0	2	736	0	0	0	7	738	833	12
	467	539	16	0	0	0	4	0	0	4	40	32	563	1109	4	4	8	4	8	447	8	4	0	16	478	667	14
	81	448	17	0	0	0	0	0	0	6	58	122	471	733	3	0	.7	0	0	.7	0	0	0	3	.7	655	8
	173	1463	72	18	0	0	0	0	0	90	66	66	1642	1970	9	0	6	6	0	155	0	.3	0	15	161	1802	11
	157	400	18	18	0	0	0	0	0	65	18	52	502	729	2	3	0	0	3	58	0	0	0	5	61	576	10
	179	1041	53	9	0	0	0	0	0	43	40	77	1158	1455	10	3	6	0	0	124	3	0	3	16	130	1288	12
STN 4 After	1	129	22	4	0	0	2	0	0	0	0	0	157	167	2	0	0	1	0	0	0	0	0	2	1	160	7
	47	166	21	5	0	0	3	.7	0	63	3	11	259	318	2	3	3	0	3	0	0	0	0	7	3	281	12
	206	412	76	5	0	0	0	5	0	11	22	114	510	852	2	0	5	0	0	0	0	0	0	8	0	652	9
	101	999	39	6	0	17	0	0	0	39	22	56	1100	1280	2	0	6	0	6	752	0	6	0	8	763	1192	12
	117	539	19	5	0	3	0	0	0	304	11	27	869	1024	0	0	3	0	5	120	3	0	0	3	128	914	11
	191	864	34	0	0	.7	0	0	0	86	14	54	994	1362	2	.4	7	0	0	34	0	0	0	9	34	1102	10
STN 5 Before	132	1434	29	4	0	2	0	0	0	0	0	0	1468	1631	24	24	14	0	0	38	2	55	0	62	95	1558	11
	740	1249	118	3	0	3	0	.3	0	110	8	4	1485	2272	8	3	0	0	0	80	14	3	0	10	96	1526	13
	69	1184	69	0	0	0	.4	0	0	101	38	76	1354	1537	21	.4	0	0	0	57	19	13	0	21	88	1522	11
	219	2003	103	7	0	21	7	0	0	120	14	150	2260	2643	4	0	0	0	0	96	0	0	0	11	96	2429	10
	239	1334	45	0	0	12	.8	0	3	139	0	.4	1534	1795	7	0	9	3	3	52	6	0	0	17	64	1559	13
	184	1856	125	0	0	3	.4	.4	0	125	75	39	2113	2411	19	3	7	3	0	157	0	0	0	29	161	2256	13
STN 5 After	0	410	78	7	20	0	0	0	0	0	0	0	517	519	9	2	2	0	2	4	2	2	0	13	9	532	11
	58	187	22	0	2	0	3	.6	0	63	10	70	277	360	9	2	0	0	0	2	0	0	0	11	2	369	11
	95	660	14	0	0	0	0	.4	0	225	27	0	899	1022	7	0	0	0	7	82	0	0	0	7	89	933	8
	86	554	29	3	0	3	0	0	0	106	10	10	701	806	7	0	0	0	0	48	0	0	0	7	48	722	9
	29	468	20	0	0	0	0	0	0	170	9	84	661	783	13	0	0	0	0	90	0	0	0	13	90	764	7
	64	442	52	3	0	3	0	0	0	176	0	0	687	791	6	0	6	0	12	150	0	0	0	12	162	688	9
STN 6 Before	41	651	43	5	0	.7	3	.7	.3	0	0	0	722	779	49	14	15	.7	0	2	2	13	0	82	18	797	15
	.6	264	32	0	0	0	5	.6	0	7	7	37	315	359	2	10	12	0	0	0	2	.3	.6	25	6	382	13
	148	1765	92	15	0	5	0	.6	0	107	36	167	1988	2340	19	35	29	0	0	51	5	0	0	82	56	2276	13
	70	1391	153	8	0	8	15	1	.5	70	4	53	1663	1730	1	35	31	0	0	31	0	23	0	67	54	1796	15
	96	1372	152	7	0	11	24	.5	0	200	31	24	1812	1971	3	17	7	0	0	87	4	7	0	29	98	1860	15
	33	1639	72	0	0	7	7	0	0	0	92	151	1725	2026	7	13	26	0	0	7	0	0	0	46	7	2014	11
STN 6 After	2	440	82	0	0	0	5	2	0	53	.8	21	584	608	5	19	20	0	0	0	.7	7	0	43	7	656	12
	7	111	45	4	0	0	6	0	0	25	12	2	192	213	14	50	17	2	0	0	0	0	0	82	2	288	11
	.8	1147	75	5	0	3	2	1	0	42	15	43	1277	1336	6	7	5	0	0	0	0	9	0	18	9	1360	13
	74	1590	114	10	0	5	0	0	0	59	20	20	1779	1836	14	29	30	0	0	20	5	20	0	73	44	1916	13
	20	1207	91	0	0	4	4	.7	0	167	9	34	1502	1565	5	20	14	0	0	6	1	0	0	39	7	1557	13
	24	669	76	4	0	0	0	1	0	0	12	16	209	226	1	4	12	0	0	32	4	0	0	17	36	798	12

Appendix 5. Counts of Organisms Normalized to #/1000 cc Sediment for Spoil Site-Phase I.

	Nematodes	Streblospio benedicti	Pseudopolydora kempi	Polydora ligni	Capitella (C) ovincola	Eteone lighti	Notomastus (C) tenuis	Glycinde armigera	Nephthys Californicus	worm fragments	Oligochaete "A"	Oligochaete "B"	Total Polychaetes	Total Annelid	Macoma inconspicua	Mya arenaria	Clinocardium nuttalli	Modiolus sp.	Ostracoda	Harpactocoid	Cumacean	Corophium	Pycnogonids	Total bivalves	Total Arthropods	Total Organisms	Total Taxa
STN 10 Before	52	187	19	0	0	0	0	0	0	13	1	10	218	281	3	3	0	0	0	0	0	0	6	0	7	242	8
	113	163	14	0	0	0	0	0	0	31	8	3	208	333	4	3	0	0	0	0	0	0	7	0	7	233	8
	19	491	23	4	0	0	0	0	0	46	2	21	564	597	5	3	9	0	0	3	1	.3	17	4	13	622	13
	50	177	2	3	0	0	0	.8	0	13	5	16	196	282	2	2	2	3	0	16	0	10	5	29	15	241	14
STN 10 After	5	10	5	0	0	0	0	.3	0	20	0	0	35	40	.6	0	0	0	5	0	0	0	.6	5	6	37	7
	0	80	13	3	3	0	0	0	0	0	0	0	99	99	4	6	0	5	0	3	0	3	9	11	10	126	10
STN 11 Before	0	35	0	0	0	0	0	3	0	0	0	0	45	65	0	0	1	0	0	0	0	15	1	15	6	55	5
	0	14	0	0	0	2	4	0	0	0	0	0	32	37	.9	0	0	0	0	0	0	0	.9	0	9	22	5
	3	10	0	0	0	0	0	1	0	3	0	0	19	22	1	1	1	1	0	0	0	0	4	1	8	22	8
	3	0	0	0	0	0	0	.6	0	0	0	0	3	5	0	0	0	0	0	0	0	0	0	0	3	1	2
STN 11 After	0	5	2	0	0	0	0	0	0	3	0	0	10	10	4	0	0	0	0	0	0	0	4	0	3	18	4
	0	7	0	1	0	0	.7	0	0	0	0	0	9	15	1	2	0	.7	0	0	0	0	4	.7	7	16	7
STN 12 Before	55	1353	14	0	0	5	.6	.3	0	52	0	14	1434	1505	11	9	5	0	0	0	3	0	20	3	13	1487	11
	664	1801	24	0	0	12	.7	0	0	136	6	71	1992	2733	26	18	0	0	0	53	12	36	44	101	14	2187	13
	197	1341	34	0	0	0	18	0	0	440	6	45	1832	2080	20	23	6	0	0	17	6	17	48	39	12	2004	13
	109	682	0	4	0	4	0	0	0	67	4	72	762	947	17	38	21	0	0	0	0	42	76	46	12	1027	11
STN 12 After	0	50	13	3	.3	0	.3	.3	0	8	.3	0	75	75	2	.7	0	0	0	0	0	0	3	0	9	81	10
	4	844	64	11	0	0	5	0	0	82	15	4	1008	1031	24	12	32	0	0	0	1	17	73	18	12	1184	13

* Total organisms does not include nematodes, ostracods or harpacticoids which were not quantitatively retained in the 0.50 mm sieve.

Appendix 6. Counts of Organisms Normalized to No. /1000 cc Sediment for Dredge and Spoil Sites - Phase II.

Taxa	October 12		October 19		November 2		November 29	
Sample:	7A	7B	8A	8B	9A	9B	10A	10B
			Station 1					
Streblospio benedicti	440	573	448	579	334	480	164	349
Pseudopolydora kempi	29	23	10	12	8	22	8	0
Polydora ligni	.3	0	0	0	0	0	0	0
Capitella (C) ovincola	4	14	14	16	4	14	69	104
Notomastus (C) tenuis	0	3	0	0	0	0	0	0
Eteone lighti	1	0	0	0	2	3	5	5
Scolopos sp.	0	1	0	0	0	0	0	0
Nematoda	152	815	1347	2360	1612	1942	2325	1621
Oligochaeta "A"	7	6	0	0	4	11	28	5
Oligochaeta "B"	11	5	15	16	14	8	24	29
Macoma inconspicua	2	3	.6	.9	4	1	4	6
Mya arenaria	.3	0	0	0	0	0	0	.3
Clinocardium nuttallii	1	0	2	0	2	6	3	0
Modiolus sp.	2	4	2	0	2	3	0	0
Ostracoda	3	29	81	121	76	99	56	19
Cumacea	4	5	2	5	0	0	0	0
Amphipoda	0	1	2	0	0	0	0	0
Harpacticoida	15	273	138	292	176	193	140	354
Archelia nudiuscula	1	0	0	0	4	0	0	0
Achelia chelata	0	1	0	0	0	0	0	0
Unidentified Annelida	0	3	2	2	2	3	5	0
Unidentified Acarina	0	5	3	2	0	0	3	0
Unidentified Hydroida	.3	1	0	0	0	0	0	0
Polychaeta Fragments	24	46	15	12	90	61	45	11
Pycnogonida Fragments	.6	0	2	2	0	6	0	0
Total Individuals	527	698	518	647	470	618	358	509
Total Taxa	17	19	14	11	14	13	13	10

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Appendix 6. (Continued)

Taxa	October 12		October 19		November 2		November 29	
Sample:	7A	7B	8A	8B	9A	9B	10A	10B
			Station 2					
Streblospio benedicti	388	39	130	946	722	707	364	277
Pseudopolydora kempi	16	0	3	27	7	5	8	0
Polydora ligni	0	0	0	0	2	0	0	0
Capitella (C) ovincola	5	3	3	12	63	12	116	53
Notomastus (C) tenuis	0	0	0	0	0	0	0	16
Eteone lighti	3	0	0	9	5	5	8	8
Armandia bioculata	0	0	0	3	0	0	0	0
Nematoda	610	73	238	969	1904	1855	800	1269
Oligochaeta "A"	5	0	0	15	2	10	3	0
Oligochaeta "B"	3	0	0	30	27	24	11	8
Macoma inconspicua	2	4	0	6	4	5	1	8
Mya arenaria	0	0	0	9	0	0	0	0
Clinocardium nuttallii	0	0	0	3	5	5	6	0
Modiolus sp.	3	0	0	3	10	0	11	0
Ostracoda	38	11	65	24	34	110	226	160
Cumacea	0	0	6	0	5	0	3	8
Amphipoda	0	0	0	0	5	2	0	0
Harpacticoida	88	0	258	190	312	440	262	717
Achelia nudiuscula	3	3	0	0	10	0	0	0
Achelia chelata	3	0	0	0	0	0	0	0
Unidentified Annelida	5	0	6	0	10	0	6	8
Unidentified Acarina	0	3	3	0	7	0	3	5
Unidentified Hydroida	0	0	0	0	2	0	0	0
Polychaeta Fragments	52	3	9	39	66	62	55	35
Pycnogonida Fragments	0	0	0	0	2	0	0	0
Total Individuals	488	51	160	1102	954	837	595	426
Total Taxa	14	7	9	14	19	12	15	12

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Appendix 6. (Continued)

Taxa	October 12		October 19		November 2		November 29	
Sample:	7A	7B	8A	8B	9A	9B	10A	10B
			Station 3					
Streblospio benedicti	405	385	1039	895	460	684	338	223
Pseudopolydora kempi	20	8	38	35	10	19	3	13
Polydora ligni	0	0	0	5	0	0	0	0
Capitella (C) ovincola	5	8	4	0	0	2	81	0
Notomastus (C) tenuis	.3	.4	0	0	.3	0	0	.3
Eteone lighti	0	0	4	4	7	12	5	2
Armandia bioculata	0	0	0	0	0	2	0	0
Scolopos sp.	0	0	0	0	2	0	0	0
Nematoda	31	216	62	84	642	393	250	50
Oligochaeta "A"	8	8	4	11	7	12	3	0
Oligochaeta "B"	11	11	8	18	36	39	11	0
Macoma inconspicua	4	9	5	5	10	7	8	9
Mya arenaria	3	3	.2	0	2	.3	3	3
Clinocardium nuttallii	3	3	0	0	0	7	3	4
Modiolus sp.	0	6	0	0	0	0	6	0
Ostracoda	0	48	6	5	19	19	13	0
Cumacea	0	3	2	5	2	10	3	3
Amphipoda	0	0	0	0	0	0	0	2
Harpacticoida	13	166	201	323	92	366	236	157
Unidentified Annelida	0	0	2	0	2	5	5	17
Unidentified Acarina	3	0	0	0	0	0	0	0
Unidentified Hydroida	0	0	0	2	0	0	0	2
Polychaeta Fragments	18	20	111	40	160	155	56	0
Pycnogonida Fragments	0	3	0	0	0	0	0	0
Total Individuals	480	467	1223	1025	698	954	525	278
Total Taxa	12	15	12	12	14	15	15	13

(Continued on next page)

Appendix 6. (Continued)

Taxa	October 12		October 19		November 2		November 29	
Sample:	7A	7B	8A	8B	9A	9B	10A	10B
			Station 4					
Streblospio benedicti	690	433	1298	757	764	348	1197	1774
Pseudopolydora kempi	33	18	53	49	21	15	34	77
Polydora ligni	0	0	3	5	3	0	3	7
Capitella (C) ovincola	0	2	0	.3	0	0	.4	0
Notomastus (C) tenuis	0	0	0	0	0	3	0	0
Glycinde armigera	0	0	0	0	0	0	.4	2
Eteone lighti	3	0	12	0	8	3	3	0
Armandia bioculata	3	0	0	0	0	0	3	0
Arenicola pusilla	0	0	0	.3	0	0	0	0
Nematoda	50	80	166	49	112	89	259	508
Oligochaeta "A"	10	9	41	22	10	10	48	70
Oligochaeta "B"	3	9	27	19	57	3	55	111
Macoma inconspicua	6	3	9	1	5	3	11	29
Mya arenaria	3	0	3	0	5	0	0	7
Clinocardium nuttallii	3	0	3	0	8	5	10	35
Modiolus sp.	3	2	9	0	0	0	0	0
Ostracoda	10	13	30	3	10	20	7	70
Cumacea	0	2	12	0	10	3	0	0
Amphipoda	0	0	0	0	0	0	10	14
Harpacticoida	93	29	246	19	130	86	93	487
Crangon communis	0	0	0	0	0	0	.4	0
Unidentified Acarina	0	0	0	0	0	3	0	0
Unidentified Annelida	23	4	9	8	18	3	0	0
Polychaeta Fragments	76	87	71	100	172	53	124	250
Total Individuals	856	569	1550	961	1081	452	1499	2376
Total Taxa	14	12	15	12	14	14	16	13

(Continued on next page)

Appendix 6. (Continued)

Taxa	October 12		October 19		November 2		November 29	
Sample:	7A	7B	8A	8B	9A	9B	10A	10B
			Station 5					
Streblospio benedicti	843	876	699	879	377	461	925	1134
Pseudopolydora kempi	40	52	5	26	5	12	14	16
Polydora ligni	5	0	0	0	11	9	3	8
Capitella (C) ovincola	0	0	0	3	0	0	7	0
Notomastus (C) tenuis	0	2	3	3	8	0	0	0
Glycinde armigera	0	0	0	0	0	.4	.4	0
Eteone lighti	3	0	1	5	0	3	3	12
Armandia bioculata	0	0	0	0	3	0	0	0
Scolopus sp.	0	0	0	0	3	0	0	0
Neries sp.	0	0	.3	0	0	0	0	0
Nematoda	43	57	125	319	211	14	548	555
Oligochaeta "A"	24	22	11	13	8	14	38	47
Oligochaeta "B"	99	72	139	97	96	52	217	198
Macoma inconspicua	11	18	4	5	14	7	75	36
Mya arenaria	11	0	.3	5	5	0	10	16
Clinocardium nuttallii	0	2	0	5	16	0	14	27
Modiolus sp.	0	0	0	0	0	0	7	4
Ostracoda	8	0	3	13	27	3	53	43
Cumacea	5	0	0	3	3	0	0	4
Amphipoda	0	0	8	0	0	0	0	0
Harpacticoida	80	71	21	192	69	26	548	256
Cancer magister	0	0	.3	0	0	0	0	0
Unidentified Annelida	5	2	30	28	11	3	38	0
Polychaeta Fragments	93	96	85	125	232	119	143	229
Total Individuals	1139	1142	989	1197	792	680	1494	1731
Total Taxa	13	10	15	15	16	12	16	14

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Appendix 6. (Continued)

Taxa	October 12		October 19		November 2		November 29	
Sample:	7A	7B	8A	8B	9A	9B	10A	10B
			Station 6					
Streblospio benedicti	936	761	1819	2597	1393	1354	2870	1396
Pseudopolydora kempi	79	37	115	141	41	40	28	23
Polydora ligni	1	0	2	4	3	0	0	0
Capitella (C) ovincola	0	0	2	0	0	0	21	0
Notomastus (C) tenuis	2	0	8	7	0	0	0	6
Glycinde armigera	.5	3	.5	1	0	0	2	0
Eteone lighti	0	2	6	4	6	0	21	3
Armandia bioculata	0	0	2	0	0	0	0	0
Scolopos sp.	0	2	2	0	3	0	7	0
Nematoda	57	6	59	145	74	69	182	320
Oligochaeta "A"	19	17	2	26	19	45	14	49
Oligochaeta "B"	68	26	123	272	110	206	428	348
Macoma inconspicua	4	6	7	31	50	46	68	104
Mya arenaria	7	11	21	33	19	6	56	74
Clinocardium nuttallii	7	26	39	52	91	69	168	271
Modiolus sp.	0	0	0	0	0	0	0	3
Ostracoda	2	2	1	11	0	0	0	0
Cumacea	2	2	6	7	6	17	0	6
Amphipoda	7	6	40	41	6	0	0	6
Harpacticoida	20	11	115	93	22	69	63	154
Achelia chelata	0	2	0	0	0	0	0	0
Unidentified Annelida	3	2	4	4	30	6	0	9
Unidentified Bivalve	0	0	2	0	0	0	0	0
Unidentified Acarina	0	0	2	0	0	0	0	0
Unidentified Hydroida	13	0	29	179	8	6	0	0
Polychaeta Fragments	96	52	100	149	152	34	133	18
Pycnogonida Fragments	0	0	0	0	0	0	0	3
Total Individuals	1245	955	2331	3548	1937	1823	3816	2319
Total Taxa	17	17	23	18	16	12	13	16

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Appendix 6. (Continued)

Taxa	October 12		October 19		November 2		November 29	
Sample:	4A	4B	5A	5B	6A	6B	7A	7B
			Station 10					
Streblospio benedicti	1140	1124	1075	177	146	Missing Data	466	715
Pseudopolydora kempi	23	10	5	0	5		0	7
Polydora ligni	7	0	5	0	0		0	0
Notomastus (C) tenuis	7	0	0	0	0		0	0
Glycinde armigera	2	.7	0	2	0		1	.5
Eteone lighti	0	0	0	0	0		0	4
Arenicola pusilla	0	.7	0	0	0		0	0
Nematoda	163	235	454	145	101		85	141
Oligochaeta "A"	3	0	22	12	14		16	14
Oligochaeta "B"	59	42	59	18	27		19	72
Macoma inconspicua	10	9	4	2	0		4	30
Mya arenaria	4	7	11	.7	0		0	0
Clinocardium nuttallii	0	0	0	0	5		10	7
Modiolus sp.	7	16	5	18	5		0	4
Cumacea	0	0	0	0	0		0	7
Amphipoda	0	0	0	0	18		4	0
Harpacticoida	0	0	0	0	9		0	4
Unidentified Annelida	0	0	11	6	0		6	0
Polychaeta Fragments	118	21	27	12	5		143	152
Total Individuals	1380	1230	1224	248	225		669	1013
Total Taxa	11	9	10	10	9		9	12

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Appendix 6. (Continued)

Taxa	October 12		October 19		November 2		November 29	
Sample:	4A	4B	5A	5B	6A	6B	7A	7B
			Station 11					
Streblospio benedicti	71	18	13	30	12	17	120	78
Pseudopolydora kempi	0	0	0	3	0	0	5	2
Nepthys californicus	0	0	0	0	1	0	0	0
Scolopos sp.	0	0	4	0	8	0	0	0
Nematoda	4	35	4	13	0	57	35	20
Oligochaeta "A"	4	0	2	7	0	0	0	0
Oligochaeta "B"	0	0	2	17	5	10	10	2
Macoma inconspicua	4	0	.5	0	0	5	0	5
Mya arenaria	0	0	4	1	0	0	0	0
Clinocardium nuttallii	0	0	0	0	1	0	0	0
Modiolus sp.	0	0	0	10	0	0	0	0
Ostracoda	0	0	0	0	0	7	0	0
Cumacea	0	4	0	3	0	0	0	0
Harpacticoida	0	0	0	3	5	20	0	0
Unidentified Annelida	0	4	0	0	5	0	15	4
Unidentified Bivalvia	0	0	0	0	0	0	0	2
Polychaeta Fragments	0	0	2	3	0	3	10	2
Total Individuals	79	26	28	74	32	35	160	95
Total Taxa	4	4	7	9	7	6	5	7

(Continued on next page)

Appendix 6. (Continued)

Taxa	October 12		October 19		November 2		November 29	
Sample:	4A	4B	5A	5B	6A	6B	7A	7B
			Station 12					
Streblospio benedicti	1203	1326	927	1114	1466	800	1101	1661
Pseudopolydora kempi	5	33	24	24	0	14	4	25
Polydora ligni	11	13	13	0	11	3	26	3
Capitella (C) ovincola	0	3	0	0	0	0	0	0
Notomastus (C) tenuis	0	1	0	9	3	0	0	0
Glycinde armigera	.3	0	0	.7	.3	0	0	0
Nepthys californicus	0	0	0	0	.3	0	0	0
Eteone lighti	5	3	11	0	6	4	15	43
Armandia bioculata	0	0	0	0	0	0	4	0
Neries sp.	.3	0	0	.4	0	0	0	0
Nematoda	295	254	74	216	97	35	162	92
Oligochaeta "A"	8	3	1	12	6	5	0	9
Oligochaeta "B"	25	23	24	41	17	19	23	37
Macoma inconspicua	12	4	6	26	15	18	0	7
Mya arenaria	3	13	5	6	9	18	11	1
Clinocardium nuttallii	22	16	5	21	25	26	4	.4
Modiolus sp.	0	0	0	0	0	0	0	6
Ostracoda	0	3	2	0	0	0	0	3
Cumacea	3	3	0	6	0	1	0	0
Amphipoda	8	46	13	15	6	24	11	6
Harpacticoida	11	0	0	33	33	0	11	9
Unidentified Annelida	0	0	3	3	6	5	11	18
Unidentified Hydroida	0	0	0	0	0	0	0	3
Polychaeta Fragments	304	221	91	98	226	91	87	285
Total Individuals	1610	1708	1123	1376	1797	1028	1297	2104
Total Taxa	15	15	13	14	15	13	12	16