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Abstract approved: Andrew G. Carey, Jr.

One hundred and sixty 0.1 meter^2 Smith-McIntyre grab samples were taken on the Oregon Continental Shelf at eight seasonal stations between 75 and 450 meters depth. The five replicate grab samples per season per station were analyzed for macrofauna (> 1.0 mm). Particular attention was paid to shelled Mollusca, Cumacea, and Ophiuroidea. The samples were analyzed for total species, number of specimens, wet weight, and ash free dry weight. Seventeen environmental parameters were measured at each station at each season.

Results showed no seasonal variation in either the infaunal composition in total species, numbers, or biomass, or in the sediment environmental parameters. The average values for all stations over the year-long study were 597 individuals per meter^2, 36.5 grams wet weight per meter^2, and 2.57 grams ash free dry weight

per meter^2. These values are lower than those reported for Southern California and for the Northeast coast of the United States.

Four species groups which were the dominant fauna in beach sand, silty sand, sandy silt, and glauconite sand were extracted by R mode factor analysis. The Q mode factor analysis showed two distinct sand communities in glauconite sand and beach sand. The silty sand stations had high loading to two factors while the sandy silt stations had high loading to no factors. A fourth community of organisms was described for the Oregon continental shelf in addition to the three previously described off Washington.

The results of regression analysis on nine major environmental factors showed no meaningful correlation that accounted for more than 39 percent of the total variation. Only seven of the 21 most abundant molluscan species showed meaningful significant correlation to one or more of the environmental variables. This may be an indication of biotic interdependence.

A Comparative Study of the Infauna of the Central Oregon Continental Shelf

by

Gerard Adrian Bertrand, Jr.

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A COMPARATIVE STUDY OF THE INFAUNA OF THE CENTRAL OREGON CONTINENTAL SHELF

I. INTRODUCTION

Although the infauna of the southern California and nearshore Washington continental shelf has been studied in some detail, there has been little done in Oregon on the distribution, abundance and seasonal variation of the infaunal shelf communities. Knowledge of the composition of these communities and their seasonal changes could form the base for future investigations of benthic production. Studies on selective feeding by demersal fish or of changes in feeding habits with seasons, sex, or size must also have as their base a thorough knowledge of the major food source, the infauna. For these reasons a study of the infauna off the central Oregon shelf was undertaken in July 1968. The study had as its objectives: the determination of 1) the composition of infaunal communities in a wide variety of shelf sediment types, in numbers of individuals and species, 2) the standing stock of the infaunal components, 3) the extent of seasonal variation in species composition, numbers, and standing stock, 4) the relationship of the infaunal communities to each other and to various sediment types and depths, and 5) the relationship of major species in numbers and frequency of occurrence to a wide variety of environmental parameters.

Quantitative subtidal benthic investigations were first initiated by Petersen and Jensen (1911) using a small half-moon shaped grab that sampled an area of 0.1 m^2. Based on his studies in Denmark Petersen (1913, 1918) advanced the concept of benthic communities as statistical units. This concept became widely known and accepted by terrestrial ecologists. The advantage of the Petersen grab over previous methods used to investigate the benthos was that it enabled the investigator to enumerate such faunistic parameters as number of species, number of individuals, and standing stock per unit area.

The utility of the Petersen method of mapping and enumerating the benthic communities led to its use in a large number and wide variety of other areas. Packard (1918) presented work on the molluscs obtained with an orange peel grab by the U. S. Albatross in 1912 and 1913 in San Francisco Bay. Davis (1923, 1925) conducted studies on the bottom fauna on Dogger Bank in the North Sea. And Ford (1923) investigated benthic communities in the English Channel. Zenkevitch et al. (1928) attempted to estimate the productivity of the benthos in the Kara and Barents Seas. The relationship of the benthos to the demersal fish population was investigated by Steven (1930) using a quantitative grab similar to that used by Petersen. Because the distribution of the benthos was patchy, Steven took five grab samples at each station and combined them. Working with molluscs off the coast of Greenland, Thorson (1933, 1934) confirmed the idea of benthic communities based on dominant members. Stephen (1933, 1934) and Lindroth (1935) first rejected the idea of benthic communities because of the difficulty of delineating the boundaries between them.

The first attempt to delineate benthic communities in the United States was made by Shelford and Towler (1925) using Petersen grab samples obtained in Puget Sound. Shelford _et al_. (1935) continued this survey work in Puget Sound covering a large area but with a small number of samples. Hartman (1955) used an orange peel bucket as a sampler to survey the bottom fauna of the San Pedro Basin off Southern California. The extensive study by Barnard and G. Jones (1959) for the State Water Quality Control Board of California delineated the species composition and distribution by sediment types and depth on a large area of the Southern California shelf. Meredith Jones (1961) working in a small area off Port Richmond, San Francisco Bay, California occupied four stations every five to eight weeks for a period of 14 months. Although the number of stations M. Jones used was small, the number of samples was very large; he was able to estimate the distributional patterns of the species studied.

Lie (1968) conducted an extensive investigation of the benthic infauna of Puget Sound using the Van Veen grab. This quantitative study yielded a great deal of information about sampling efficiency, biomass distribution, species distribution, and much useful information on conversion factors from wet weight to ash free dry weight. The work is distinguished by the large number of samples and completeness of the data. Lie and Kelly (1970) extended this work to the mouth of Puget Sound and to the open Washington coast. Using factor analysis on the 35 most abundant species they were able to distinguish three distinct communities lying parallel to the coastline in sand, silty sand, and silt substrates. The only work on the Oregon continental shelf is that of Carey (in press) on the interrelationships of eight stations off Newport, Oregon from 25 to 200 meters. In this work the similarity between the three stations is computed based on polychaete species distribution, numbers, and biomass.

II. MATERIALS AND METHODS

The Study Area

The area chosen for investigation lies between 75 and 450 meters on the Oregon continental shelf between the Umpqua River and the Yaquina River (Figure 1). It is a region of diverse sediments and is well-suited to a study of animal-sediment relationships. The most characteristic feature of this area of the continental shelf is Heceta Bank. This bank is 33 kilometers long and up to 15 kilometers wide, and it dominates the outer portion of the shelf (Maloney, 1965). The eastern portion of the shelf inside the bank is very gently sloping, smooth and sediment covered. The primary sediment of the inner portion of the shelf is clean, well-sorted detrital sand that occurs to a depth of 100 meters. These sands grade into silty sands and silts with glauconitic sands predominating on the topographic lows on the outer shelf. The two primary sources for sediments on the Oregon shelf are rivers and the erosion of coastal terrace deposits (Runge, 1965). Rivers contribute the finer grain sediments while the terrace deposits contribute the coarse grain materials. The complexity of the study area is increased by the deposit of fine grain sediments near shore from the river mouths. Unlike the coast of Washington the study area has considerable heterogeneity of sediment distribution.

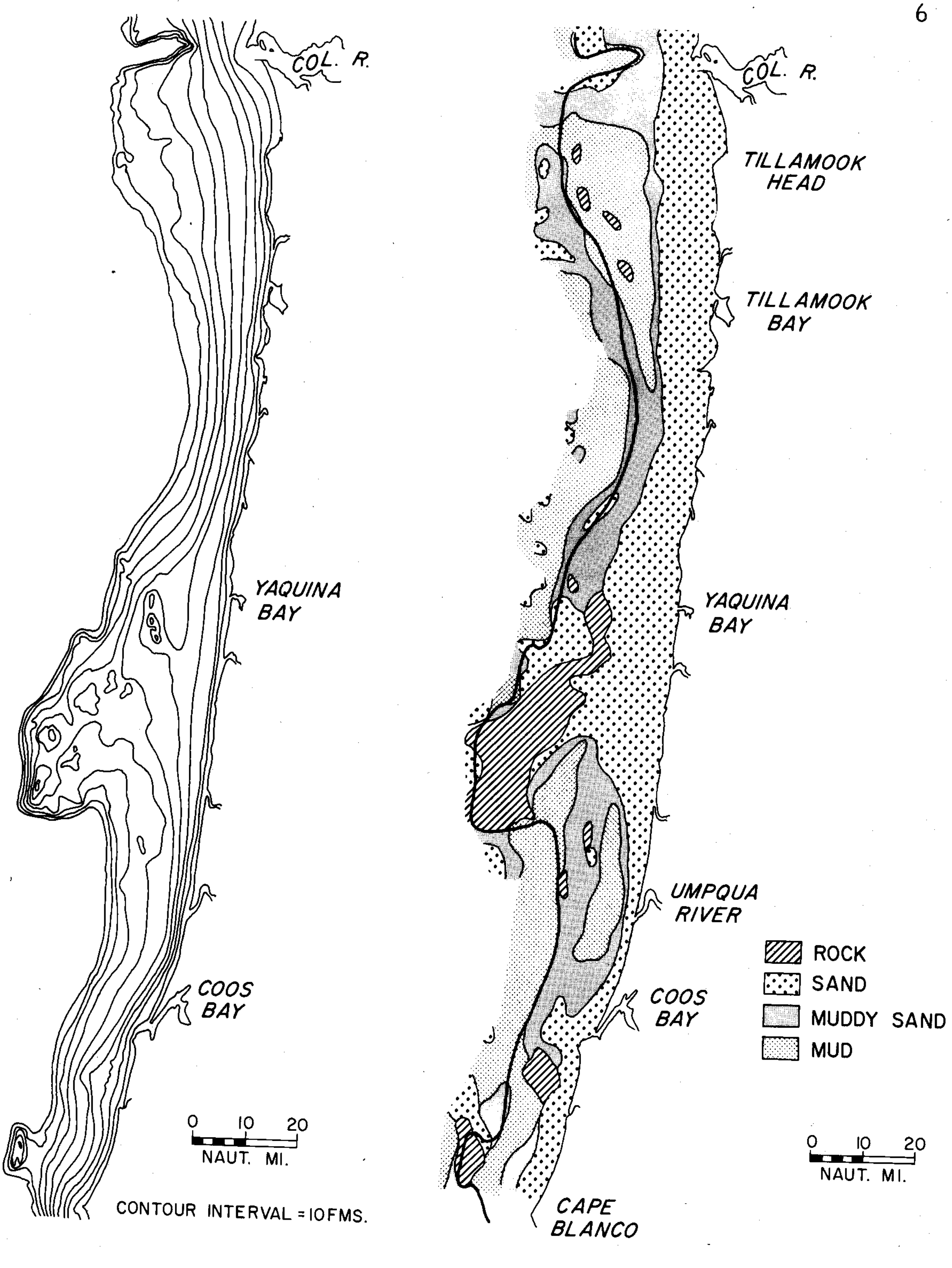


Figure 1. Distribution of sediment types and bathymetry. One mile equals 1.85 kilometers, 1 fathom equals 1.83 meters (Byrne and Panshin, 1968).

The entire shelf area is characterized by high production from upwelling during the summer months and by high river run-off and deposition during the winter months. This run-off reaches a peak during the spring when melting snows make their contribution.

Station Selection

During July 1968 the initial Sea Grant cruise sampled 16 stations (Figure 2) to determine sediment homogeneity within a single station. Only those stations with uniform sediment distribution were chosen as seasonal stations. Upon arrival at station, a buoy with a radar reflector was moored to ensure accurate navigation while on station. Station position was determined by Loran C and a Precision Depth Recorder. Position fixes were taken between each grab sample and the ship's drift corrected to maintain position. Samples were taken at the center of the station and at the apices of an equilateral triangle one nautical mile (1.85 km) to a side with the moored buoy as its center. One or two Smith-McIntyre grabs (Smith and McIntyre, 1954) were taken at each apex and one Smith-McIntyre grab from the center of the station. In addition an anchor-box dredge (Carey and Hancock, 1965) was taken at the station's center. Quantitative beam trawls (Carey, in press) were taken between apices of the triangle. Homogeneity of the sediments at each station was determined by particle size analysis of Phleger cores (Fowler and Kulm, 1966)

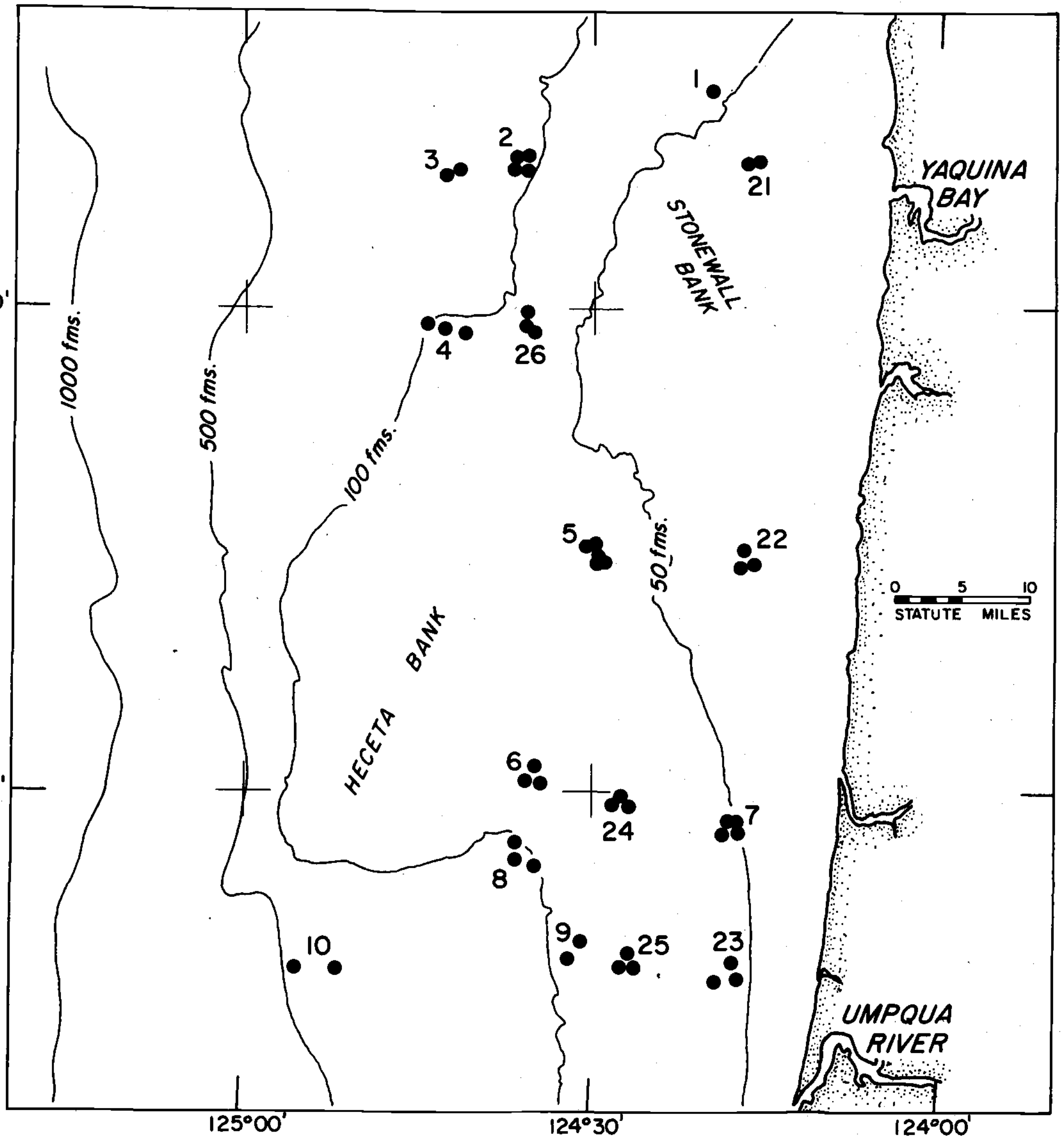


Figure 2. The 16 initial Sea Grant stations sampled in July, 1968. One nautical mile equals 1.85 kilometers; 1 fathoms equals 1.83 meters.

taken in conjunction with the Smith-McIntyre grabs. Of the original 16 stations sampled nine were selected for seasonal study. One of the seasonal stations, station 1 off the Yaquina River, was abandoned because of poor weather on two occasions and was not included in the present investigation. The remaining eight stations and cruise data are given in Table 1. The distribution of these stations on the Oregon continental shelf is shown in Figure 3. These stations, as originally conceived, were in pairs to sample the same sediment type at different depths and compare the faunas. Stations 2 and 7 were one pair, 6 and 8 another, and 10 and 15 a third pair. Stations 22 and 1 would also have been a pair if 1 had not been abandoned. Station 23 was intermediate between stations 6 and 8, and 10 and 15 in sediment type. Particle size distribution within a station can be seen in Figure 4.

Choice of Sampler and Sieve Size

The sampler chosen for this study was an 0.1 meter^2 Smith-McIntyre grab. Smith and McIntyre (1954) and Wigley (1967) found this grab to be more efficient than the similar Van Veen grab (Thamdrup, 1938). Sampling for the entire investigation was conducted from the research vessel *Cayuse*. Because the *Cayuse* is an 80 foot vessel the sampling was very dependent on weather conditions. The Smith-McIntyre grab was chosen as it is most reliable of the

Table 1. The nine seasonal Sea Grant stations and cruise dates.

Stations	Latitude	Longitude	Depth (meters)
SG 2	44°39.0'N	124°35.9'W	200
SG 6	44°01.0'N	124°35.7'W	150
SG 7	43°57.4'N	124°18.0'W	100
SG 8	44°55.8'N	124°35.7'W	200
SG 10	43°48.5'N	124°51.0'W	450
SG 15	44°09.0'N	124°25.0'W	100
SG 22	44°14.3'N	124°16.8'W	75
SG 23	43°48.5'N	124°17.8'W	100

Cruise Number	Departure Date (1 week duration)
C6810C	October 22, 1968
C6901C	January 24, 1969
C6904C	April 21, 1969
C6907C	July 23, 1969

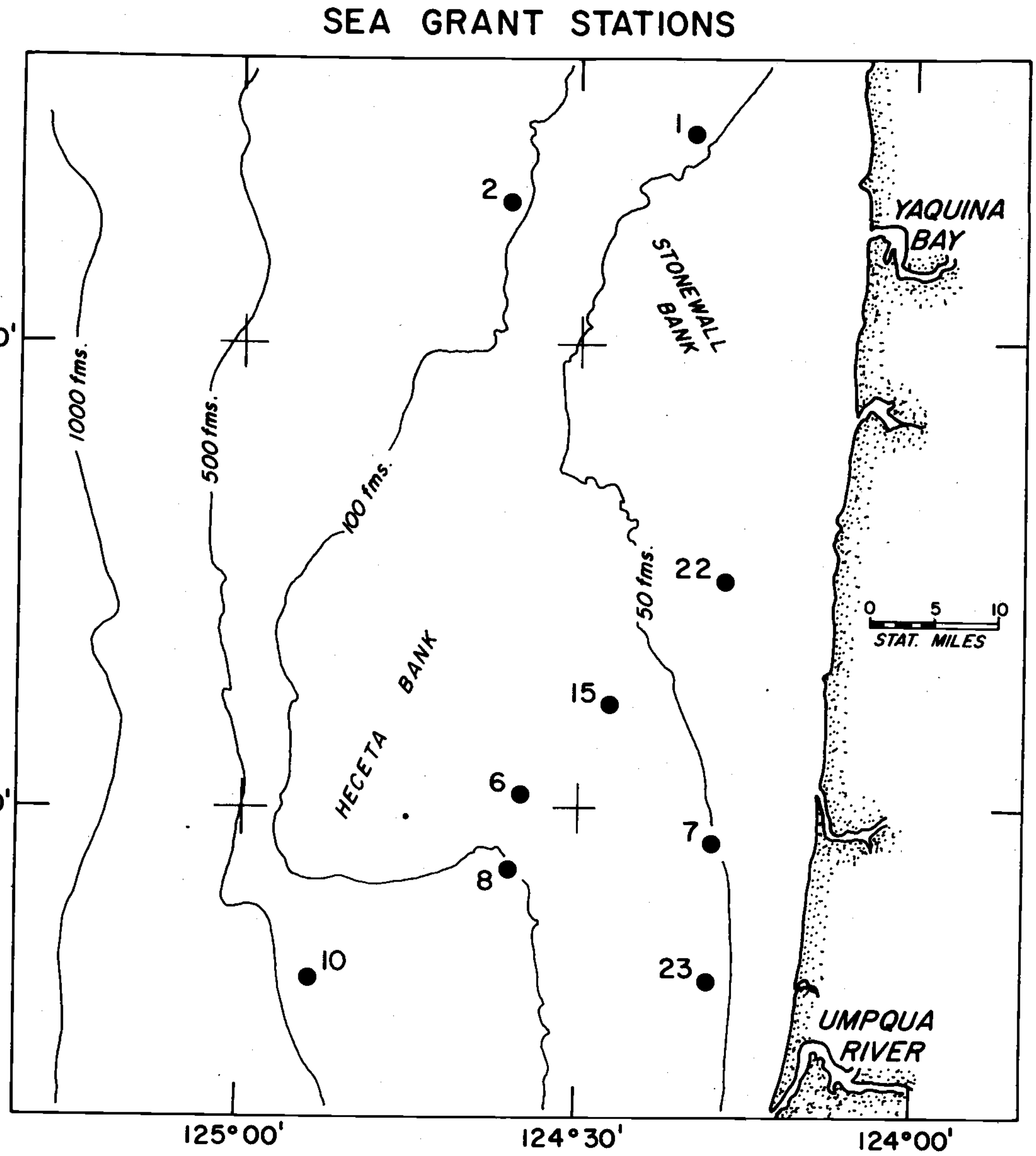


Figure 3. The nine Sea Grant stations sampled seasonally. One nautical mile equals 1.85 kilometers; 1 fathom equals 1.83 meters.

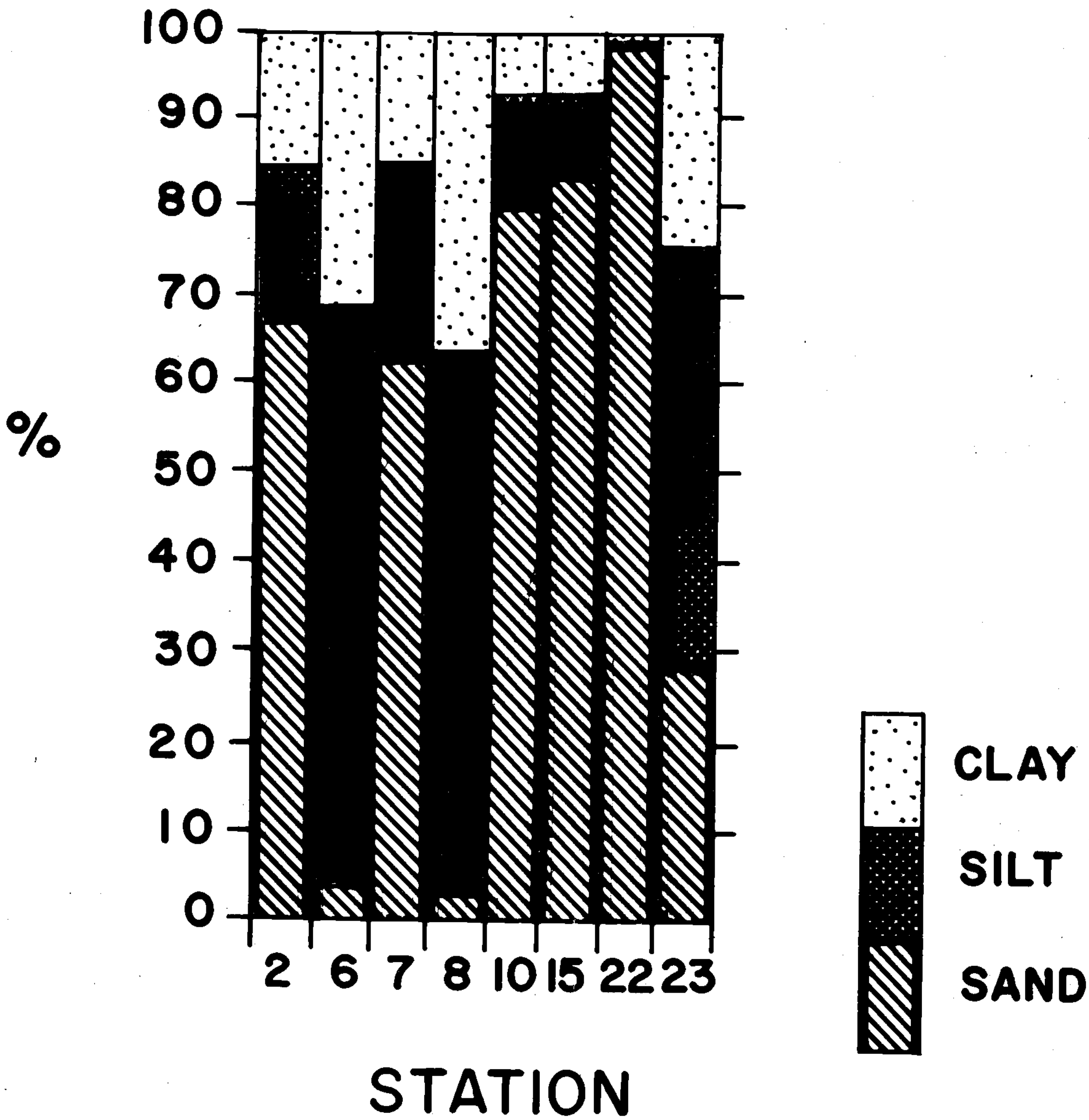


Figure 4. Sediment particle size distribution by station.

quantitative grabs in marginal weather conditions (Smith and McIntyre, 1954; Lie, 1968). Except at station 10, the deep station at 450 meters, pretripping of the sampler in the water column caused by ship's roll was minimal.

The bite taken by the Smith-McIntyre grab from the bottom was compared to those of the Van Veen and the Petersen grabs by Gallardo (1965). The Petersen and Van Veen grabs bite deeper along the edges; the Smith-McIntyre bites deepest at the center. Further, the Smith-McIntyre was most affected by substrate, taking a slightly semi-circular bite in mud and a rectangular bite in sand. It is, however, more effective on hard bottoms than either of the other grabs. The grab is also most consistent in getting a constant volume from a homogeneous substrate.

During the present study the grab sampler was lowered at a constant two to three meters per second until it reached a point ten meters above the bottom. The speed was then increased to five meters per second. This increase in speed allowed the grab to hit the bottom solidly and minimized the effect of the ship's roll. Upon retrieval the grab sample was placed in a hopper similar to that described by Holme (1959) and modified by Carey (Carey and Paul, 1968) for work off the Oregon coast. The grab was opened and the sample washed onto a screen with a 0.42 mm aperture with a fine stream of sea water from a hose. Reish (1959) showed that this screen size would be effective in retaining 90 percent of the infaunal specimens, species, and biomass collected. It did, however, allow most of the fine silts and clays to pass through the sieve thus reducing the volume to be preserved and sorted. The remainder of the sample was preserved in ten percent formaldehyde buffered with $Na_2B_4O_7$. The samples were then brought to the laboratory for processing.

Number of Samples

There has been a great deal of discussion in the literature about what constitutes an adequate sample in benthic ecology. Thorson (1957) suggested a "standard unit" of 0.1 m^2 for 0 to 200 meters and 0.2 m^2 for 200 to 2,000 meters. This standard unit has its drawbacks, depending on the type of study underway and the goals of the investigation. If only the most abundant species with the highest frequency of occurrence are required to characterize the fauna, 0.1 m^2 may be an adequate sample. If, however, the goal of the investigation is the understanding of the interaction of the species comprising the fauna then a far greater number of samples is needed. The number of samples necessary is a function of the uniformity of the environment, the species distribution, and the object of the study.

Holmes (1953), N. Jones (1956) and Longhurst (1958) have shown the relationship between the number of samples and the cumulative number of species for various types of bottom samplers. Longhurst (1958, 1959) in particular has shown the relationship between number of species and number of individuals for the Smith-McIntyre grab at two shallow subtidal stations off the Sierra Leone River on the West African shelf. His data show that five replicate 0.1 m^2 Smith-McIntyre grabs sample greater than 50 percent of the total number of species sampled by 20 0.1 m^2 replicate samples. Over 50 percent of the individuals at each of his stations was attributable to less than ten percent of the number of species. The data suggest that the dominant species account for a lesser percent of the total number of individuals with increasing depth.

It was suggested by Longhurst (1959, 1964) that a minimum area of 0.5 m^2 sampled by five replicate 0.1 m^2 grab samples was necessary to characterize the fauna. Lie (1968) tested this hypothesis in Puget Sound and found that three to four 0.1 m^2 samples were sufficient for collecting the species that made up 95 percent of the total number of specimens. He also found that 75 to 85 percent of the species collected by ten 0.1 m^2 grab replicate samples were also collected by five 0.1 m^2 replicate samples. For this reason, five replicate 0.1 m^2 grab samples were chosen as the standard for each seasons' sampling at each of the eight stations. A sixth grab was taken to insure that the minimum of five was maintained in the event a grab sample was lost, mislabeled, not preserved properly, or that an insufficient volume of sediment was sampled.

The amount of sediment in each sample was measured with a dipstick when the top plates of the grab were opened. Those with insufficient volume to assure a rectangular cut into the upper 15 centimeters of bottom were not kept. Benthic investigators have, in the past, measured the volume of each sample but used it only to explain difficulties with the sample. Since most organisms live in the upper few centimeters it is believed that a 15 cm depth is sufficient to capture the majority of specimens, species, and biomass (Lie, 1968).

In the laboratory the field data were examined without looking at the samples and the grab that had the least volume was put aside. Occasionally a grab was imperfectly preserved and this was exchanged for the one put aside. Variations in volume were minimized by summing the fauna in the five grabs at each season for analysis.

A close check was made on position and it was corrected and maintained throughout the sampling period. Grabs were made consecutively with a maximum of one half hour between samples.

Environmental Sampling

With each set of six Smith-McIntyre grabs a number of environmental parameters was also sampled. A modified Smith-McIntyre grab (Carey and Paul, 1968) was used for simultaneous collection of sediment and bottom water. This modification consisted of a bottom-triggered Fjarlie bottle (Fjarlie, 1953) mounted on the side of the grab. The reversing thermometer rack on the Fjarlie bottle trips automatically when the water sample is taken. The grab was lowered to five to ten meters off the bottom and allowed to equilibrate for ten minutes before the grab was lowered and the tripping occurred. Oxygen and temperature were determined on shipboard. Salinity was determined with a Hytech Model 261 inductive salinometer in the laboratory. A nutrient sample was drawn into a polyethylene bottle and deep-frozen immediately. The nutrient samples were analyzed for all silicates, nitrates, and phosphates on a Technicon Model 1 Autoanalyzer after return to port. A Phleger multiple corer with five core barrels was taken at each station. One core was used for particle size analysis and another was frozen for sediment nutrient studies. If the sampler failed to secure a core for the sediment parameters, they were taken from an additional Smith-McIntyre grab.

Laboratory Processing

In the laboratory the faunal samples were washed on stainless steel screens of 0.1 mm and 0.42 mm mesh. The macrofauna for this study was retained on the first screen and about half of the meiofauna on the second, smaller screen. The material from the 1.0 mm screen was then placed in 70 percent isopropyl alcohol for later sorting. A screen size of 1.0 mm was chosen because by convention this is the separation between the macrofauna and the smaller meiofauna. Reish (1959) demonstrated that this screen size captured over 90 percent of the total biomass and almost 90 percent of the total number of species. Because of this dominance in biomass and number of species the macrofauna is thought to be indicative of the infaunal community.

The samples were sorted by placing them in a large rectangular Pyrex dish on white paper and picking the animals out with forceps and with the aid of a 3x magnifying lamp. The procedure was then repeated. The species were first sorted into major groups; however, a number of groups that were not part of the infauna were discarded. Large calanoid copepods and euphausiids were contaminants in the sea water used to wash the grabs on board ship. Hard bottom forms such as Hydroida, hard bottom Anthozoa and Brachiopoda were removed from the sample. Anomuran crabs, large asteroids, and sea pens of the genus Balticina were also removed from the grab samples. These groups, although soft bottom inhabitants, are epifauna and are more adequately sampled by trawls than by grabs.

Because the infauna of the Oregon coast is poorly known, the taxonomic problems involved are large. Identification of all species in the grab samples was impractical because of time limitations; consequently, three groups, molluscs, cumaceans, and ophiuroids were chosen for detailed work. The remainder of the fauna was counted and weighed but not identified to species. Thorson (1951, 1957) demonstrated the importance of molluscs in characterizing benthic communities. Molluscs form a conspicuous and abundant segment of the fauna on the Oregon continental shelf; they are thought to be indicative of the fauna as a whole. All individuals of all taxa in all grabs were counted with the exception of the polychaetes. Polychaetes were counted from two grabs from each station. Only anterior ends were counted as individuals unless the size or identity made the individual conspicuous from the rest in which case a posterior end was counted. Only apparently live-caught individuals were counted as part of the fauna.

Wet Weights and Ash Free Dry Weights

Wet weights were taken for each major group within each grab sample except for the molluscs in which the three most abundant gastropod and the three most abundant bivalve species in each station were weighed separately. The samples had been preserved in 70 percent isopropyl alcohol for 10 to 22 months before weighing. Each subsample was blotted to remove excess surface moisture; a ten minute interval before weighing allowed all surface moisture to evaporate and for the asymptote to be approached in weight loss from evaporation. An H5 Type Mettler analytical balance was used for weighing. All molluscs were weighed in their shells; polychaetes were removed from their tubes. Because of their considerable taxonomic value and possible future work that can be done on the samples, the specimens were not burned to obtain ash free dry weights. Conversion factors from wet weight to ash free dry weight were used instead (Table 2). The conversion factors of Lie (1968), Stander (1970), and Carey (1970) are quite consistent with those reviewed by Thorson (1957). Wherever possible conversion factors for the same species or members of the same genus were used. When this was not possible, conversion factors for the general group were used.

Laboratory Environmental Sample Processing

Particle Size Analysis

Sediment particle size was measured by the standard procedures of Krumbein and Pettijohn (1938). The fine fractions were analyzed by the pipette method while the coarse sand fractions were analyzed by the settling tube method according to Emery (1938). Cumulative percent of the weight of the size fraction was determined for 20 phi sizes ranging from 0 to 7.966. In addition, the Inman, Trask, and Folk and Ward parameters of median grain size, mean grain size, sorting coefficient, skewness, and kurtosis were calculated. Of these parameters, percent sand, percent silt, percent clay, Inman median grain size, Folk and Ward mean grain size, and

Table 2. Preserved wet weight to ash free dry weight conversion factors.

	(Lie, 1968)	(Stander, 1969)	(Carey, 1970
Anthozoa			0.113
Turbellaria	0.133		
Nemertea	0.133		
Sipunculoidea	0.130		
Echiurida			0.130
Polychaeta	0.133		
Aplacophora			0.130
Gastropoda			0.083
Pelecypoda	0.055		
Scaphopoda			0.060
Crustacea	0.150		
Brisaster latifrons		0.044	
Allocentrotus fragilis		0.037	
Ophiuroidea	0.122		
Holothuroidea	0.076		

Folk and Ward sorting coefficient (Shepard, 1963) were selected for correlation with the fauna. A total of 32 seasonal samples from the eight Sea Grant stations was analyzed and an additional 56 samples from the initial 16 stations were analyzed to determine sediment homogeneity within a station.

Water and Sediment Analysis

Replicate analyses were run on each of the frozen nutrient samples obtained from the Fjarlie bottle attached to the Smith-McIntyre grab. The frozen sediment sample from the Phleger corer was analyzed for nitrogen with an F and M (Model 185) CHN carbon, hydrogen, and nitrogen analyzer. Duplicate or triplicate samples were run from each core sample. Total carbon was measured by dry combustion in a Leco induction furnace and measurement of the evolved CO_2 in a Leco gas analyzer (Curl, 1963). The sediment was dried, ground, and then completely oxidized in the heat generated by the furnace. Calcium carbonate was measured by acidifying the dried ground sediment with 0.1 N HCl and measuring the CO_2 evolved. The percent by weight of organic carbon was estimated by difference between total carbon and calcium carbonate carbon.

Data Analysis

Data were analyzed on the Oregon State Open Shop Operating System (OS3) using the CDC 3300 Computer of the Oregon State University Computer Center. The AIDN program developed by Dr. Scott Overton (unpublished) of the Oregon State Statistics Department was used for analysis of the grab-to-grab, station-to-station, season-to-season variation in the fauna.

Stepwise, multiple linear regression was performed utilizing the *STEP I program (Draper and Smith, 1966). The variable with the highest correlation to the data is selected at each step in the process, and those variables already entered are re-examined at every stage in the regression to determine if the contribution of a selected variable becomes insignificant and should be removed. Both the F statistic and Student's t statistic are evaluated at each step in the regression.

The *FAST Factor Analysis Program of Dr. Tjeerd van Andel of the Oregon State University Department of Oceanography was used to analyze the faunal data for species groups and station groups. The *STEP I program of the Oregon State University Statistics Department Program Library was used for regression analysis to study the relationship of environmental factors to particular species. The Olivetti Programma 101 desk calculator was used for converting wet weights to ash free dry weights.

Some Computational Definitions and Methods

The AIDN Program calculates two measures of diversity. One of these measures is Sd^2, the diversity measure proposed by Simpson (1949). Sd^2 is an estimator of Simpson's 1949 index λ which is defined for the entire population as

$$\lambda = \sum_{i=1}^{Z} \pi_i^2 ,$$

where:

π_i = proportional value of the ith species in the population and

Z = total number of species in the population.

The estimator is

$$Sd^2 = \sum_{i=1}^{S} P_i^2 = \sum_{i=1}^{S} \frac{n_i^2}{N^2} = \frac{\sum_{i=1}^{S} n_i^2}{N^2} ,$$

where:

$P_i = n_i/N$ = proportion of total individuals in ith species;

n_i = number of individuals of ith species in the sample;

N = total number of individuals in the sample;

S = total number of species in the sample.

The estimator ranges from 1/N to 1.

The other index computed by the AIDN Program is the Shannon-Wiener information function, H. With logarithmic bases of e and 2 the indices are

$$\underline{H}_e = -\sum_{i=1}^{N} P_i \log_e P_i, \text{ and}$$

$$\underline{H}_e = -\sum_{i=1}^{N} P_i \log_2 P_i.$$

Lie (1968) found that the increase in $\underline{H}_2$ between single samples and five pooled samples was about eight percent. The difference in $\underline{H}_2$ from five to ten samples was only four percent. He concluded that five replicate samples of 0.1 m^2 were sufficient to use the Shannon-Wiener function $\underline{H}$ as a valid index of diversity.

The statistical comparison of samples in synecological studies has been difficult. The similarity index (SIM I) is one way of making this comparison. Similarity can be defined as the sum of the products of the proportions of individuals in five species common to two samples.

$$SIM_{12} = \sum_{i=1}^{S} P_{1i} P_{2i}.$$

P_{1i} = proportion of ith species in first collection.

P_{2i} = proportion of ith species in second collection.

S = number of species present in both collections.

An index of this similarity measure can be given by SIM I.

$$SIM\ I_{12} = \frac{SIM_{12}}{(Sd_1)(Sd_2)} \qquad \text{Limits} = 0 \text{ to } 1.$$

This is scaled by the factor $(Sd_1)(Sd_2)$ which is the product of the square roots of Simpson's diversity index. Grabs with no species in common have a similarity of 0, while those which have all species in common in equal proportions have a similarity of 1.

The third method of comparing two samples or collections of samples is that of difference (MacArthur, 1965). The index is

$$\mathrm{DIF}\ (1, 2) = -\exp\left[\sum_{i=1}^{N} \left[\frac{P(i,1) + P(i,2)}{2}\right] \mathrm{LN} \left[\frac{P(i,1) + P(i,2)}{2}\right]\right]$$

$$-\exp\left[\sum_{i=1}^{N} \left[\frac{-P(i,2)\ \mathrm{LN}\ P(i,2)}{2}\right] + \sum_{i=1}^{N} \left[\frac{P(i,1)\ \mathrm{LN}\ P(i,1)}{2}\right]\right].$$

where:

$P(i, 1)$ = proportion of the ith species in the first collection;

$P(i, 2)$ = proportion of the ith species in the second collection;

and

N = total number of species for each collection.

The difference index (DIF) ranges from 1 to 2. One is total accord of the samples and 2 total difference.

Levins (1968) gives two measures of niche breadth, which are measures of the dominance of a species or collection of species in a collection of samples. The measures are:

$$B_2 = \exp\left[-\sum_{i=1}^{N} \left[\frac{P(i,j)}{Q_2}\right]\right] LN \left[\frac{P(i,j)}{Q_2}\right], \text{ and}$$

$$B_5 = \frac{1}{\sum_{j=1}^{N} \left[\frac{P(i,j)^2}{Q_2}\right]};$$

where:

$$Q_2 = \sum_{j=1}^{N} P(i,j),$$

$P(i, j)$ = proportion of the ith species in the jth collection,

and

N = total number of collections.

The measure ranges from 1 to N.

These were converted to mean niche breadth according to McIntire and Overton (1970).

Factor Analysis

The same species subjected to the AIDN analysis of similarity and difference were also subjected to a factor analysis. Factor analysis gives an overall correlation among species and stations in the R and Q modes. The R Mode orders the species according to station and Q mode orders the stations according to the species composition. The R Mode procedures followed were the same as those of Lie (1968). Ones were placed on the principal diagonal and the species counts, X, were transformed by the equation

$$X^* = \ln(X+1).$$

This was done to give a variance for the species that was independent of the mean (Bartlett, 1947). The positive eigenvalues and associated eigenvectors for the matrix were determined and the first six principal components rotated for interpretation. Rotation was done using the Varimax criterion of Kaiser (1958). Data for the Q Mode analysis were transformed by the percent range transformation according to Imbrie and van Andel (1964) by the equation

$$X^* = \frac{(X - X_{min})}{(X_{max} - X_{min})} \times 100.$$

The original value is X and X^* is the transformed value. This equates all data. The rare species are treated just as the most abundant species. Factor loadings of greater than ± 0.5 were treated as significant in both the R and Q Modes of factor analysis. For a detailed explanation of the method see Lie and Kelly (1970).

III. RESULTS

The Benthic Environment

The 17 environmental parameters studied were sampled at each season throughout the course of the year. The results of the analysis of these 17 environmental parameters are given in Table 3. In this table the mean values for the four seasons are given. Complete data on the environmental parameters can be found in the Appendix. The large standard deviation in depth at station 10 is caused by relocation of the stations; it was moved from 490 meters depth to 450 meters depth to avoid a rocky area. After depth, the next six parameters are from the bottom water samples. These parameters remained fairly consistent over the range of the eight stations. Temperature and oxygen show a decrease with depth. At the time of analysis the chemistry laboratory of the Department of Oceanography at Oregon State was recording an error of up to five percent in the measurement of phosphate. For the measurements of nitrates and silicates, the error ranged up to 25 percent. This explains in part the very high standard deviation for these two nutrients. Total carbon and calcium carbonate were measured from the sediment sample taken from the Phleger corer. The values for each season are an average of three replicate subsamples. The four sediment parameters, percent total

Table 3. The 17 sampled environmental parameters by station.

Environmental Parameter	Station	2	6	7	8	10	15	22	23
Depth	Mean	190.5	147.7	99.5	195.0	458.7	101.5	74.0	102.0
	Std. Dev.	7.05	2.63	.058	8.12	23.79	1.91	1.15	1.63
Salinity ‰	Mean	33.94	33.59	33.36	33.92	33.95	33.72	33.33	33.68
	Std. Dev.	0.07	0.42	0.61	0.12	1.18	0.26	0.55	0.27
Temperature °C	Mean	7.14	7.18	8.16	7.82	5.57	7.72	8.02	7.83
	Std. Dev.	0.95	1.07	1.31	1.66	0.07	0.91	1.13	0.88
Oxygen ml/l	Mean	2.48	2.55	3.14	2.40	1.87	2.85	3.74	3.03
	Std. Dev.	0.36	1.09	1.75	0.53	0.98	1.19	1.65	0.85
Silicate μm/l	Mean	36.25	41.7	39.50	40.75	43.25	38.50	32.75	36.25
	Std. Dev.	14.41	11.59	17.60	16.64	12.66	19.14	1.88	12.12
Phosphate μm/l	Mean	2.42	2.82	2.68	2.94	2.54	2.39	2.10	2.72
	Std. Dev.	0.41	0.40	0.48	0.76	0.58	0.37	0.29	0.34
Nitrate μm/l	Mean	24.70	25.82	24.30	25.70	28.30	23.75	19.45	24.67
	Std. Dev.	8.45	5.94	10.31	10.35	6.17	9.45	11.05	5.84
% Total Carbon	Mean	1.04	1.73	0.63	1.68	0.86	0.45	0.11	1.38
	Std. Dev.	0.17	0.19	0.10	0.18	0.29	0.06	0.05	0.10
% Calcium Carbonate	Mean	0.05	0.05	0.05	0.09	0.01	0.02	0.02	0.05
	Std. Dev.	0.00	0.01	0.03	0.01	0.01	0.02	0.01	0.02
% Organic Carbon	Mean	0.98	1.68	0.58	1.59	0.85	0.43	0.10	1.33
	Std. Dev.	0.17	0.18	0.09	0.18	0.29	0.07	0.04	0.11

Table 3. Continued.

Environmental Parameter	Station	2	6	7	8	10	15	22	23
Sediment Nitrogen $x 10^{-6}$/gm sediment	Mean	0.11	0.17	0.62	0.16	0.06	0.04	0.00	0.10
	Std. Dev.	0.01	0.02	0.01	0.01	0.02	0.00	0.00	0.01
Folk and Ward Mean Particle Size	Mean	4.62	6.85	4.20	7.22	2.60	2.99	1.88	6.01
	Std. Dev.	0.22	0.34	0.65	0.47	0.48	0.30	0.16	0.57
Folk and Ward Sorting Coefficient	Mean	2.77	2.86	2.31	2.65	2.26	1.81	0.45	2.88
	Std. Dev.	0.48	0.19	0.62	0.45	0.34	0.55	0.02	0.42
Inman Median Grain Size	Mean	3.46	5.87	3.38	6.45	2.00	2.78	1.89	4.96
	Std. Dev.	0.02	0.42	0.38	0.22	0.48	0.15	0.15	0.32
% Clay by Wgt.	Mean	14.74	30.28	11.66	35.32	7.77	7.28	0.93	23.60
	Std. Dev.	1.49	4.56	4.63	4.62	1.93	2.15	0.86	4.62
% Silt by Wgt.	Mean	16.79	66.58	22.12	62.11	13.42	8.64	0.35	48.13
	Std. Dev.	1.68	4.05	1.82	2.73	9.61	3.13	0.24	2.79
% Sand by Wgt.	Mean	68.46	3.13	63.72	2.57	78.81	84.07	98.72	28.26
	Std. Dev.	2.70	3.01	9.39	2.19	7.91	3.53	1.06	7.39

carbon, percent calcium carbonate, percent organic carbon, and sediment organic nitrogen were very consistent over the four seasons. The standard deviation was low. The values of the standard deviations for the six textural parameters chosen are a good indication of the low variability of sediment type within the station.

The sample correlation matrix was calculated using the *STEP I Program. The sample correlation coefficient r was calculated according to Snedecor and Cochran (1967) by the equation

$$r = X_i X_j / (X_i^2)(X_j^2)$$

where:

X_i = ith variable of N variables,

X_i = jth variable of N variables, and

N = 17.

The null hypothesis that the population correlation coefficient P was equal to 0 was tested at the five and one percent significance levels of r. If the number of pairs of variables to be tested is N, the degrees of freedom in this case are N-2. The correlation coefficient matrix calculated by combining all seasons and all stations is shown in Figure 5. In this case there are 30 degrees of freedom. The value for rejecting the null hypothesis that P is equal to zero at the five percent level is 0.349. At the one percent level it is 0.449.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1 Depth	1.000																	1
2 Salinity	.402	1.000																2
3 Temperature	-.059	-.582	1.000															3
4 Oxygen	-.388	-.743	.726	1.000														4
5 Silicate	.156	.564	- 670	-.759	1.000													5
6 Phosphate	.080	.275	-.151	-.249	.450	1.000												6
7 Nitrate	.225	.669	-.668	-.741	.935	.499	1.000											7
8 Total Carbon	.163	.266	-.101	-.265	.131	.420	.180	1.000										8
9 Calcium carbonate	-.231	.008	.205	-.110	.084	.451	.086	.615	1.000									9
10 Organic carbon	.178	.263	-.106	-.255	.123	.405	.173	.998	.583	1.000								10
11 Sediment nitrogen	.116	.276	-.025	-.242	.144	.460	.199	.938	.670	.932	1.000							11
12 Mean particle size	-.143	.173	.140	-.161	.055	.446	.102	.902	.749	.891	.919	1.000						12
13 Sorting	.218	.339	-.208	-.413	.213	.462	.312	.763	.542	.756	.755	.724	1.000					13
14 Median grain size	-.200	.144	.181	-.133	.060	.431	.083	.871	.746	.859	.890	.980	.611	1.000				14
15 % Clay	-.035	.214	.106	-.168	-.056	.468	.122	.900	.729	.888	.928	.974	.696	.969	1.000			15
16 % Silt	-.065	.083	.075	-.147	-.083	.426	.099	.923	.667	.918	.877	.938	.624	.945	.922	1.000		16
17 % Sand	.061	.138	-.072	.175	-.090	-.471	-.120	-.927	-.717	-.920	-.903	-.963	-.678	-.965	-.956	-.986	1.000	17
	1 Depth	2 Salinity	3 Temperature	4 Oxygen	5 Silicate	6 Phosphate	7 Nitrate	8 Total carbon	9 Calcium carbonate	10 Organic carbon	11 Sediment nitrogen	12 Mean particle size	13 Sorting	14 Median grain size	15 % Clay	16 % Silt	17 % Sand	

■ 5%

░ 1%

Figure 5. The correlation coefficient matrix for all stations at all seasons.

All variables associated with the sediment parameters, total carbon (variable no. 8) through percent sand (variable no. 17) are highly correlated at the one percent level (Figure 5). Variables eight through 16 show a high negative correlation for variable 17 (percent sand). The correlations between the last six variables are, of course, expected because these are reciprocal measurements of the same sample. Depth (variable no. 1) shows a high positive correlation with salinity and a high negative correlation with temperature and oxygen. Temperature, as expected, shows a high inverse correlation with depth and salinity, and a high positive correlation with oxygen. Of the nutrients, silicates and nitrates are positively correlated with salinity and negatively correlated with temperature and oxygen at the 1 percent level. Phosphorus is positively correlated with silicates and nitrates and all variables in the sediment except percent sand where the correlation is negative.

In summary, salinity increases in depth while temperature and oxygen decrease. The nutrients, silicates, phosphates, and nitrates increase with increasing salinity and with decreasing temperature and oxygen. In the sediment data there is a paradox. Total carbon, calcium carbonate and organic carbon increase with percent clay and percent silt, yet they also increase with an increase in mean particle size and median grain size. This increase in grain size is usually caused by an increase in the percent sand, yet all of these parameters are negatively correlated with percent sand. Positive increase in percent silt and clay with mean particle size and with median grain size could indicate an increase in large fragments of material mixed with fine sediments.

Station Summary

Station 2

Station 2 is at approximately 200 meters depth; the sediment is silty sand. A thin silt layer has been observed overlying a sandy layer in the cores and in the Smith-McIntyre grab samples. Based on a correlation coefficient matrix for this station (2 degrees of freedom, the 1% level is $r > 0.990$) both total carbon and organic carbon are significantly correlated at the one percent level with an increase in median grain size. Sediment nitrogen shows high positive correlation at the five percent level with salinity, silicates and water nitrates.

Station 6

Station 6 is at 150 meters depth; the sediment is primarily clayey silt. Organic carbon is 1.68 percent of the sediment by weight.

Station 7

Station 7 is at 100 meters depth; the sediment is silty sand. Sediment particle size is very much like that of station 2; however, the silt at station 7 does not form a layer on the top of the sand as it does at station 2, but is mixed throughout.

Station 8

Station 8 can be paired with station 6. It is at 200 meters depth and is almost identical in sediment type with station 6 (clayey silts). Like station 6 it is relatively high in percent total carbon by weight of the sediment (1.59 percent).

Station 10

Station 10 is unique among the eight stations. It is the deepest station (460 meters), and it is the only station in which glauconite composes a large percent of the sediment. In particle size station 10 is much like stations 15 and 22. However, the sand fraction is glauconite and not beach sand. A large standard deviation in percent silt and percent sand (Table 3) is indicative of the patchiness in distribution of the sediment. Of the eight stations, station 10 is lowest in temperature and oxygen concentration.

Station 15

Station 15, at 100 meters depth, is a silty sand station low in both organic carbon and organic nitrogen. Station 15 lies between station 6 and 8 at a shallower depth (Figure 2). This station is an example of the patchy distribution of sediments and rapid change that occurs within sediments on the Oregon shelf.

Station 22

Station 22 is at 75 meters depth. The sediment is composed of 90 percent beach sand derived from terrace deposits. The organic carbon in the sediment at 0.1 percent by weight is the lowest of the eight stations and the organic nitrogen in the sediments cannot be detected by our methods. Station 22, with the lowest standard deviation (Table 3), is the most consistent in terms of sediment. The beach sand is clean and well sorted.

Station 23

Station 23 lies at a depth of 100 meters and is composed of sandy silt. This station is influenced by the Umpqua River. The standard deviations of the organic carbon and calcium carbonate parameters show a fairly high variability. Station 23 is third highest of the eight stations in percent total carbon with 1.38 percent by weight. The composition of station 23 was the most variable of the eight stations with silt, clay, sand, and some gravel making up fractions of the sediment.

Environmental Seasonality

The water parameters derived from the Fjarlie bottle samples reflect the surface conditions on the Oregon shelf. With the increase of salinity during the summer months there is a decrease in both temperature and oxygen. This is reversed in winter with salinity being lower and temperature and oxygen being higher. The silicates, phosphates, and nitrates are highest in summer and reach low points during the winter months. The summer upwelling does not discernibly affect the sediment parameters studied in this investigation. However, seasonality in the sediment parameters may have been missed since replicate samples were taken only once during each season. There is no noticeable seasonality in percent total carbon, calcium carbonate, organic carbon, or organic nitrogen in the sediment. Seasonal changes in sediment characteristics might be expected at station 23 which is influenced by the Umpqua River, however, none was found. See Appendix I for seasonal environmental data.

Sampling Results

The usual way of determining if a community is sampled adequately is to plot the cumulative number of species as a function of increased number of samples. The slope at the upper end of the curve demonstrates whether the sample is adequate. If the number of species increases markedly with an increasing number of samples, more samples are needed; or if the curve is asymptotic, an adequate number of samples has been obtained. The samples are normally randomized before plotting to remove variability caused by sampling error (Longhurst, 1959; Lie, 1968). However, the samples were not taken at random in this study, but in groups of five, and following the standard procedure would not be as informative as plotting the samples by seasonal groups. The cumulative number of species as a function of area sampled and the number of samples is shown in Figure 6. These samples are plotted as they were taken, the first five from the fall of 1968 and the last five from the summer of 1969. At stations 8, 6, 10, and 22 the curve is fairly flat, indicating a low increase in the number of species with increased sampling; however, at stations 2, 7, 15, and 23 the increase is rather rapid between five and ten grabs after which it leveled off.

An explanation of this increase can be better seen by looking at the percent increase in the number of species versus the increase in

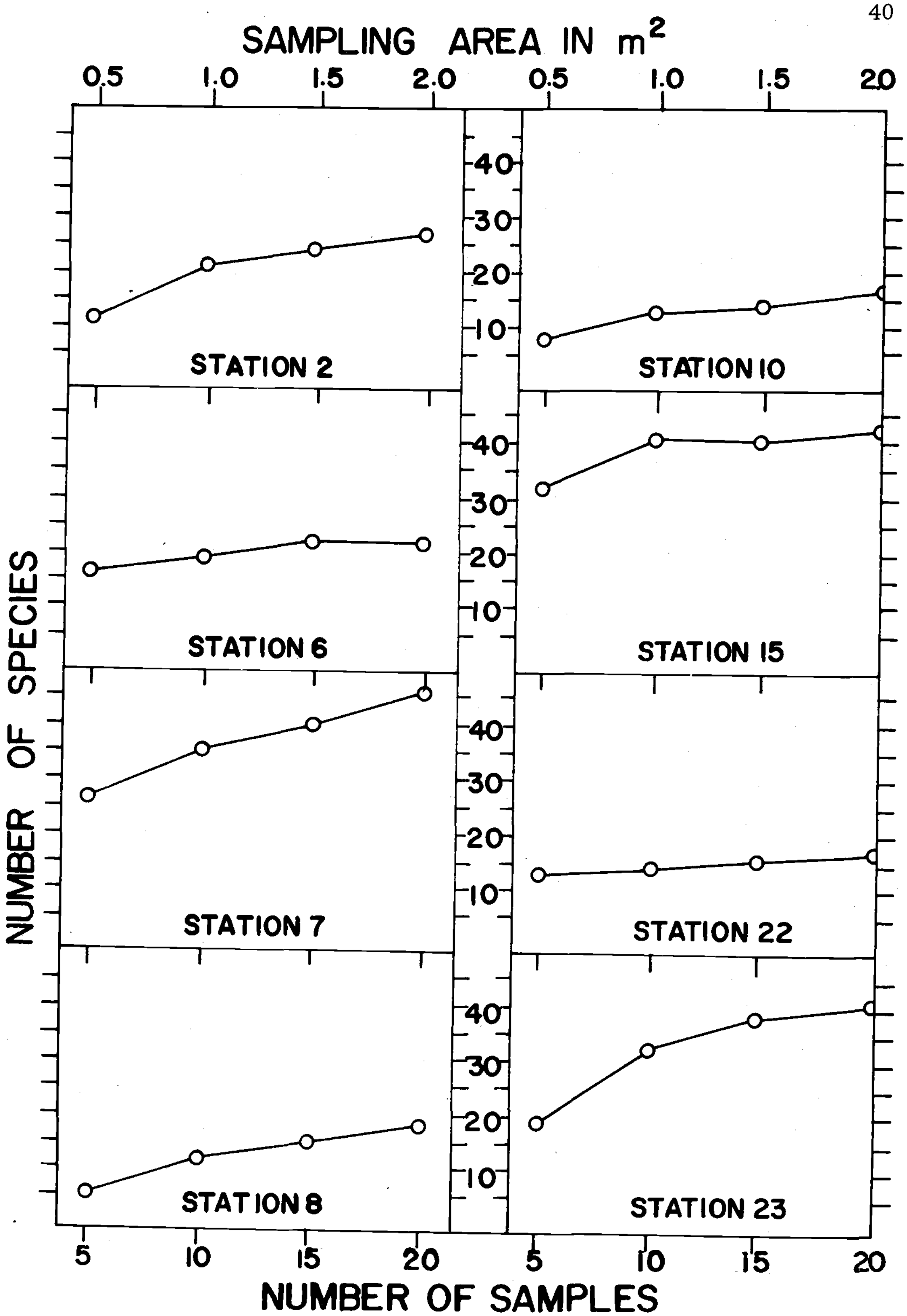


Figure 6. Cumulative number of species of molluscs, ophiuroids and cumaceans with increased sampling (20 0.1 m^2 samples).

number of individuals from the additional species. This information, based on the shelf mollusca, ophiuroids, and cumaceans is given in Table 4. Five of the eight stations have over 50 percent of the total number of species taken in the first five replicate samples. This agrees well with Longhurst's data. However, two of the stations, stations 2 and 8, are considerably below the 50 percent level. Stations 2, 7, 8, 10, and 22 also show a ten percent or greater increase in the number of species even after 15 grabs have been taken. At first glance it would appear that these communities had been inadequately sampled. However, a different picture emerges when one looks at the number of individuals from the added species. With the exception of stations 8 and 23, the number of individuals added falls rapidly after five grabs have been taken. This indicates that the species being added are rare and occur in low numbers.

The high percentage of individuals added from additional species at station 8 is explained by the low numerical density of fauna. Station 8 has 53 individuals of the mollusca, ophiuroids, and cumaceans per 20 grabs (i.e. 2.0 m^2). Species are widely scattered, and the addition of a few individuals greatly affects the percent increase.

At station 23, however, the total number of species is relatively large. Thirty percent of the 44 percent increase in total individuals between five and ten grabs is caused by the bivalve, Macoma carlottensis. This species occurs in large numbers but with low

Table 4. Percent of the total number of species and total number of individuals from the added species.

Sample Increase	Percent of the total number of species								Percent of the total number of individuals from added species							
	Station															
	2	6	7	8	10	15	22	23	2	6	7	8	10	15	22	23
5	39.3	69.5	55.3	33.3	50.0	72.2	70.0	48.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
5 to 10	35.7	13.0	21.3	33.3	31.2	20.4	10.0	31.7	15.6	4.4	14.9	75.0	11.9	9.8	5.3	44.6
10 to 15	10.7	17.4	10.6	16.7	6.2	0.0	10.0	14.6	10.3	6.0	2.8	40.0	1.2	0.0	1.4	6.9
15 to 20	14.3	0.0	12.8	16.7	12.5	6.8	10.0	4.9	12.9	0.0	6.5	17.6	2.8	5.0	1.3	3.4
Total no. Sp.	28	38	47	18	16	44	20	41								
Total no. Indiv.									271	265	661	53	430	538	548	614

frequency of occurrence; it has a clumped distribution.

The surprisingly large increase in the number of species with additional grab samples shows that a complete enumeration of the infauna on the Oregon continental shelf would be difficult. However, as Longhurst (1959) has shown, this increase in number of species does not invalidate a benthic synecological study since the great majority of individuals found in any group of samples comes from a few species. The small increase in the number of individuals from the additional species shows that the major species have been captured by five grab samples. Thus five 0.1 m^2 samples adequately represent the fauna.

Species Distribution and Abundance

It is generally assumed in benthic ecology that sandy substrates have fewer species with larger numbers of individuals per species than do soft bottomed sediments (Hedgpeth, 1957). Data from the eight stations studied in this investigation do not fully support this assumption. Figure 7 which is based on the 83 species of major interest, plus two species of polychaetes, three species of echinoderms, and one species of nemertean illustrates this. Stations 10 and 22, two of the predominately sand stations (see Figure 4) have the lowest number of species, yet these two stations rank fourth and fifth in number of individuals. However, station 15 which is 84 percent sand

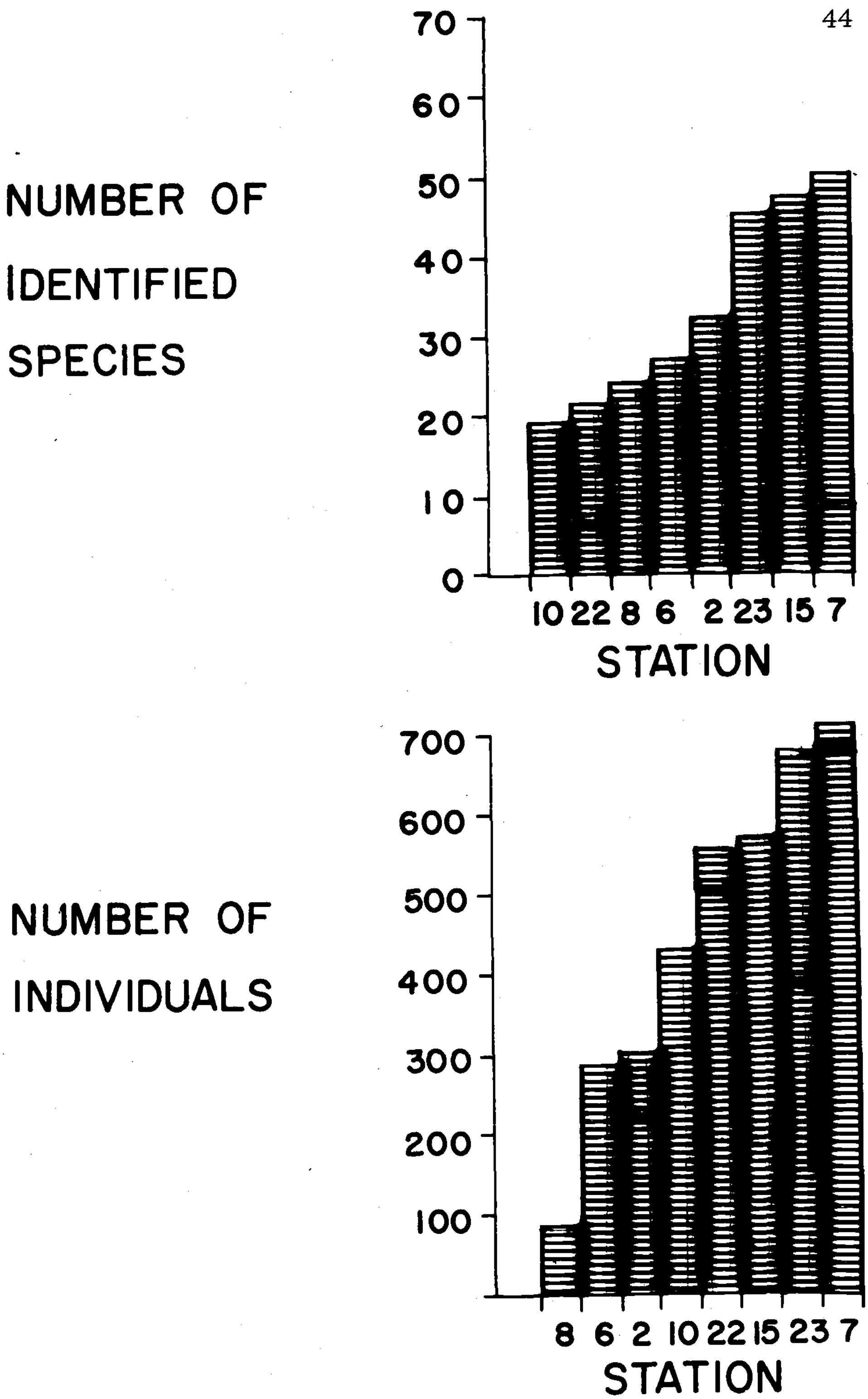


Figure 7. Total number of identified species and individuals of molluscs, ophiuroids and cumaceans per two meters^2.

is second in total number of identified species and third in total number of individuals. A comparison between rankings based on species and on individuals demonstrates that only the sand stations, 10 and 22 shift rank in relation to the others.

The distribution of species among the major taxonomic groups at each station is shown in Figure 8. Over 90 percent of the number of individuals at each station are either polychaetes or molluscs. Crustaceans and echinoderms comprise a small part by number of the total fauna. Animals not belonging to these four major groups make up less than one percent of the total fauna by numbers. Except at station 8, the molluscs can be seen to make up a significant percent of the total number of individuals at each station. The number of individuals in each of the major groups by station is shown in Table 5.

A total of 82 species of molluscs, cumaceans, and ophiuroids were identified in this study. There were four species of scaphopods, 31 species of bivalves, 30 species of gastropods, ten species of cumaceans, and eight species of ophiuroids. The identified species are listed by family and station in the Appendix. For statistical analysis each of these plus six additional species and one group for decalcified individuals, of which there were few, were given a code number (Table 6).

Of the three groups under major consideration the molluscs

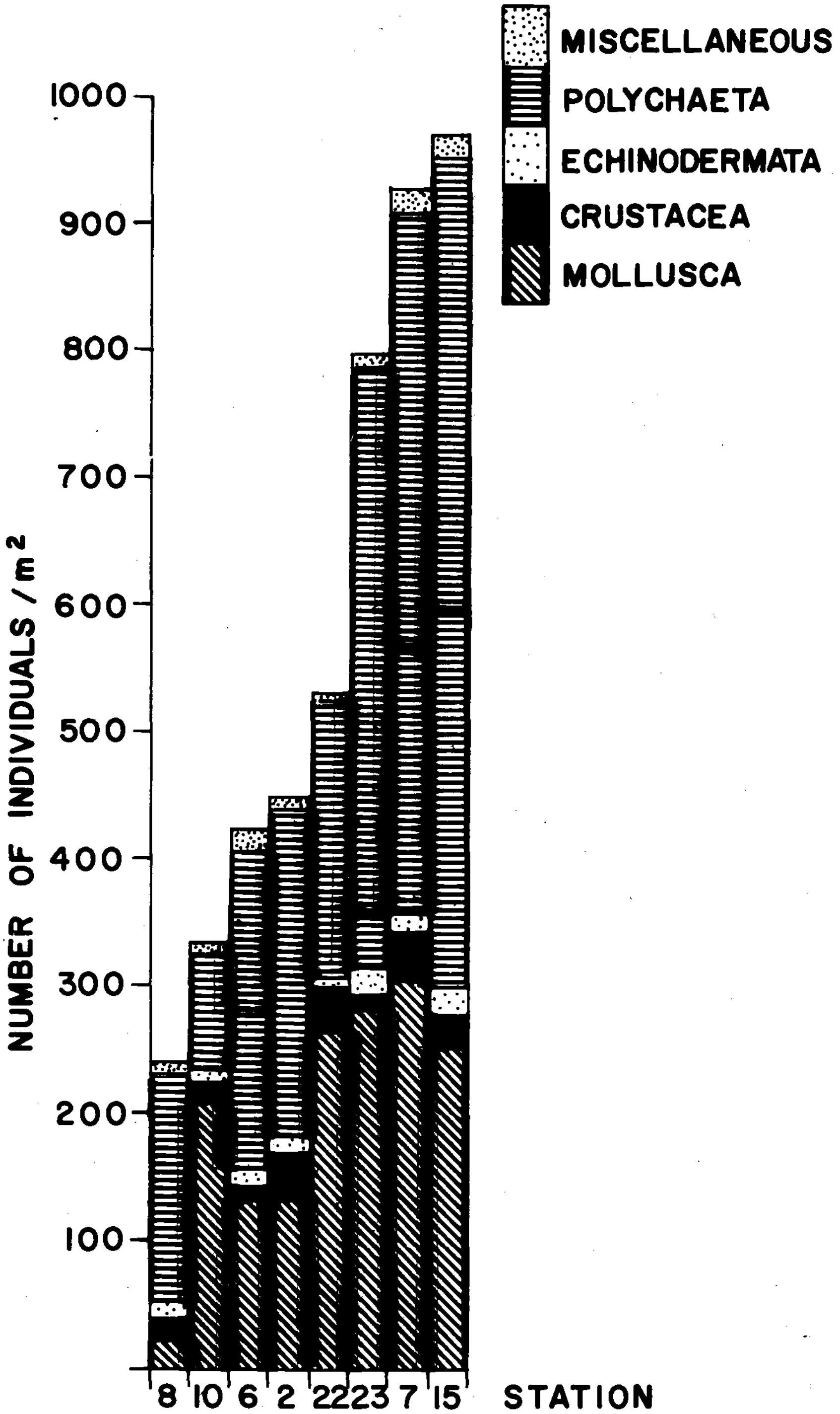


Figure 8. Distribution of the total number of individuals by major taxa.

Table 5. Number of individuals per $meter^2$ by major taxa.

Station	Pelecypoda	Gastropoda	Scaphopoda	Aplacophora	Crustacea	Echinodermata	Polychaeta	Miscellaneous	Total
2	99	13	23	3	36	13	266	6	459
6	78	31	22	10	12	7	266	4	430
7	137	69	114	8	32	17	558	13	948
8	12	3	5	9	17	9	188	4	247
10	203	4	4	-	15	8	106	3	343
15	165	70	23	-	30	14	672	14	988
22	179	79	15	-	33	3	230	4	543
23	152	44	96	2	7	19	495	6	821

Table 6. Species code list for all molluscs, ophiuroids and cumaceans.

Code Number	
1	*Acila castrensis* Hinds
2	*Nucula tenuis* Montagu
3	*Nuculana austini* Oldroyd
4	*Nuculana minuta* Fabricius
5	*Yoldia ensifera* Dall
6	*Yoldia thraciaeformis* Storer
7	*Yoldia cecinella* Dall
8	*Huxleyia minuta* Dall
9	*Crenella discussata* Montagu
10	*Megacrenella columbiana* Dall
11	*Musculus nigra* Gray
12	*Cardita ventricosa* Gould
13	*Pseudopythina* "A"
14	*Lucinoma annulata* Reeve
15	*Adontorhina cyclia* Berry
16	*Axinopsida serricata* Carpenter
17	*Thyasira bisecta* Conrad
18	*Thyasira gouldii* Philippi
19	*Nemocardium richardsoni* Whiteaves
20	*Compsomyax subdiaphana* Carpenter
21	*Psephidia lordi* Baird
22	*Macoma carlottensis* Whiteaves
23	*Macoma elimata* Dunill & Coan
24	*Tellina carpenteri* Dall
25	*Tellina salmonea* Carpenter
26	*Pandora filosa* Carpenter
27	*Lyonsia pugettensis* Dall
28	*Cardiomya pectinata* Carpenter
29	*Cardiomya planetica* Dall
30	*Odontogena borealis* Cowen
31	*Thracia trapezoides* Conrad
32	Decalcified bivalve
33	*Solariella varicosa* Mighels and Adams
34	*Solariella nuda* Dall
35	*Balcis* sp.
36	*Epitonium caamanoi* Dall and Bartsch
37	*Epitonium tinctum* Carpenter
38	*Epitonium acrostephanus* Dall
39	*Tachyrhyncus lacteolus* Carpenter
40	*Bittium minutum* Carpenter
41	*Polinices pallidus* Broderip and Sowerby
42	*Boreotrophon dalli* Kobelt
43	*Exilioidea rectirostris* Carpenter
44	*Mohnia exquisita* Dall
45	*Neptunea liratus* Gmelin
46	*Mitrella gouldi* Carpenter

Table 6. Continued.

Code Number	
47	Nassarius fossatus Gould
48	Nassarius mendicus Gould
49	Olivella baetica Carpenter
50	Olivella biplicata Sowerby
51	Oenopota sp.
52	Ophiodermella rhines Dall
53	Ophiodermella incisa Carpenter
54	Rectiplanes thalaea Dall
55	Mangelia sp.
56	Odostomia sp.
57	Turbonilla pedroana Dall and Bartsch
58	Turbonilla aurantia Carpenter
59	Acteocina culcitella Gould
60	Acteocina eximia Baird
61	Cylichna attonsa Carpenter
62	Acteon punctocaelatus
63	Unioplus macraspis
64	Amphiodia urtica
65	Ophiura sarsi
66	Ophiura lutkeni
67	Axiognathus pugetana
68	Unioplus euryaspis
69	Amphiuridae
70	Ophiura sp.
71	Campylaspis rubicunda
72	Eudorella pacifica
73	Leucon longirostris
74	Hemilamprops californiensis
75	Diastylis paraspinulosa
76	Eudorella pellucida
77	Diastylis dalli
78	Diastylis bidentata
79	Colurostylis occidentalis
80	Diastylis "A"
81	Dentalium rectius
82	Dentalium pretiosum
83	Cadulus stearnsii
84	Cadulus californicus
85	Sternaspis scutata Renier
86	Travisia brevis Moore
87	Pentamera populifera Stimpson
88	Brisaster bretifrons Agassiz
89	Allocentrotus fragilis Jackson
90	Nemertine sp A

play a predominant part. The numbers of individuals of cumaceans and ophiuroids are quite low; therefore, the molluscs were chosen to illustrate the faunal differences between stations. The number of individuals per meter^2 of the most important species and their percent occurrence in each station are demonstrated in Figures 9 and 10. The importance of a particular species at a given station was determined by ranking the species within that station by number of individuals per meter^2 and by percent occurrence within the 20 grabs taken. The ranking of each species in percent occurrence was multiplied by the corresponding ranking to give an importance value. Only those species that have a sum total of more than six individuals for the 20 grabs were considered.

The general similarity of stations 2 and 6, and stations 23, 7, and 15 can be seen in the graphs. Station 10 and station 22 are unlike any of the other stations. The low number of species at station 8 is caused by the rare species that were too low in numbers to be used.

The graphs demonstrate that a very small amount of clumping occurs. Those species that are high in numbers generally have a high percent occurrence. Fifty percent occurrence means that a species appeared in ten of the 20 grabs taken at that station. With this method a clumped distribution is quite evident. At station 10, species no. 9, Crenella discussata, has over 200 individuals and yet occurs in only 30 percent of the grabs. At station 23, species

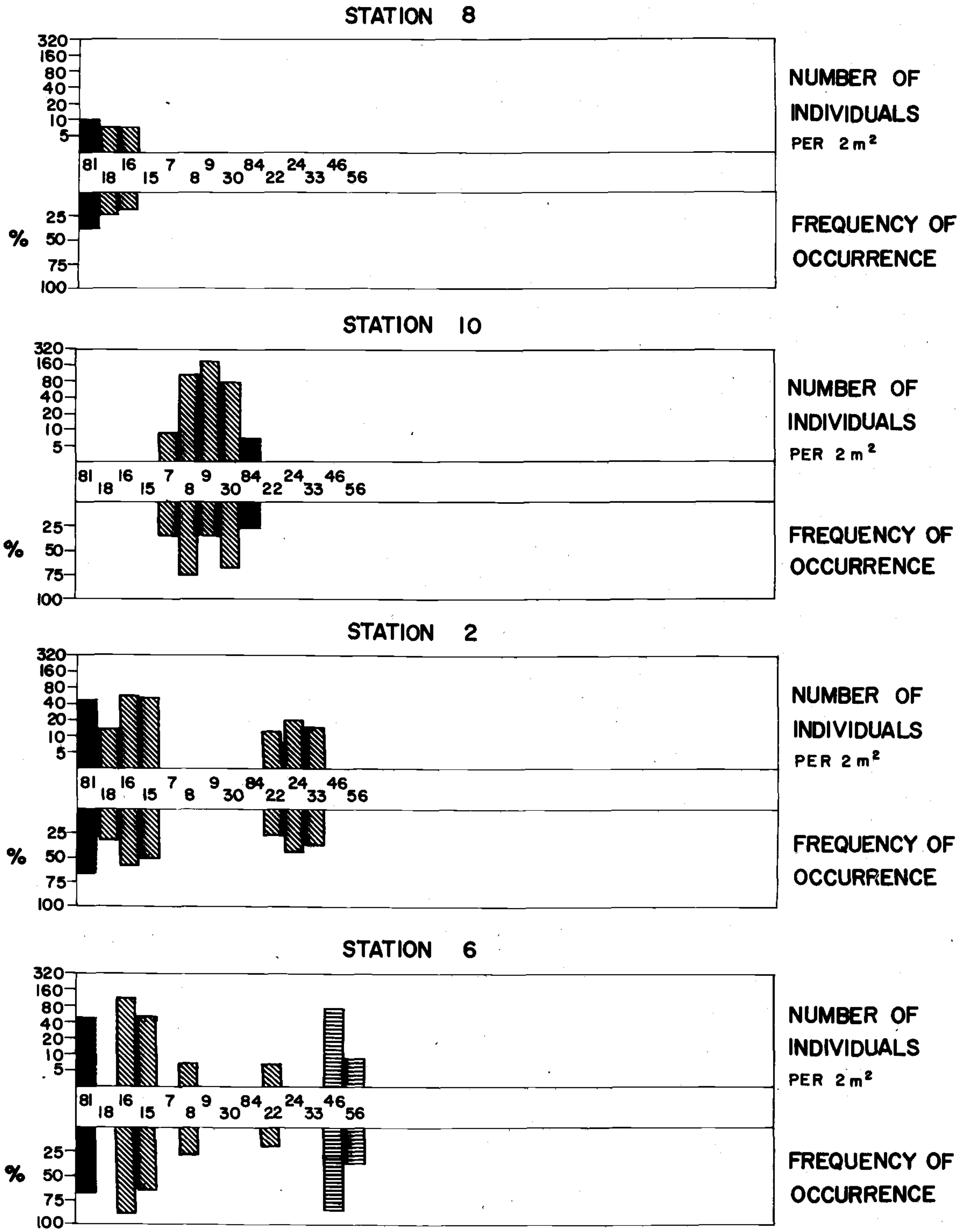


Figure 9. Distribution of major molluscan species at stations 8, 10, 2, and 6.

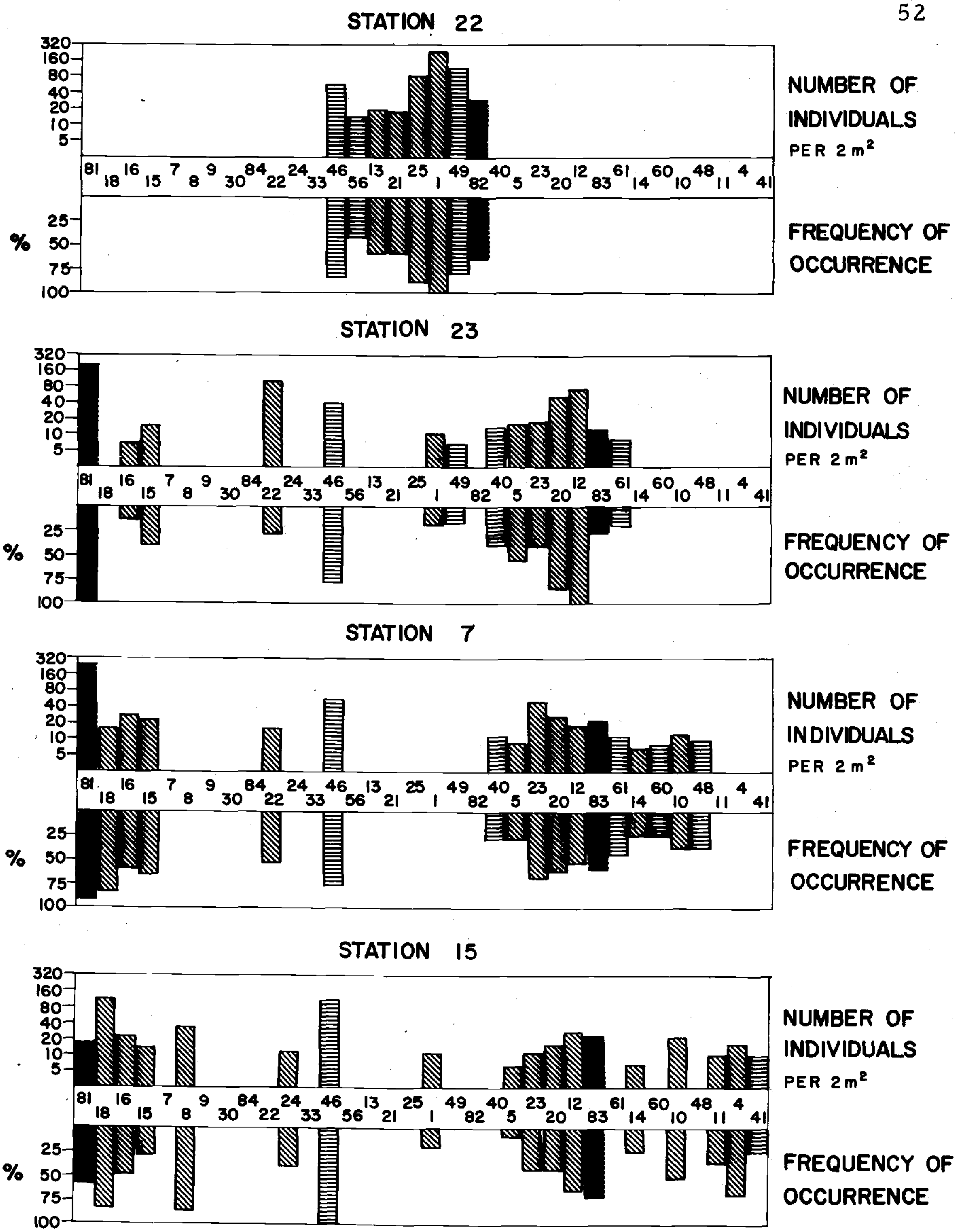


Figure 10. Distribution of major molluscan species at stations 22, 23, 7, and 15.

no. 22, Macoma carlottensis, has over 100 individuals that occur in only 25 percent of the grabs.

Mitrella gouldi, species no. 46, is an abundant, wide-spread species at stations 15, 8, 10, 2, and 6. These five stations cover a wide range of sediment types from nearly 100 percent silt at station 6 to nearly 100 percent sand at station 22. The factors determining the distribution of this gastropod seem to be something other than sediment type.

In-Station Variation

The statistical parameters provided by the AIDN Program allow us to measure the within station variation of the grabs from season to season. Because of the limitations of the program, the five grabs from each season were lumped together and analyzed as a block. This is an acceptable procedure because five grabs were originally taken as a block on each cruise to provide a reasonable estimate of the fauna at a particular station for each season.

One measure of within-station variation is the similarity index, SIM I. The mean and range of the six pairs of samples that can be compared among the four seasons at each station are illustrated in Figure 11. This is not a comparison of station-to-station variation, but only within station variation. At six of the stations the similarity is high and the range is relatively small; this indicates that there is

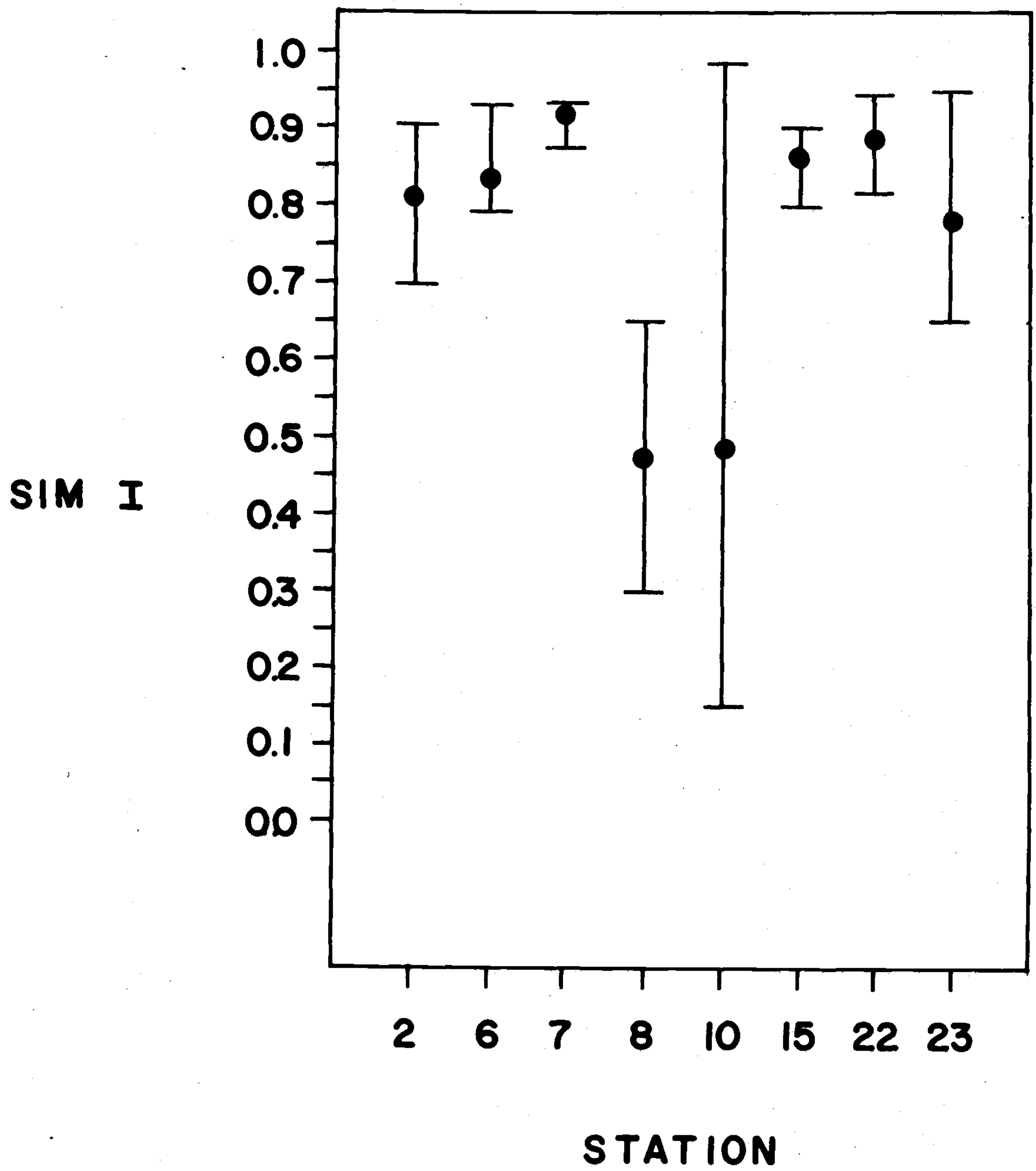


Figure 11. Within station variation of similarity index (SIMI) during the sampling period.

little seasonal variation in either the species present or the proportion of individuals of each species within these stations. However, stations 8 and 10 show a very wide range of variation and an intermediate similarity. As demonstrated previously, this variation at station 8 can be explained on the basis of a few specimens of a relatively large number of species. The large variation at station 10 is an indication of the clumping of the very abundant bivalve, Crenella discussata. Two blocks of samples which both have Crenella discussata present show a high similarity while those that do not have C. discussata show a low similarity with those that do.

These variations would be nullified if only presence-absence data were used rather than proportions of individuals, however. Presence-absence is thus less realistic and represents a loss of data. We are not only interested in what species occur but what their abundance is when they do occur.

A different manner of looking at the same fauna is given by difference index (DIF). This index varies between one and two. The greater the difference between the samples, the higher the number. The in-station variation in the difference index is plotted in Figure 12. As can be seen again the same picture that emerged with the similarity index is seen here. Station 8 and station 10 show a high difference and much variation within station. All six other stations show a very low difference and very low station variation.

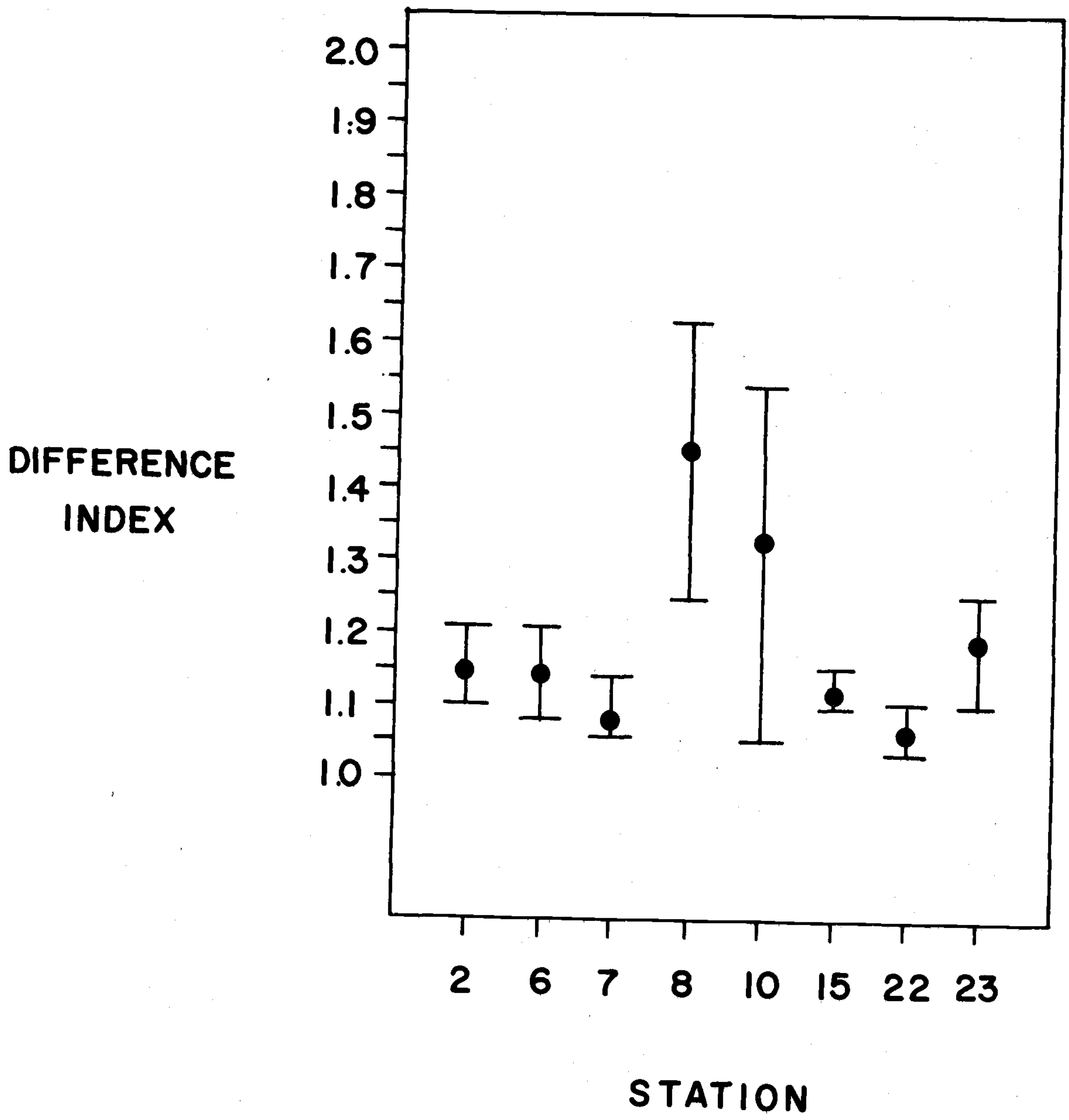


Figure 12. Withing station variation of difference index (DIF) during the sampling period.

The in-station variation in diversity Sd^2 can be seen in Figure 13. Station 8 which has very low similarity and very high difference within station shows a high diversity, i.e. a low number of individuals per high number of species. The species at station 8 are also not evenly distributed by season. The two sand stations, station 10 and station 22, show the lowest diversity and the greatest range within station. Because of the low number of species at these two stations, Sd^2 changes considerably if one species changes its proportions in a given block of samples. The clumping at station 10 would cause part of the variation here, while the placement of the mean at station 22 indicates that it is only one set of samples that has caused a large amount of variation. This was due to the low proportion of species no. 13, Pseudophythina "A," during the winter sampling period. Stations 10 and 22 have a generally low diversity (Figure 13). Station-to-station diversity will be discussed in a later section. The variation within station for difference similarity, and Simpson's Sd^2 within station are listed in Table 7.

A fourth and final method of looking at in-station variation is that of the weighted mean niche breadth. Summed for all the species in the station it is a measure of endemism. Low niche breadth for a group of samples means that the species found in those samples are found primarly in those samples, and few or none are found elsewhere. Table 8 gives the means of Levin's two measures of niche

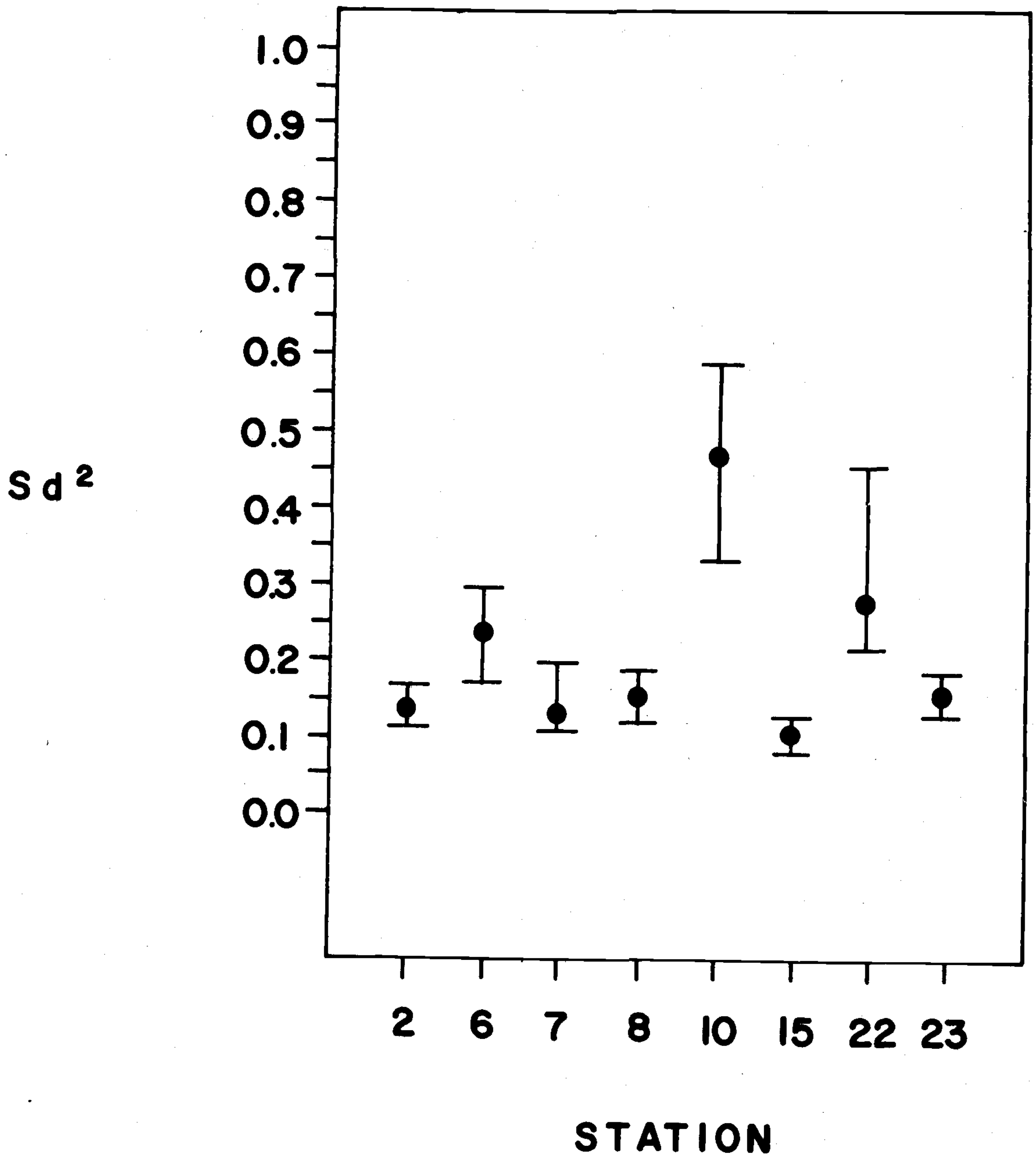


Figure 13. Within station variation of Sd^2 during the sampling period.

Table 7. Within station comparisons of DIF, SIMI, and Sd^2.

2	6	7	8	Dif	10	15	22	23
1.11	1.10	1.11	1.63		1.47	1.11	1.08	1.26
1.14	1.08	1.10	1.50		1.54	1.12	1.05	1.11
1.20	1.21	1.10	1.45		1.05	1.13	1.12	1.21
1.15	1.11	1.08	1.53		1.05	1.13	1.04	1.24
1.17	1.21	1.10	1.36		1.41	1.13	1.10	1.20
1.21	1.20	1.14	1.25		1.47	1.16	1.07	1.12
6.98	6.91	6.63	8.72	Total	7.99	6.78	6.46	7.14
1.16	1.15	1.10	1.45	$\bar{\mu}$	1.33	1.13	1.08	1.19
1.11-	1.08-	1.08-	1.25-		1.05-	1.11-	1.04-	1.11-
1.21	1.21	1.14	1.63	Range	1.54	1.16	1.12	1.2

2	6	7	8	SIM I	10	15	22	23
.872	.841	.910	.306		.198	.922	.911	.658
.916	.938	.904	.476		.158	.878	.951	.952
.695	.808	.936	.537		.992	.897	.834	.876
.849	.838	.979	.375		.972	.922	.928	.673
.840	.788	.897	.538		.290	.850	.939	.686
.743	.805	.882	.677		.258	.809	.829	.936
4.915	5.018	5.508	2.909	Total	2.868	5.278	5.392	4.781
.819	.836	.918	.485	$\bar{\mu}$	.478	.880	.899	.797
695-	788-	882-	306-		.158-	.809-	829-	658-
916	938	936	677	Range	.992	.922	951	952

				Sd^2				
.1463	.1777	.1287	.1875		.5845	.1058	.2052	.1725
.1368	.2699	.1299	.1250		.3271	.0871	.2432	.1719
.1748	.1829	.1894	.1800		.4832	.1094	.2285	.1658
.1181	.2851	.1068	.1211		.4626	.0999	.4501	.1333
.5760	.9156	.5548	.6136	Total	1.8574	.4022	1.1270	.6435
.1440	.2289	.1387	.1534	$\bar{\mu}$	.4643	.1005	.2817	.1609
118-	.178-	.107-	.121-		.327-	.087-	.205-	.133-
175	.285.	.189	187	Range	584	109	450	172

Table 8. Two measures of weighted mean niche breadth (Levins, 1968) within station by season.

Station	Season	R(2)	R (5)
2	Fall	13.0196	11.0321
	Winter	12.3893	10.5026
	Spring	14.2168	12.1772
	Summer	10.1254	8.4326
6	Fall	14.4556	12.3017
	Winter	14.4762	12.4625
	Spring	15.9335	13.8026
	Summer	14.7282	12.4691
7	Fall	14.3696	12.7228
	Winter	13.4880	11.9357
	Spring	15.1327	13.4969
	Summer	13.4443	11.9376
8	Fall	12.0808	10.5194
	Winter	11.8173	10.0470
	Spring	10.9520	9.4437
	Summer	12.2766	10.3883
10	Fall	2.6490	2.4139
	Winter	5.3696	4.1957
	Spring	5.6172	4.2377
	Summer	3.3581	2.9081
15	Fall	12.3411	10.6762
	Winter	12.0349	10.3575
	Spring	12.6427	10.9087
	Summer	12.4046	10.7166
22	Fall	5.5663	4.7890
	Winter	5.7434	4.8590
	Spring	6.6199	5.6814
	Summer	6.5033	5.4509
23	Fall	13.4888	11.8995
	Winter	12.0883	10.1627
	Spring	13.9121	12.3282
	Summer	13.9517	12.1116

breadth (McIntire and Overton, 1970). The species that occur at station 10 and station 22, the two sand stations, are found here and are not found at other stations in any great proportion. Conversely, the other six stations, the sandy silt and silty sands, show a wide interchange of species. Within each station there is little seasonal variation. The greatest variation comes at station 10; this is again due to clumping.

Station-to-Station Variation

Station-to-station variation has been analyzed by the same methods used for variation within the station. To study station-to-station relationships the seasons within a station are summed and the various indices computed on these sums. Similarity indices on a station-to-station basis are listed in Table 9. Station 2 is most similar to stations 6 and 8; station 6, likewise, is most similar to 8 and to 2. Station 8 is closely related to 7 which is in turn closely related to stations 15 and 23. Stations 10 and 22 are not closely related to any other.

The difference index points out a similar pattern (Table 10). Stations 2, 6, and 8 are closely allied and station 7 is much like 6 and 8. Station 15 and 23 are quite close and these are, in turn, closest to station 7. Again, 10 and 22 are very different from all the others as indicated by the high values; they are also very different

Table 9. Similarity index (SIMI) between stations.

Station	2	6	7	8	10	15	22	23
2	1.000							
6	.788	1.000						
7	.569	.517	1.000					
8	.777	.726	.771	1.000				
10	.002	.020	.008	.066	1.000			
15	.314	.451	.557	.574	.139	1.000		
22	.011	.079	.072	.043	.000	.173	1.000	
23	.488	.387	.885	.606	.007	.384	.064	1.000

Table 10. Difference index (DIF) between stations.

Station	2	6	7	8	10	15	22	23
2	1.000							
6	1.216	1.000						
7	1.320	1.313	1.000					
8	1.222	1.225	1.324	1.000				
10	1.943	1.922	1.910	1.859	1.000			
15	1.427	1.383	1.169	1.374	1.766	1.000		
22	1.918	1.783	1.778	1.867	1.991	1.612	1.000	
23	1.374	1.413	1.109	1.443	1.922	1.284	1.805	1.000

from each other. The differences between stations are much larger than they are within a station.

Another widely used measure of diversity is the Shannon-Weiner function $\underline{H}$. Simpson's diversity index Sd^2 and the Shannon-Weiner function $\underline{H}_e$ are illustrated in Figure 14. The sand stations, 10 and 22, are the lowest in diversity. It is surprising, however, that the station with the greatest diversity is station 15, because this station has 84 percent sand. The Shannon-Weiner function shows separation of the station groups as shown by similarity and difference. Station 22 has low diversity; 7, 15, and 23 have high diversity, while 2, 6, and 8 are intermediate.

Simpson's Sd^2 gives a very similar picture with the exception that station 8 becomes second highest in total diversity. Both indices utilize the proportions of individuals and treat the data in a similar fashion.

The last measure of station-to-station difference, the weighted mean niche breadth (Table 11), delineates stations 10 and 22 as narrow and different from any of the other stations. This result is consistent with the other measures for station-to-station differences.

The station-to-station relationships for similarity and for difference are summarized in Figure 15. The most similarity and the least difference between two stations are indicated. Stations 2, 6, and 8 are a station group; 7 is closest to 2; 15 and 23 are close, and 10 and

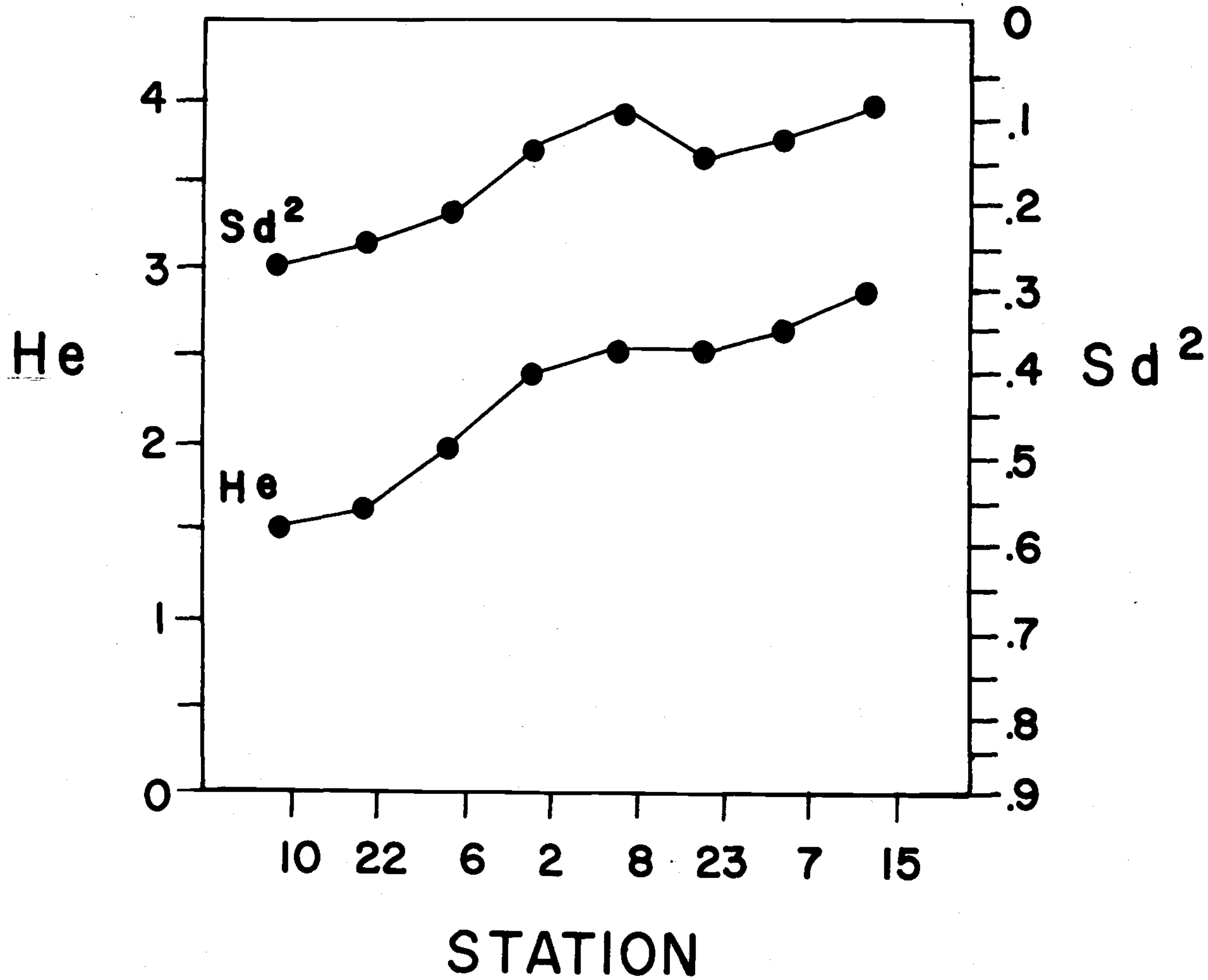
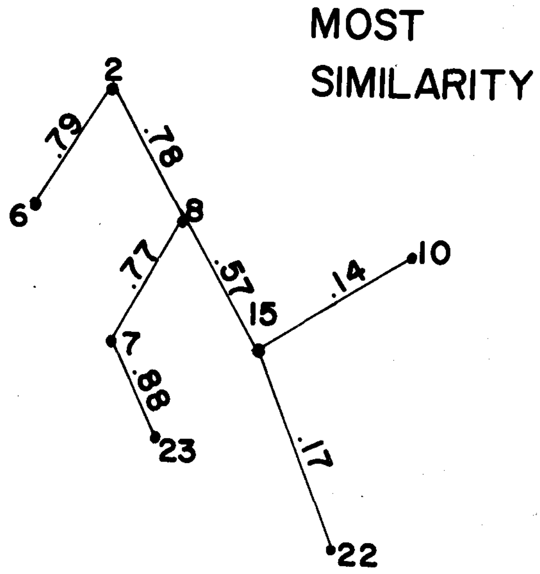


Figure 14. Comparison of the Shannon-Weiner function, $\underline{H}_e$ and Simpson's diversity index, Sd^2 for all stations.



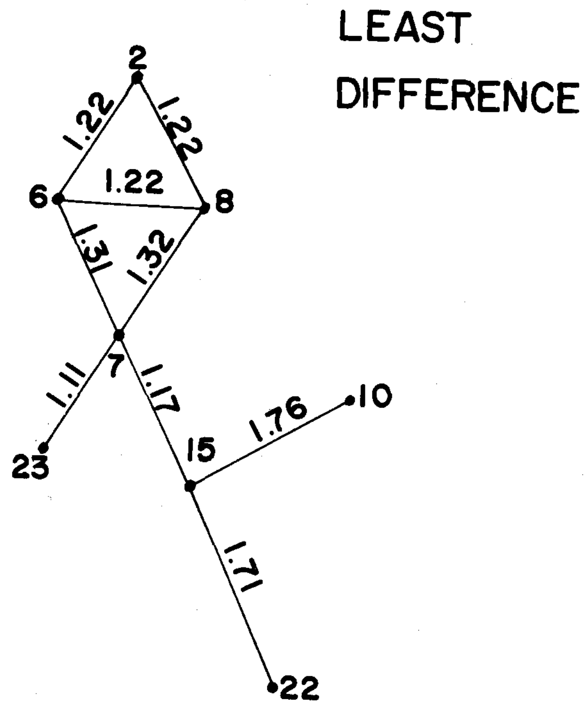


Figure 15. A two dimensional representation of the relationships between stations based on the greatest value of SIMI between stations (upper) and the lowest value of DIF (bottom).

Table 11. Two measures of weighted mean niche breadth (Levins, 1968) summed for all seasons within a station.

Station	B_2	B_5
2	3.8895	3.3520
6	4.4372	3.8338
7	4.2196	3.7775
8	3.8758	3.3702
10	1.5928	1.3676
15	3.7835	3.2931
22	1.8015	1.5734
23	4.1035	3.6329

22 are far removed from any of the others. Using the difference index, 2, 6, and 8 are identical in difference. Stations 2, 6, and 8 are also equidistant from station 7 to form an isosceles triangle. Stations 7, 23, and 15 are not very different from each other while stations 10 and 22 are very different from any of the others and from each other.

Season-to-Season Variation

By summing separately the difference and similarity indices for eight stations, we can compare seasons at all eight stations to each other (Table 12). There is no significant difference between seasons in the samples analyzed. Likewise, the similarity index shows a very high similarity between all seasons. Simpson's diversity index, the Shannon-Weiner function $\underline{H}_e$, and two measures of niche breadth for each of the seasons demonstrate that there is no significant seasonal variation in the fauna as a whole (Table 13).

To investigate the possibility that the large number of species from the three groups was masking any seasonal variation in the numbers of individuals per species, the entire set of data was run over again for the molluscs only. The results using just the molluscs are almost identical to those using the molluscs, cumaceans, and ophiuroids. The full set of data on molluscs can be found in the Appendix. In addition, the results are also almost identical

Table 12. Difference index (DIF) and similarity index (SIMI) between seasons summed for all stations.

	Fall	Winter	Summer	Spring
Fall	1.000			
Winter	1.085	1.000		
Summer	1.088	1.057	1.000	
Spring	1.064	1.110	1.101	1.000

Similarity Index

	Fall	Winter	Summer	Spring
Fall	1.000			
Winter	.875	1.000		
Summer	.877	.935	1.000	
Spring	.920	.829	.829	1.000

Table 13. Seasonal variations in Sd^2, He, B_2, B_5 summed for all stations.

Season	Sd^2	He	B_2	B_5
Fall	.0660	3.195	3.522	3.392
Winter	.0587	3.257	3.634	3.451
Summer	.0740	3.073	3.706	3.549
Spring	.0602	3.235	3.512	3.371

analyzing three grabs instead of five indicating that 0.3 m^2 is a sufficient area to sample seasonally.

Seasonal variation can also be studied by using numbers of individuals (Figure 16). The very large number of bivalves in the fall at station 10 and winter at station 23 is due to the clumped species Crenella discussata and Macoma carlottensis. At station 2 the fall peak is again caused by Macoma carlottensis. Although there is some variation in number, no pattern can be seen.

Standing Stock

This investigation, like many others in benthic synecology, has as one of its primary aims the evaluation of the standing stock as a food source for demersal fishes. Biomass was divided into edible and unedible fractions to better assess food supply available to the fishes. Data from preliminary stomach analysis of the Dover Sole, Microstomus pacificus at Sea Grant stations 2 and 6 aided in determination of food fractions. The edible portion of the infauna consists of all the infauna minus the echiurids, holothurians, echinoids, and burrowing anemones. The total wet weight of the edible portion, by season, is given in Figure 17.

Station 10 ranks fifth in number of individuals; but it supports the lowest total wet weight biomass of fauna. At this sand station, most of the animals are small, and the large number of bivalves

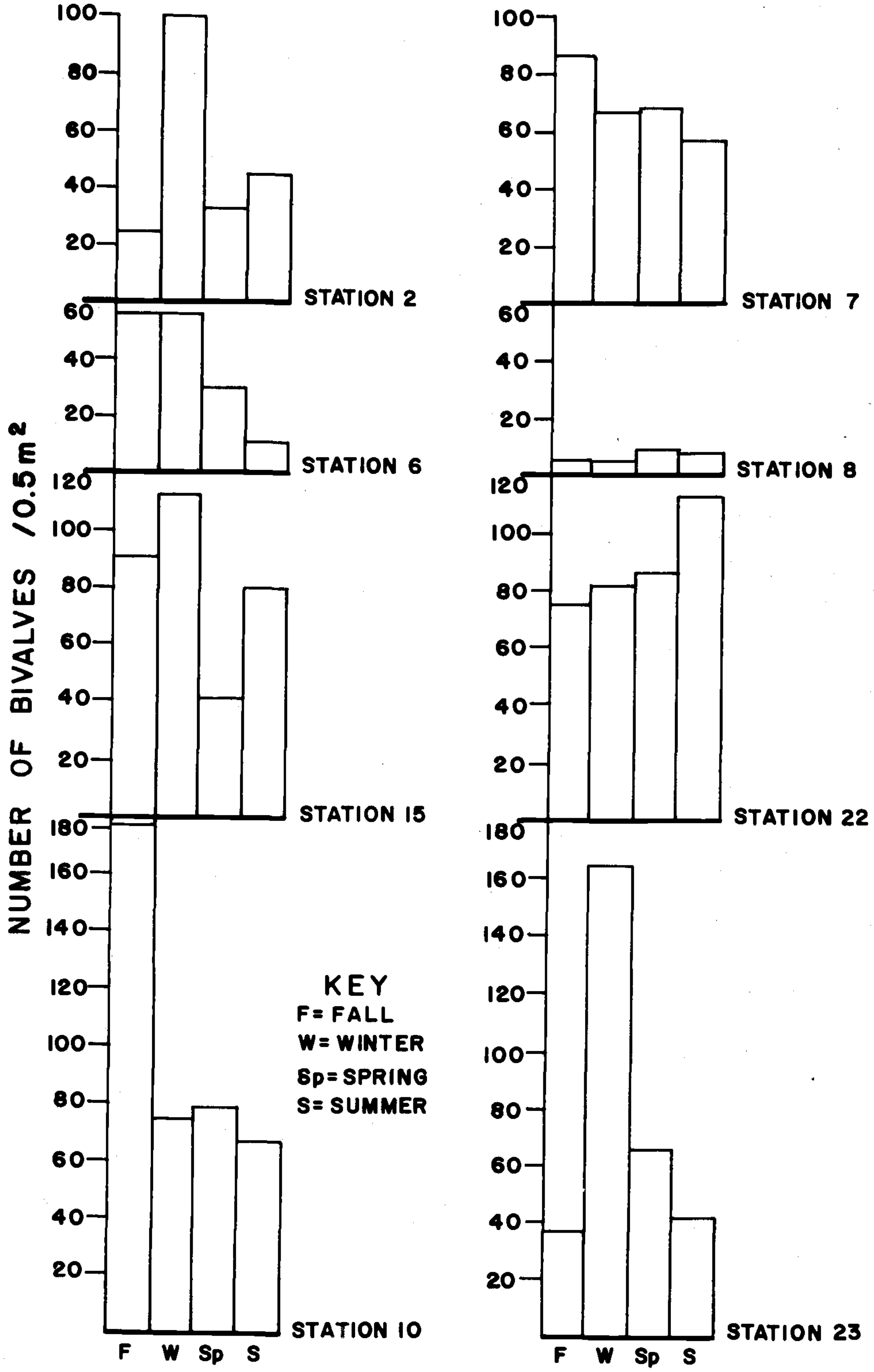


Figure 16. Seasonal variation in the number of bivalves for all stations.

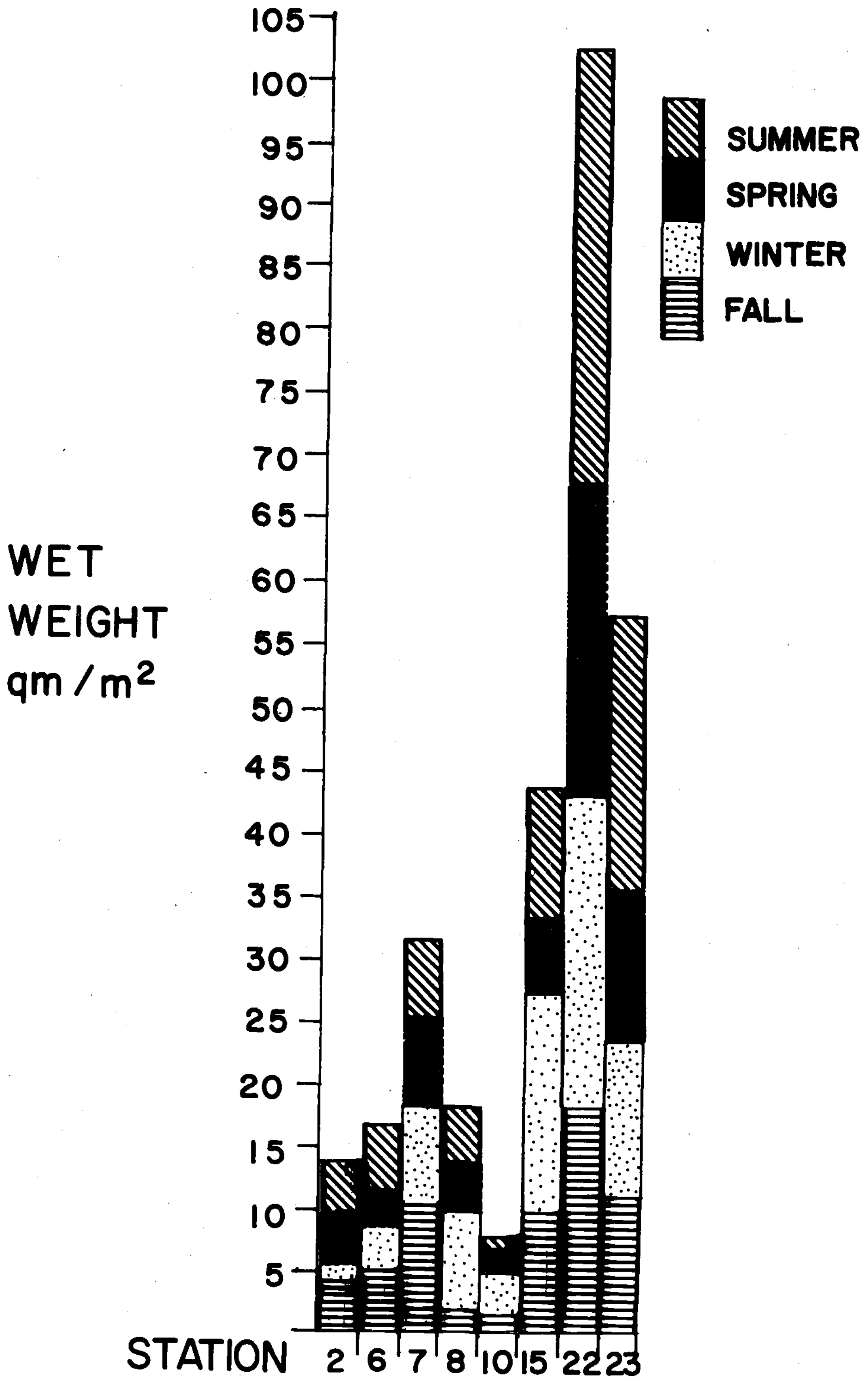


Figure 17. Wet weight in grams per meter^2 of the edible fraction of the biomass within all stations.

present are very thin-shelled. Because of the very large fraction of molluscs in the sample, station 22 ranks fourth in number of individuals but supports the greatest biomass. This is due to Acila castrensis, the dominant bivalve at this station, which is quite large and heavy-bodied. No seasonal pattern could be demonstrated in the wet weight biomass.

The ash-free dry weight standing stock (Figure 18) is much the same as that of wet weight. However station 10 ranks relatively higher than stations 2, 6, and 8 due to the large molluscan fraction. Molluscs have a higher conversion to ash free dry weight than echinoderms. Again, there seems to be no seasonal pattern.

Total ash free dry weight of all animals contained in the grabs is shown by major taxa in Figure 19 and Table 14. There is a very large increase in ash free dry weight at stations 2 and 8 due to the presence of a large echinoid, Brisaster latifrons. A large proportion of the ash free dry weight is comprised of molluscs at stations 7, 15, 22, and 23. The closely related stations 2, 6, and 8 have a large fraction of their biomass as echinoderms. The echinoderm fraction appears large at station 10 becuase the large number of bivalves are very small. The presence of a few large echinoids greatly influences the biomass.

The edible fraction of the biomass (wet weight) illustrates the lack of seasonal variation in the biomass (Figure 20). There are

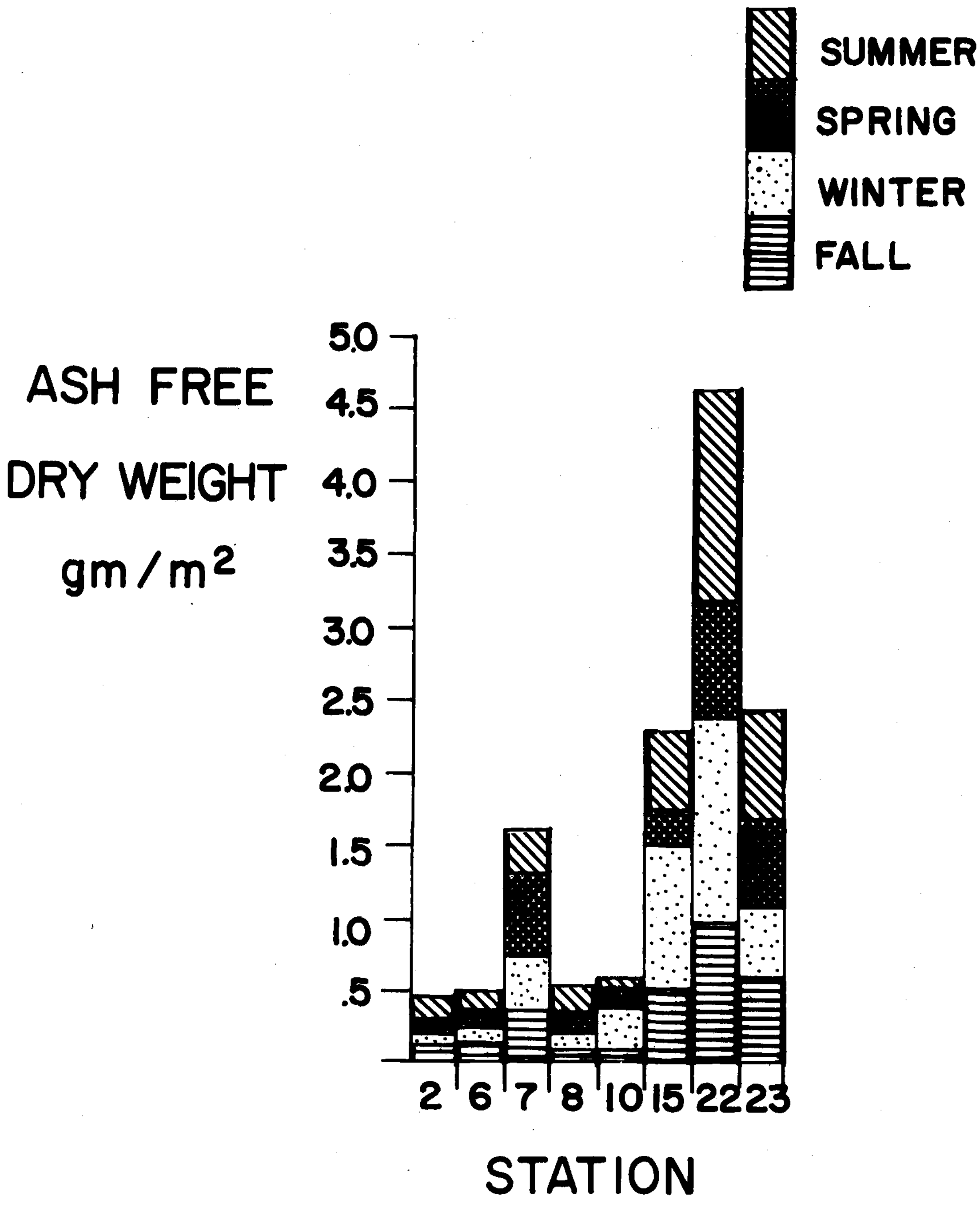


Figure 18. Ash free dry weight in grams per meter^2 of the edible fraction of the biomass within all stations.

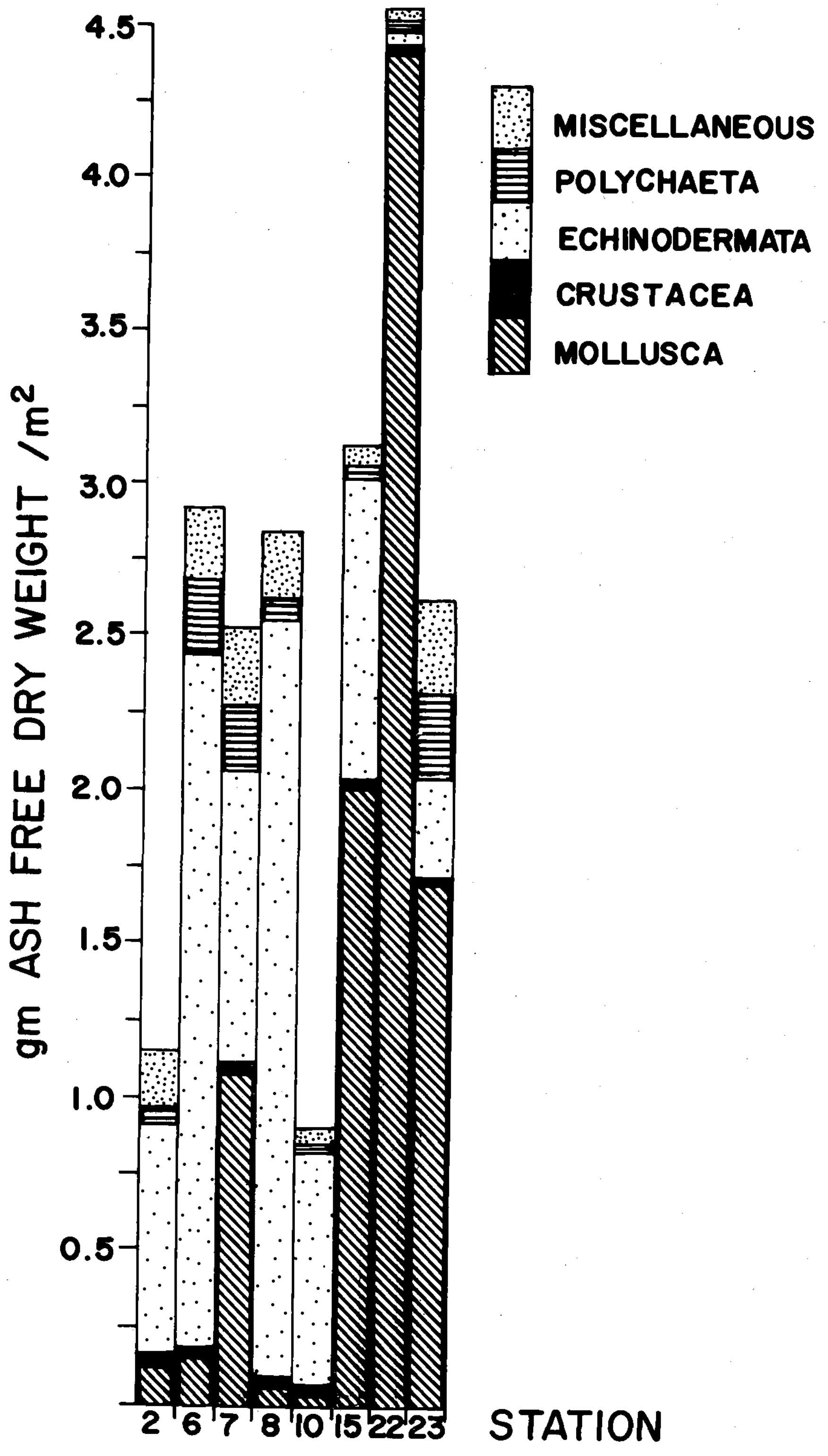


Figure 19. Total ash free dry weight in grams per meter^2 of the major taxa by station.

Table 14. Ash free dry weight in grams per meter^2 of the major taxa by station.

Station	Polychaeta	Echinodermata	Crustacea	Mollusca	Miscellaneous	Total
2	0.1395	0.7858	0.0043	0.1567	0.0368	1.1231
6	0.1712	2.2863	0.0083	0.2018	0.2214	2.8889
7	0.1745	1.0214	0.0046	1.0990	0.2043	2.5038
8	0.1879	2.4694	0.0030	0.0667	0.0710	2.7977
10	0.0345	0.7807	0.0046	0.0476	0.0381	0.9055
15	0.0814	0.9337	0.0041	2.0870	0.0572	3.2634
22	0.0449	0.0070	0.0059	4.4963	0.0174	4.5716
23	0.3023	0.3061	0.0011	1.7433	0.2529	2.6058

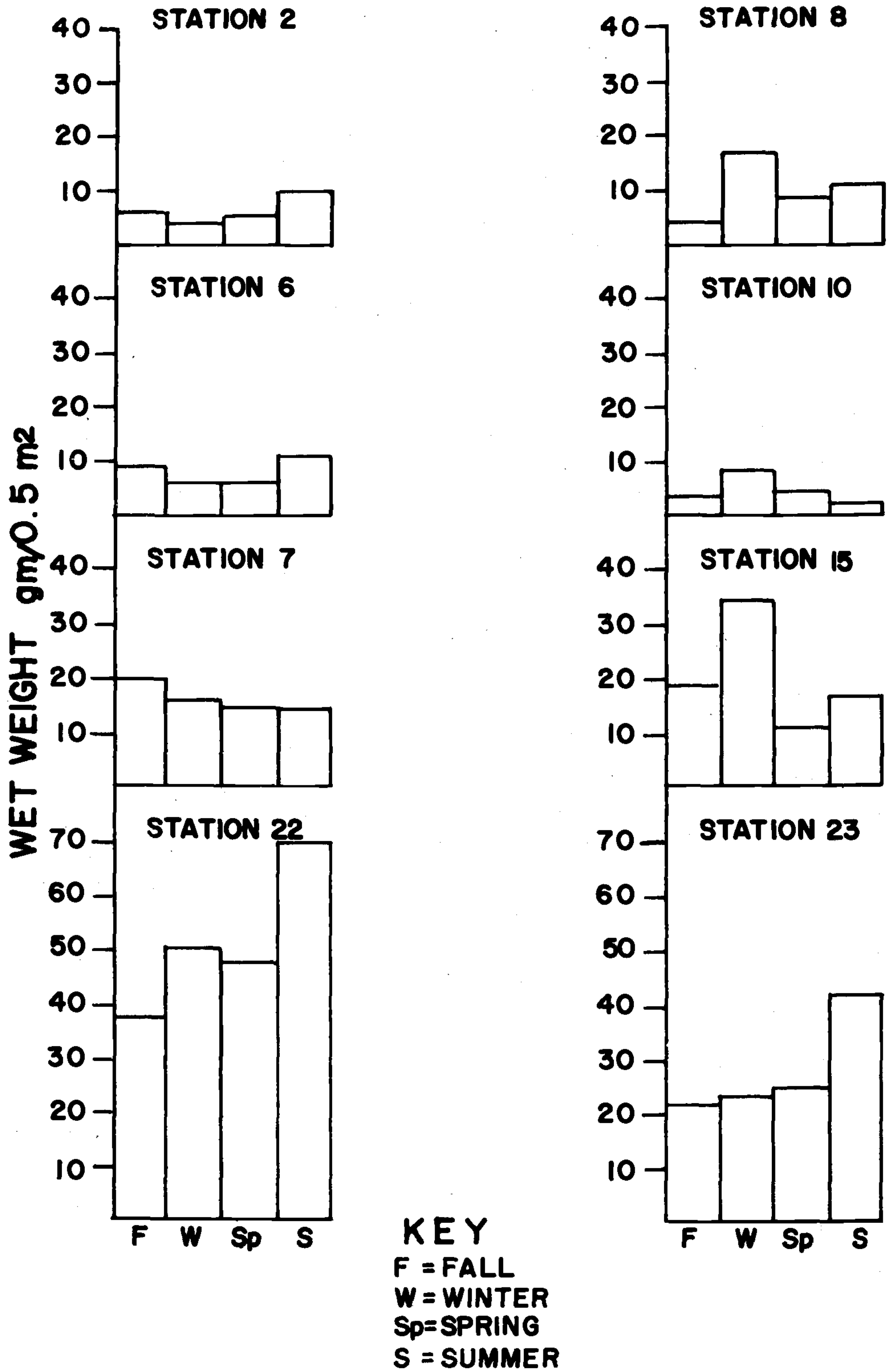


Figure 20. Seasonal variation in grams per meter^2 of the wet weight of the edible fraction of the biomass.

anomalies in the seasonal pattern that can be explained by the presence of some large animal in one or two grabs. At station 10 the large winter weight was caused by three large ophiuroids, *Ophiura sarsi*. At station 15 the winter variation is caused by two large bivalves of the species *Cardita ventricosa*. The summer peak at station 23 is due to three large polychaetes of the species *Travisia brevis*. These anomalies are also demonstrated by ash free dry weight (Figure 21). Nevertheless, there seems to be no consistent seasonal pattern in either the wet weight or the ash free dry weight for biomass.

Factor Analysis

R Mode

In the R mode of factor analysis 15 factors were originally extracted which explained 75.8 percent of the total variance. Of these 15 factors the first six accounted for 46.2 percent of the total variance. Beyond the sixth factor there was a gradual decrease in the percent variance explained by each of the succeeding factors, all contributed less than four percent of the total variance. Table 15 shows the eigenvalue, the percent of the total variance explained, and the cumulative percent of the total variance for each of the 15 factors. The first six factors were chosen for rotation and interpretation. Four distinct species groups resulted from varimax rotation (Table 16).

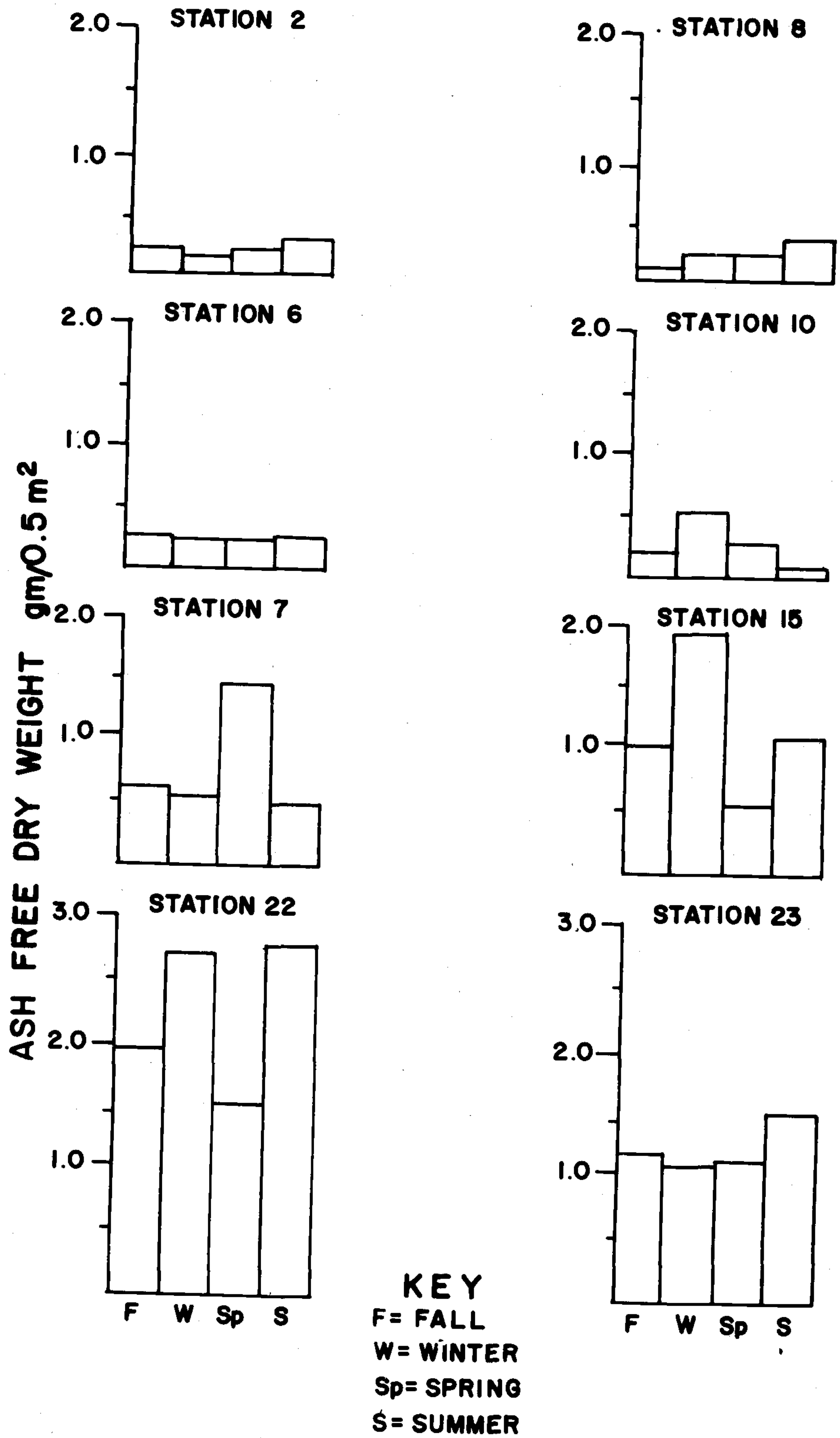


Figure 21. Seasonal variation in grams per meter^2 of the ash free dry weight of the edible fraction of the biomass.

Table 15. The 15 factors extracted by R mode factor analysis: eigenvalue, percent total variation explained, and cumulation percent total variation by factor.

Factor	Eigenvalue	Percent	Cumulative Percent
1	4.69543	13.41551	13.41551
2	3.55251	10.15002	23.56553
3	2.50754	7.16440	30.72992
4	2.23332	6.38093	37.11085
5	1.85996	5.31417	42.42502
6	1.67686	4.79104	47.21606
7	1.46045	4.17271	51.38877
8	1.37969	3.94198	55.33075
9	1.17003	3.34294	58.67369
10	1.11976	3.19932	61.87301
11	1.07019	3.05769	64.93070
12	1.01390	2.89684	67.82755
13	.98118	2.80337	70.63092
14	.95863	2.73894	73.36985
15	.85493	2.44266	75.81251

Table 16. The four species groups extracted by R mode factor analysis.

Code	Species	FACTORS I	II	III	IV	V	VI
10	*Megacrenella columbiana*	0.57	0.19	0.05	-0.14	-0.47	0.13
18	*Thyasira gouldii*	0.66	0.16	-.04	-0.06	-0.34	-0.09
40	*Bittium minutum*	0.52	0.20	-0.03	-0.14	0.25	-0.30
83	*Cadulus stearnsii*	0.52	0.30	-0.29	-0.09	0.16	0.07
01	*Acila castrensis*	-0.47	0.68	0.18	-0.24	-0.08	-0.06
25	*Tellina salmonea*	0.44	0.60	0.26	-0.21	-0.07	-0.09
46	*Mitrella gouldi*	0.39	0.55	-0.08	0.02	-0.26	0.09
49	*Olivella baetica*	-0.43	0.69	0.12	-0.26	-0.13	-0.05
82	*Dentalium pretiosum*	-0.38	0.56	0.21	-0.21	-0.08	-0.10
12	*Cardita ventricosa*	0.29	0.22	-0.50	0.05	0.24	0.32
11	*Musculus niger*	-0.03	-0.05	-0.57	0.26	-0.27	-0.21
22	*Macoma carlottensis*	0.02	0.23	-0.69	-0.09	0.22	0.08
81	*Dentalium rectius*	0.34	0.17	-0.58	0.18	0.37	-0.14
08	*Huxleyia minuta*	0.13	-0.39	0.13	-0.65	-0.10	0.17
09	*Crenella discussata*	-0.02	-0.32	-0.05	-0.65	0.01	-0.06
30	*Odontogena borealis*	-0.04	-0.47	0.08	-0.72	0.06	0.07
84	*Cadulus californicus*	-0.05	-0.28	-0.18	-0.53	-0.18	-0.22

Species Group I. Species group I is most clearly represented at station 7. It is only at this station that all four of these species occur in any abundance. These species occur less abundantly at station 15 and station 23. These three stations are the only stations at which these four species occur.

Species Group II. Species group II is clearly representative of station 22. Three of the five species, Dentalium pretiosum, Olivella baetica, and Tellina salmonea are found only in station 22. Acila castrensis is found at stations 7, 15, and 23 also, but in much lower numbers. Mitrella gouldi is very widely scattered and abundant at four stations (see Figures 9 and 10). It has, however, a very high frequency of occurrence at station 22 (85%) and is quite abundant with 23 individuals per meter^2. These five species are the five most abundant species at station 22.

Species Group III. Species group III is most nearly representative of station 23, but like those species that loaded on factor 1, these species also are found to a lesser degree at stations 7 and 15. The three species, Cardita ventricosa, Macoma carlottensis, and Dentalium rectius, are found in abundance at station 23, while the fourth species, Musculus niger, has only six individuals at station 23. At the very similar station 15 there are ten individuals present; however, station 15 has very low numbers of species 22, Macoma carlottensis. Stations 15 and 23 are very close to station 7 although they differ slightly from station 7 in some of their components.

Species Group IV. Three of the four species in this group, Crenella discussata, Odontogena borealis, and Cadulus californicus, are found only at station 10. The fourth species, Huxleyia minuta, although found at other stations, is abundant only at station 10. The separateness of this group is seen by the low loadings, or their reversed sign within a loading, to all other factors. Species group II has high positive loadings in factor 2, while species group IV has high negative loadings in factor 2.

Stations 2, 6, and 8 had no species group particular to them possibly because of the low numbers of species and the relatively low number of individuals. Their dominant fauna, Axinopsida sericata, Thyasira gouldi, and Dentalium rectius, also occur to a lesser degree at other stations. If a wider range of taxonomic material was used in the R mode factor analysis, perhaps a species group ascribable to these stations would become evident.

Q-Mode

The Q mode of factor analysis was originally run for 160 samples utilizing 89 species (Appendix 2) in combination with the 17 environmental variables. The results, using all the species and the environmental factors, explained 86.8 percent of the total variance; however, 55.7 percent was explained by the first factor and an additional nine percent by the second factor. Because this was impossible to interpret meaningfully, the Q mode was run again minus the environmental factors to make it conform to the study of Lie and Kelly (1970). Four factors were selected for rotation and interpretation. These four factors explained 62.3 percent of the total variance; 23.3 percent of this total variance was still ascribable to factor 1. However, the results were amenable to interpretation.

A significant number of grabs, greater than 50 percent at each station, show a high loading to the first factor at stations 2, 7, 15, and 23 (Table 17). A number of grabs within these stations also have significant loading to factor 2. These two factors are thought to represent the silty-sand, sandy-silt stations that lie between stations 22 and 10. The only station that has shown a significant loading at all to factor number 3 is station 22. At this station 75 percent of the grabs show a high loading to factor number 3. No other sample at any station shows a high loading to this factor.

Factor number 4 has significant loadings only within station 10. Sixty percent of the grabs taken at station 10 have a factor loading greater than ±0.5 to this factor. Only one other grab at the other seven stations shows a significant loading to this factor; this is grab number 65 at station 8 which shows a loading of 0.58 to factor number 4. There is no explanation for this except only three individuals of the 89 species studied were found in this sample. Only 40 percent of the

Table 17. Results of Q mode factor analysis with four factors rotated.

Station	Sample Number	I	II	III	IV
2	3	.53	.78	-0.11	-0.09
	5	,54	,55	-0.13	-0.10
	6	.53	-0.31	-0.33	-0.31
	7	.52	.44	-0.14	-0.09
	9	.53	.36	-0.01	-0.15
	10	.57	.05	-0.31	-0.20
	11	.51	-0.29	-0.24	-0.22
	12	.59	.25	-0.32	-0.30
	13	.52	-0.35	-0.25	-0.27
	16	.54	.77	-0.12	-0.07
	18	.53	.24	-0.18	-0.08
Station 6	23	.52	-0.38	-0.27	-0.32
	26	.53	-0.48	-0.29	-0.27
	28	.56	-0.37	-0.26	-0.16
	30	.51	-0.23	-0.16	-0.18
	31	.56	-0.39	-0.31	-0.36
	32	.53	-0.30	-0.09	-0.23
	34	.53	-0.30	-0.24	-0.28
	36	.56	-0.61	-0.17	-0.09
Station 7	41	.55	.42	-0.16	-0.14
	42	.58	.54	-0.19	-0.15
	43	.58	.47	-0.20	-0.07
	44	.54	-0.09	-0.14	-0.08
	45	.52	.00	-0.11	-0.06
	46	.58	.40	-0.18	-0.18
	47	.55	.39	-0.14	-0.12
	50	.55	.40	-0.17	-0.05
	51	.58	.30	-0.20	-0.09
	52	.62	.41	-0.23	-0.06
	53	.54	-0.07	-0.17	-0.10
	54	.56	-0.08	-0.19	-0.20
	55	.58	.48	-0.20	-0.16
	57	.51	-0.16	-0.15	-0.09
	58	.57	.40	-0.15	-0.04
	59	.55	.32	-0.10	-0.09
Station 8	65	.42	-0.08	.07	.58
	69	.54	.78	-0.12	-0.09
	78	.50	.36	-0.10	-0.03

Table 17. Continued.

Station	Sample Number	I	II	III	IV
10	83	.45	-0.16	.00	.53
	86	.47	-0.14	.03	.73
	87	.43	-0.08	.09	.73
	88	.42	-0.07	.08	.58
	89	.46	-0.01	.03	.63
	90	.43	-0.07	.09	.70
	91	.42	-0.07	.08	.62
	92	.45	.01	.02	.53
	93	.41	-0.08	.09	.62
	94	.44	-0.08	.09	.84
	95	.44	-0.07	.08	.63
	98	.40	-0.08	.08	.50
Station 15	101	.59	.31	-0.22	-0.09
	102	.50	-0.01	-0.11	.06
	103	.61	.27	-0.21	-0.13
	106	.50	-0.06	-0.12	-0.04
	107	.51	-0.04	-0.08	.11
	109	.54	-0.03	-0.11	-0.01
	110	.50	.00	-0.08	.08
	112	.61	.51	-0.20	-0.07
	113	.58	.62	-0.13	-0.07
	115	.52	.01	-0.00	.04
	120	.52	-0.03	-0.10	.28
Station 22	121	.44	-0.07	.66	-0.15
	122	.52	.34	.47	-0.20
	123	.46	-0.04	.55	-0.12
	126	.50	-0.09	.33	-0.20
	127	.46	-0.09	.77	-0.22
	128	.45	-0.08	.80	-0.21
	129	.44	-0.06	.79	-0.18
	130	.47	-0.10	.81	-0.24
	131	.46	-0.05	.53	-0.13
	132	.47	-0.11	.75	-0.22
	133	.44	-0.06	.57	-0.13
	135	.45	-0.08	.70	-0.18
	136	.46	-0.09	.62	-0.15
	137	.44	-0.09	.60	-0.14
	138	.48	-0.12	.56	-0.05
	140	.43	-0.11	.54	-0.13

Table 17. Continued.

Station	Sample Number	I	II	III	IV
23	142	.55	.51	.02	-0.12
	143	.56	.69	-0.14	-0.12
	144	.57	.47	-0.16	-0.10
	145	.52	.46	-0.10	-0.07
	146	.55	.41	-0.16	.03
	147	.52	-0.01	-0.04	-0.13
	148	.59	.33	-0.21	-0.08
	149	.53	-0.11	-0.12	-0.16
	150	.52	-0.07	-0.11	-0.11
	151	.53	-0.04	-0.16	-0.09
	154	.54	.39	-0.15	-0.01
	155	.55	.44	-0.13	-0.10
	156	.51	-0.16	-0.13	-0.06
	159	.52	-0.07	-0.08	-0.03
	160	.51	-0.16	-0.13	-0.02

grabs at station 6 show a high loading to any factor and this is to factor 1. Station 8 shows almost no loading with two of the 20 grabs loading on factor number 1. The lack of significant response for these two stations is again thought to be based on the low numbers of individuals and low numbers of species.

The agreement between R mode and Q mode is quite good. R mode extracted four species groups, two of which were found in the silty-sand, sandy-silt stations, one from the deep glauconite sand, station 10, and one from the beach sand, station 22. Q mode shows that by aligning the stations by species variation, the silty-sand stations show heavy loadings to two factors, factor 1 and factor 2. Where the beach sand environment, station 22, is the only station to show high loadings to factor 3, the glauconitic sand environment, station 10, shows high loadings to factor 4 and stands by itself. These three species groups represented by the nearshore beach sand, the intermediate depth silty-sand, and the deep glauconitic sand, represent three shelf communities. While the two sand stations on the extremes of the depth range are consistent and distinct, the silty-sand, sandy-silt stations show intergradation with two subgroups being distinguishable; those in predominately silt area or silt-covered areas represented by stations 2, 6, and 8 and those in silty-sand areas represented by stations 7, 15, and 23. The silt stations 6 and 8 do not align with any of the factors or species groups. The interrelationships of the seasonal stations indicated by the AIDN and factor analyses are shown in Figure 22.

Regression Analysis

The 21 most abundant shelled molluscs in the samples were examined using regression analysis (Table 18). The nine environmental variables chosen for regression were depth; salinity, temperature, and dissolved oxygen of bottom water; calcium carbonate, organic carbon, sorting coefficient, percent silt, and percent sand of sediments. The remaining variables were highly correlated with one or more of the variables used and thus their use would have been redundant.

Ten of the 21 species showed significant regression with one or more variables based on the F statistic; in only seven of these were the results meaningful. The relatively high percent variation explained by salinity for *Olivella baetica*, *Acteocina eximia*, and *Cylichna attonsa* is not biologically meaningful since salinity varies little throughout all the samples. Four of the remaining seven species show a relatively low response to depth. Depth variation accounts for 16 to 39 percent of the variation in abundance. This is generally unimpressive. Species such as *Tellina salmonea* and *Odontogena borealis* are abundant species found only at station 22 and station 10 respectively. These stations are both the shallowest and deepest stations and are distinctive in regard to the sediment types, station 22

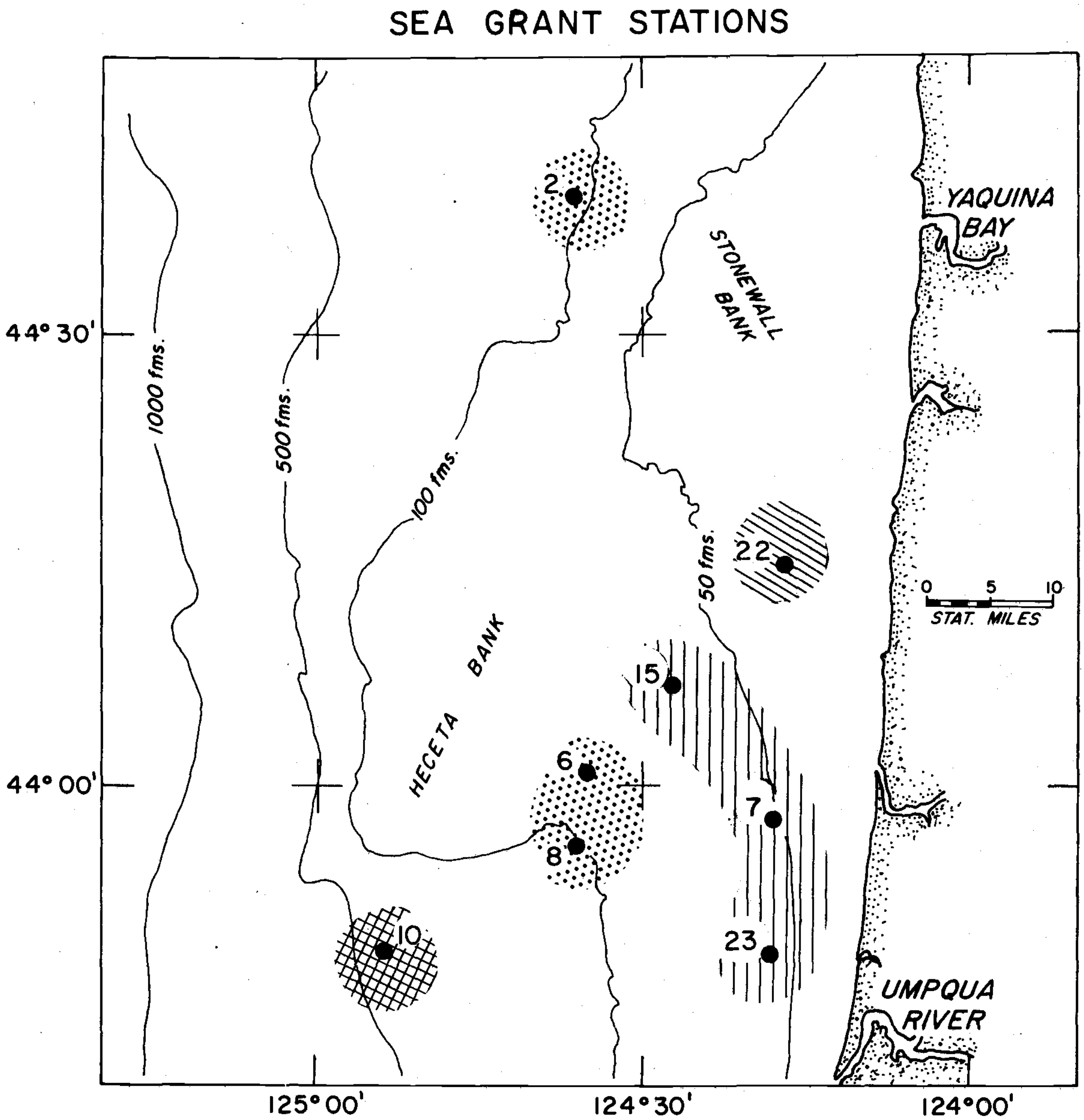


Figure 22. Interrelationships of the eight seasonal stations. One nautical mile equals 1.85 kilometers; 1 fathom equals 1.83 meters.

Table 18. Regression analysis for the 21 most abundant molluscs on nine environmental parameters.

Species	Variable	Cum. % Variation Explained	F Statistic	F.01
Tellina salmonea	Sorting	13.49	2.49	8.53
	% Sand	19.21	1.06	8.86
Odontogena borealis	S o/oo	14.59	2.22	9.07
	% Sand	17.98	4.97	9.33
Acila castrensis	Depth	34.76	15.98**	7.56
	Oxygen	42.09	3.66	7.60
Huxleyia minuta	Depth	38.86	24.16**	7.35
	% Sand	40.86	1.25	7.37
Magacrenella columbiana	Sorting	16.59	3.78	8.18
	Oxygen	18.74	0.05	8.28
Cardita ventricosa	% Sand	17.23	9.78**	7.20
	Depth	19.60	1.36	7.21
Odontorhina cyclia	Depth	16.30	9.73**	7.17
	% Silt	18.54	1.35	7.18
Axinopsida sericata	Organic Carbon	8.34	5.11	7.11
	T°C	12.07	2.32	7.12
Thyasira gouldii	Organic Carbon	18.32	10.09**	7.22
	Oxygen	21.52	1.79	7.24
Compsomyax subdiaphana	$CaCO_3$	11.78	4.81	7.39
	% Sand	14.42	1.07	7.42
Macoma carlottensis	S o/oo	26.17	7.44	8.02
	Sorting	39.73	4.49	8.10
Macoma elimata	$CaCO_3$	20.62	8.83**	7.44
	S o/oo	22.37	0.74	7.47
Bittium minutum	Depth	14.05	2.12	9.07
	Oxygen	21.35	1.11	6.93
Polinices pallidus	Sorting	13.12	1.81	9.33
	T°C	15.47	0.31	9.65
Mitrella gouldi	Organic Carbon	4.43	4.22	6.93
	Sorting	7.54	3.02	6.93
Olivella baetica	S o/oo	42.27	16.14**	8.28
	Organic Carbon	48.48	0.40	8.40
Acteocina exima	S o/oo	44.55	11.25**	8.86
	Organic Carbon	46.20	0.40	9.07

Table 18. Continued.

Species	Variable	Cum. % Variation Explained	F Variable	F.01
Cylichna attonsa	S o/oo	99.57	3735.77**	8.53
	T°C	99.86	0.31	8.68
Dentalium rectius	Depth	21.60	23.14**	6.95
	$CaCO_3$	31.63	12.17*	6.95
Dentalium pretiosum	Depth	14.30	1.83	9.65
	Salinity	33.48	2.88	10.04
Cadulus stearnsii	Sorting	38.84	19.05	7.56
		39.19	0.17	7.60

**1%
*5%

being almost 100 percent beach sand while station 10 is 84 percent glauconite. Neither of these species shows a significant correlation to percent sand or to depth. Glauconite is suspected to be of biogenic origin, formed in a reduction environment in foraminiferan testes. The size of the particles is in the same range as beach sand and the sediment particle size analysis used makes no distinction between the two. The treatment of these two sediments as the same thing in the regression analysis may in part account for the lack of significance for the sand species.

IV. DISCUSSION

The lack of seasonal changes in the abundance of infauna in the samples analyzed in this investigation is not surprising when the shelf environment is taken into consideration. The summer upwelling period and the associated high production does not appear to have a short-term, large-scale effect on the infauna of the continental shelf. There is no seasonal pattern in the sediment organic nitrogen, organic carbon or in the total carbon on the sea bottom (see Appendix I). The lack of seasonality in these and in the six sedimentary textural parameters indicates that the production and the surface waters have long-term, more widespread effect on the bottom. The effect of upwelling on production during the summer period is possibly counterbalanced by the increased runoff and flow of materials from the rivers during the winter and spring. Preliminary indications of high velocity, bottom currents (Harlett, personal communication) may also be a major factor in the lack of a discernible seasonal pattern.

The lack of seasonality in the fauna as a whole does not exclude the possibility of large-scale changes in particular species on the taxonomic groups not studied in this investigation. Thorson (1946, 1950) demonstrated the seasonality of benthic invertebrates and showed that the effect of the seasonality could be stretched over a long-term period because of differences in lengths of larval life.

Among the 35 major species of molluscs that were subjected to factor analysis, no seasonal pattern of growth of individuals or recruitment could be seen. The great majority of individuals of a given species were approximately the same size, and young were rarely found. This was particularly striking in Acila castrensis and Tellina salmonea, the two most abundant species in the beach sand community at station 22. No young of either species was found over the course of the study; although adults were found in densities of ten to 350 per square meter in over 90 percent of the grabs. If these particular species are long lived, and recruitments are scattered over a year or every other year, it is possible that recruitment could have been missed completely. Because measurements were not taken on all specimens, it is impossible to make statements about seasonal variation of individual species.

Longhurst's review (1964) of the state of benthic synecology discussed the difficulty of making comparisons between various benthic investigations. This difficulty is primarily due to the inadequacy of sample size in many previous studies and to the variation in gear used and methods of analyzing the fauna. Previous studies on the west coast of North America such as those of Shelford et al. (1935), Hartman (1955) and G. L. Jones (1964) were largely semiquantitative and the former two non-seasonal. Lie's study in Puget Sound (1968) was both quantitative and seasonal. Based on ten 0.1 m^2 grabs per season, Lie found that there was no seasonal variation in either the number of specimens per species or in the number of species. In addition, he found that there was no seasonality in the total biomass of the infauna although there was considerable variation in individual weights of each sample. The presence of large widely scattered individuals such as the echinoid Brisaster latifrons caused this. The same result had previously been demonstrated by Blegvad (1926), Steven (1930) and N. S. Jones (1952).

For a comparison of species composition, density, and total number of species, the study of Steven (1930) is inappropriate because of the paucity of molluscan fauna. Stephen (1933) determined the distribution of the major molluscan species in the North Sea based on a thousand widely scattered samples. For his offshore zone, 40 to 60 meters in depth, pelecypod densities range from three to 63 per meter^2, scaphopods from 0 to 11 per meter^2, and gastropods from 0 to 15 per meter^2. Stephen's coastal zone, however, from just subtidal to 36 meters in depth, has bivalve densities of 19 to 635 per meter^2. The numbers have little meaning, however, to the present study because of the different conditions that prevail in the two areas, the different depth range studied, and lack of sediment data. It does, however, give a general range of previously reported molluscan densities from a quantitative study.

The study of Holme (1953) in the English Channel reports densities of bivalves up to 206 per meter^2. This is less than that reported by Ford (1923) in the same area where he found 576 per meter^2. Part of the difficulty may be overestimate due to inadequate samples in the earlier study of Ford. Wigley and McIntyre (1964) in their study on the continental shelf (40 to 366 meters; 9 stations) south of Martha's Vineyard, Massachusetts found to 525 individuals per meter^2 for the molluscs and up to 5,515 per meter^2 with a mean of 2,418 per meter^2 for the total macrofauna.

Gilbert F. Jones (1964) using 355.0 25 m^2 grab samples found that the molluscs averaged 16.5% of the total fauna by species and 12% by numbers on the continental shelf (90 meters) between Point Conception and San Diego, California. He found that north of Santa Barbar the bivalve Cardita ventricosa comprised about half of the wet weight standing stock (52.4 grams per meter^2 of a total standing stock of 103.2 grams per meter^2). The mean number per meter^2 was 144. There was no apparent seasonal variation but replicate samples were not taken and in-station variation was very high. Direct comparison of the data is impossible because of the slight overlap of the depth range (15 meters).

Carey (in press) found in the quantitative study using an anchor-box dredge that at 75 meters the number of individuals ranged from just over 100 to over 4,000 per meter^2 with a mean of about 1,100 per meter^2. The difficulty of using the anchor-box dredge as a quantitative tool as shown by large in-station variation is compounded by the heterogeneity of sediment distribution. At 125 meters Carey also reported about 1,100 individuals per meter^2. The numbers at 150 meters off Newport ranged from approximately 200 to about 1800 per meter^2. The edge of the shelf showed a considerable increase with numbers ranging from 500 to almost 5,000 per meter^2, with the mean number per meter^2 for eight stations ranging from 665 to 1,943. These values are higher than those found in this study which ranged from 247 to 988 with a mean of 597 per meter^2. This is because Carey used a 0.42 mm sieve size where a 1.0 mm sieve was used in this study. Both values are lower than those found by Wigley and McIntyre (1964), and Sanders (1956) and Sanders et al. (1965) in the North Atlantic Ocean. Carey found that the infauna increased in both biomass and numbers seaward. The opposite was found in this study with the maximum coming at 75 meters and decreasing seaward to 450 meters. Numbers of individuals reached a maximum in the silty-sand stations at 100 meters and decreased seaward. The discrepancies are possibly due to differences in the sampling gear and sieve size used in the two studies.

Comparison of benthic biomass data with that of other areas is difficult since there are no standardized methods of measuring biomass. Alcohol, formaldehyde, and fresh wet weights are used as well as dry weights and ash-free dry weight. Wigley and McIntyre (1964) found that the total wet preserved weight of the macrofauna off Martha's Vineyard, Massachusetts ranged between 24.3 and 1,355.7 grams per meter^2 with an average for eight stations of 266.3 grams per meter^2. In this study wet weight ranged from 7.4 to 101.8 grams per meter^2 with an average of 36.5. This is below that found by Wigley and McIntyre on the East Coast. They found the weight of the macrofauna to be lowest at the deeper stations and highest at the shallow ones. This is true of wet weight and ash free dry weight in the present study also.

Lie (1969) in a study off the Washington coast found the ash free dry weight at 37 stations between 12 and 329 meters varied from 0.47 to 6.67 grams per meter^2 with a mean of 1.29 grams per meter^2. At 70 percent of his stations the standing crop was less than 2.0 grams per meter^2. This is considerably less than that reported by Sanders (1956) in Long Island Sound, Barnard and Hartman (1959) off Southern California, and G. F. Jones (1964) off Southern California. Shevdsov (1964), cited in Lie (1969), reported an edible fraction of eight grams per meter^2 in the Gulf of Alaska. Lie (1969) states, however, that four stations greatly influenced the mean value given by Shevdsov. The exclusion of these stations gives a biomass of 2.7 grams per meter^2. Carey (in press) reports a biomass on the nearshore shelf of 3.9 grams per meter^2 and a biomass of 4.5 grams per meter^2 at the shelf edge. In this study the ash free dry weight varied from 0.9 to 4.6 grams per meter^2. The highest value came from the nearshore sand station and the lowest value from the deep sand station, station 10. The mean weight was 2.57 grams per meter^2. Therefore the shelf of the Pacific Northwest seems to be low in biomass when compared to the Atlantic at the same latitude. It seems strange that in an area with high surface production such as the coastal waters of Oregon the standing stock and number of benthic individuals per meter^2 is so low. This would be true if the high surface production never reached the bottom due to currents which carried it off the shelf.

The only work on benthic infaunal communities off the Northwest coast is that of Lie and Kelly (1970). Using factor analysis, an index of affinity, and Fager's recurrent group analysis (Fager, 1957; Fager and Longhurst, 1968) they delineated three communities off the Washington coast. Lie and Kelly characterize three communities lying parallel to the coast of Washington; a shallow sand community from 15 to 83 meters depth, a muddy sand community from 50 to 164 meters depth, and a deep-water mud community from 117 to 317 meters depth. These three communities have their analogues off the coast of Oregon, but there are some interesting differences. Station 22 of the present investigation would be analogous to the nearshore sand community described by Lie.

The most abundant bivalve in Lie's nearshore community (unpublished data) was Tellina salmonea. This bivalve is second in abundance in the shallow sand community at station 22; however, the next four species described in Lie's first community, Macoma expansa, Tellina buttoni, Siliqua spatula, and Axinopsida sericata, do not occur at station 22. In addition, the most abundant species at station 22 is Acila castrensis. This species is three times as abundant in terms of numbers as Tellina salmonea. The intermediate community has as its five dominant bivalves Yoldia ensifera, Axinopsida sericata, Macoma elimata, Acila castrensis, Nucula belloti, and Compsomyax subdiaphana. These six species are present to some degree at stations 7, 15, and 23. The order of abundance, however, is different. Compsomyax subdiaphana plays a major role at the three stations while Acila castrensis is present in very low numbers. At stations 7 and 23 Macoma carlottensis is the much more abundant species while Macoma elimata is most abundant at 15. These stations are located within the depth range described by Lie of 50 to 164 meters and in spite of this one, specific difference can be considered as part of his muddy-sand community.

The deep mud station described by Lie has as its five dominant bivalves, in order of abundance, Axinopsida sericata, Adontorhina cyclia, Macoma carlottensis, Thyasira gouldii, and Tellina carpenteri. At stations 2, 6, and 8, which lie within the depth range described by Lie and Kelly and are mud stations, the first four species are present in abundance while the Lie's dominant species, Axinopsida sericata and Adonthorhina cyclia are co-dominants in both station 2 and station 6. At station 8, which has a very low molluscan fauna, Thyasira gouldii and Axinopsida sericata are also the co-dominants.

Therefore, Lie and Kelly's described communities stand up quite well on the Oregon coast with exceptions of certain species changing abundance in certain communities and one, Acila castrensis, becoming dominant in a community in which it does not exist in Washington. To these three communities a fourth community is added. This community is the glauconitic sand community at 450 meters. By difference index, similarity index, and factor analysis both in Q and R modes, this community has been shown to be distinct from those already described. The glauconitic sand-silt community has as its three dominant bivalve members Crenella discussata, Odontogena borealis, and Huxleyia minuta.

In the sense that these four communities lie in bands more or less parallel to the coastline the distribution of species on the Oregon shelf can be considered as a continuum as defined by Curtis and McIntosh (1951) and Whittaker (1967, 1970).

The ecotones between these communities may be quite broad and difficult to distinguish (the objection raised by Lindroth (1935) and Stephen (1933, 1934)), but this does not eliminate these communities from consideration. The distinctiveness and broad distribution of the communities is evidenced by their presence on both the Oregon and Washington coasts. The species, however, are indeed distributed along an environmental gradient, that of depth and of particle size going from coarse to very fine sediments and in some places to coarse again. Within the limits of their distribution along physical parameters, the distribution of particular species may be based on biotic factors. The species are more highly correlated with each other than with any environmental parameters.

The results of factor analysis also indicate that a large portion of the distribution is unaccounted for by the distribution of the major community dominance considered in the analysis. Predators or prey may be more highly correlated with the species in question than are those species with high factor loadings. Species with low numbers that were not considered in the analysis may be the major reason for particular distributional patterns. Lie and Kelly (1970) found that 58.7 percent of the total variation was accounted for in R mode factor analysis by four factors. This was considerably less than was found by Colebrook (1964) for four factors in a zooplankton population. The total variance in this study that was accounted for by four factors in R mode was 71.3 percent. It appears that the benthic communities on the Oregon shelf are complex and may have a very high degree of species interaction.

V. CONCLUSIONS

There are four distinct communities on the Central Oregon shelf lying in four distinct sediment types more or less parallel to the coastline. These communities can be found in the distinct substrates of beach sand, mixed silt and sand, silt, and glauconitic sand. The fauna, when compared with the East Atlantic shelf and the shelf off Southern California, is low in number of species, number of individuals, and in biomass in spite of the high production in the surface waters over the shelf. There is no significant change in the faunal composition in numbers of biomass with season at any of the stations from 75 to 450 meters. The sediment environmental parameters such as organic carbon, organic nitrogen, and particle size show no significant seasonal change. There appears to be a high degree of species interaction that indicates complex benthic communities.

The broad findings of this investigation have use in a number of ways. The apparent lack of seasonality in the infauna and the low standing crop have broad implications for fisheries biology. The understanding of the distribution of the four communities on the Oregon shelf may be of help in understanding the distributional patterns of migratory demersal fishes. The identification and enumeration of the infauna forms a base for future work on fish stomach analysis to determine selective feedings by season, sex, or size.

Lastly, the methodology and analysis of the data shows some of the things that can be done with adequate quantitative data and points to the need for additional methods to analyze particular species in reference to their total environment including the biotic and abiotic.

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APPENDICES

APPENDIX I

SEA GRANT ENVIRONMENTAL DATA

Environmental parameter	Cruise	Stations 2	6	7	8	10	15	22	23
Depth (meters)	6810	190	145	100	197	494	104	75	104
	6901	200	146	99*	200	446*	100	73	100*
	6904	189	150	100	200	443	102	75	102
	6907	183^{+}	150	99	183	452	100	73	102
Salinity (‰)	6810	33.89	33.80	32.82	33.82	33.92	33.74	33.48	33.69
	6901	33.87	33.52	32.87*	33.82	33.90*	33.38	32.68	33.32
	6904	33.96	34.01	33.78	34.02	33.87	33.74	33.16	33.74
	6907	34.04	33.04	33.99	34.03	34.13	34.01	33.99	33.97
Temperature (°C)	6810	7.66	8.01	8.20	8.26	5.66	8.18	8.67	8.24
	6901	8.19	8.20	12.04	12.04	5.61	8.78	9.21	8.88
	6904	6.60	6.15	7.43	6.58	5.51	6.87	7.50	7.04
	6907	6.11	6.38	7.04	6.47	5.52	7.02	6.70	7.18
Oxygen (ml/l)	6810	2.49	2.31	3.15	2.54	2.39	2.13	3.87	3.12
	6901	2.98	4.13	5.61*	3.08	1.23*	4.08	5.59	4.18*
	6904	2.34	2.10	1.83	2.08	2.98	3.63	3.94	2.60
	6907	2.13^{+}	1.65	1.96	1.90	0.87	1.57	1.57	2.23
Silicates (μm/l)	6911	29	39	40	19	57	3	34	34
	7002	21	27	15	38	32	17	10	21
	6904	41	47	47	48	33	41	31	40
	6907	54	54^{+}	56	58	51	63	56	50

APPENDIX I (Continued)

Environmental parameter	Cruise	Stations 2	6	7	8	10	15	22	23
Phosphate (µm/l)	6911	1.91	2.33	3.05	2.16	2.70	1.98	1.89	3.09
	7002	2.33	3.03	2.03	3.92	1.70	2.18	1.83	2.31
	6904	2.89	3.24	3.03	3.10	2.75	2.79	2.26	2.89
	6808	2.56	2.69	2.63	2.58	2.02	2.60	2.43	2.60
Nitrates (µm/l)	6911	21.2	28.4	26.6	11.5	33.7	23.7	25.6	24.2
	7002	14.8	17.8	9.4	24.5	20.0	11.2	6.6	17.0
	6904	28.67	31.70	28.10	33.35	27.33	26.08	14.41	26.49
	6907	34.1	25.4°	33.1	33.4	32.2	34.0	31.2	31.0
% Total Carbon	6810	1.05	1.71	0.62	1.57	1.06	0.52	0.07	1.30
	6901	1.08	1.86	0.51*	1.67	1.12*	0.37	0.11	1.30*
	6904	1.21	1.48	0.65	1.94	0.75	0.44	0.18	1.40
	6907	0.81	1.89	0.76	1.56	0.49	0.46+	0.10	1.51
% Calcium Carbonate	6810	.056	.056	.093	.098	.000	.002	.023	.042
	6901	.047	.042	.032*	.102	.010*	.009	.000'	.046*
	6904	.052	.051	.046	.084	.014	.028	.028	.069
	6907	.047	.070	.014	.074	.000	.049+	.019	.028
% Organic Carbon	6810	.994	1.654	0.527	1.472	1.06	0.518	0.047	1.258
	6901	1.033	1.82	0.578*	1.568	1.11	0.361	0.110'	1.254*
	6904	1.158	1.43	0.604	1.856	0.736	0.421	0.152	1.331
	6907	.763	1.82	0.744	1.486	0.49	0.411+	0.081	1.482
Sediment	6810	1034	1885	548	1555	927	468	8	1160
Organic Nitrogen	6901	1015	1675	565*	1720	498*	446	12*	1110
µgm Nitrogen	6904	1170	1390	715	1765	656	397	11	862
gm Sediment	6907	1210	1710	667	1455	537	497	12	922

APPENDIX I (Continued)

Environmental parameter	Cruise	Stations 2	6	7	8	10	15	22	23
Folk and Ward Mean Particle Size	6010	4.76	7.14	4.22	7.70	2.66	3.33	1.66	6.48
	6901	4.37	7.12	3.57*	7.06	3.05*	2.60	2.04	6.50*
	6904	4.85	6.68	5.09	7.49	1.92	3.01	1.88⁻	5.38
	6907	4.52+	6.45	3.91	6.63+	2.76+	7.01*	1.93	3.67
Folk and Ward Sorting Coefficient	6810	3.05	2.68	2.68	3.13	2.63	2.27	0.48	3.29
	6901	2.17	2.73	1.48*	2.61	2.20*	1.27	0.44	2.52
	6904	3.24	2.91	2.88	2.79	2.39	1.40	0.45⁻	3.19
	6907	2.61+	3.11	2.20	2.06+	1.83+	2.30+	0.43	2.62
Inman Median Grain Size	6810	3.47	6.31	3.25	6.65	1.63	2.83	1.70	5.13
	6901	3.47	6.12	3.10*	6.26	2.19*	2.60	2.06	5.23*
	6904	3.49	5.37	3.95	6.63	1.59	2.74	1.89⁻	4.51
	6907	3.43+	5.68	3.24	6.25+	2.61+	2.95+	1.91	4.98
% Clay	6810	15.67	34.70	13.35	39.76	9.17	9.23	0.00	26.64
	6901	12.75	33.47	6.50*	33.81	4.98*	5.58	2.07	28.17*
	6904	16.08	27.86	17.20	38.25	7.96	5.27	0.93⁻	18.22
	6907	14.46+	25.10	9.60	29.50+	8.96+	9.04+	0.73	21.39
% Silt	6810	16.68	64.07	24.84	59.14	11.91	11.67	0.00	49.62
	6901	16.76	65.09	21.24*	64.15	27.45*	7.45	0.53	50.99*
	6904	18.92	64.53	21.50	60.46	6.40	10.66	0.35	44.62
	6907	14.82+	72.62	20.92	64.69+	6.94+	4.80+	0.51	47.30
% Sand	6810	67.65	1.22	61.80	1.14	78.91	79.10	100.00	23.75
	6901	70.49	1.44	72.26*	2.04	67.60*	86.97	97.40	20.83
	6904	64.99	7.60	51.30	1.29	84.07	84.07	98.72	20.84
	6907	70.72	2.26	69.51	5.81+	84.09+	86.15	98.76	37.15

KEY: 1+ = 6808, 1° = 6901, 1' = 6911, 1* = 7002, 1⁻ = extrapolated

APPENDIX II

LIST OF SPECIES

Phylum Mollusca
Class Scaphopoda
    Family Dentaliidae
        Dentalium rectius Carpenter
        Dentalium pretiosum Sowerby
    Family Siphonodentalidae
        Cadulus stearnsii Pilsbry and Sharp
        Cadulus californicus Pilsbry and Sharp

Class Pelecypoda
    Order Protobranchia
        Family Nuculidae
            Acila castrensis (Hinds)
            Nucula tenuis Montagu
        Family Nuculanidae
            Nuculana austini Oldroyd
            Nuculana minuta (Fabricius)
            Yoldia ensifera Dall
            Yoldia thraciaeformis Storer
    Order Prionodontida
        Family Nucinellidae
            Huxleyia minuta Dall
    Order Pteroconchida
        Family Mytilidae
            Crenella discussata (Montagu)
            Megacrenella columbiana (Dall)
            Musculus nigra Gray
    Order Heterodontida
        Family Carditidae
            Cardita ventricosa Gould
        Family Kellidae
            Odontogena borealis Cowen
        Family Montacutidae
            Pseudopythina "A"
        Family Lucinidae
            Lucinoma annulata (Reeve)
        Family Thyasiridae
            Adontorhina cyclia Berry
            Axinopsida serricata (Carpenter)
            Thyasira bisecta Conrad
            Thyasira gouldii (Philippi)
        Family Cardiidea
            Nemocardium richardsoni (Whiteaves)
        Family Veneridae
            Compsomyax subdiaphana Carpenter
            Psephidia lordi Baird

Family Tellinidae
- *Macoma carlottensis* Whiteaves
- *Macoma elimata* Dunnill & Coan
- *Tellina carpenteri* Dall
- *Tellina salmonea* Carpenter

Order Eudesmodontida

Family Pandoridae
- *Pandora filosa* Carpenter

Family Lyonsiidae
- *Lyonsia pugettensis* Dall

Family Thraciidae
- *Thracia trapezoides* Conrad

Order Septibranchia

Family Cuspidariidae
- *Cardiomya pectinata* (Carpenter)
- *Cardiomya planetica* (Dall)

Class Gastropoda

Order Diotocardia

Family Trochidae
- *Solariella varicosa* (Mighels and Adams)
- *Solariella nuda* Dall

Order Monotocardia

Family Eulimidae
- *Balcis* sp.

Family Epitoniidae
- *Epitonium caamanoi* Dall and Bartsch
- *Epitonium tinctum* (Carpenter)
- *Epitonium acrostephanus* Dall

Family Turritellidae
- *Tachyrhyncus lacteolus* Carpenter

Family Cerithiidae
- *Bittium minutum* (Carpenter)

Family Naticidae
- *Polinices pallidus* (Broderip and Sowerby)

Sub Order Neogastropodia or Stenoglassa

Family Muricidae
- *Boreotrophon dalli* Kobelt

Family Neptuneidae
- *Exilioidea rectirostris* Carpenter
- *Mohnia exquisita* Dall
- *Neptunea liratus* (Gmelin)

Family Columbellidae
- *Mitrella gouldi* Carpenter

Family Nassariidae
- *Nassarius fossatus* (Gould)
- *Nassarius mendicus* (Gould)

Family Olividae
- *Olivella baetica* Carpenter
- *Olivella biplicata* (Sowerby)

Sub Order Toxoglossa
Family Turridae
Oenopota sp.
Ophiodermella rhines Dall
Ophiodermella incisa Carpenter
Rectiplanes thalaea Dall
Mangelia sp.
Order Tectibranchiata
Family Pyramidellidae
Odostomia sp.
Turbonilla pedroana Dall and Bartsch
Turbonilla aurantia Carpenter
Family Scaphandridae
Acteocina culcitella (Gould)
Acteocina eximia Baird
Cylichna attonsa Carpenter
Family Acteonidae
Acteon punctocaelatus Carpenter

Phyllum Arthropoda
Class Crustacea
Order Cumacea
Family Lampropidae
Hemilamprops californiensis Zimmer
Diastylis pellucida Hart
Diastylis paraspinulosa Zimmer
Diastylis bidentata Calman
Diastylis dalli
Diastylis "A"
Family Colurostylidae
Colurostylis occidentalis Calman
Family Leuconidae
Eudorella pacifica Hart
Lucon longirostris
Family Nannastacidae
Campylaspis rubicunda (Lillieborg)

Phyllum Echinodermata
Class Ophiuroidea
Order Ophiurida
Family Ophiuridae
Ophiura lukeni (Lyman)
Ophiura sarsi Lutken
Ophiura sp.
Family Amphiuridae
Unioplus macraspis (Clark)
Unioplus euryaspis (Clark)
Axiognathus pugetana (Lyman)
Amphiuridae sp.

APPENDIX III

STATION TO STATION AIDN PARAMETERS BASED ON MOLLUSCAN FAUNA ONLY

SIMILARITY

Station	2	6	7	8	10	15	22	23
2	1.000							
6	.790	1.000						
7	.569	.513	1.000					
8	.802	.740	.818	1.000				
10	.002	.019	.008	.054	1.000			
15	.308	.453	.558	.604	.141	1.000		
22	.011	.080	.072	.042	.000	.173	1.000	
23	.480	.383	.886	.621	.007	.382	.065	1.000

DIFFERENCE

Station	2	6	7	8	10	15	22	23
2	1.000							
6	1.216	1.000						
7	1.320	1.313	1.000					
8	1.221	1.225	1.325	1.000				
10	1.944	1.93	1.91	1.859	1.000			
15	1.427	1.383	1.169	1.374	1.765	1.000		
22	1.918	1.783	1.778	1.867	1.991	1.712	1.000	
23	1.374	1.413	1.109	1.443	1.922	1.284	1.805	1.000

WEIGHTED MEAN NICHE BREADTH

Station	B_2	B_5
2	3.8618	3.3596
6	4.5127	3.9339
7	4.2324	3.8153
8	4.0826	3.5919
10	1.5242	1.3204
15	3.7852	3.3166
22	1.8089	1.5774
23	4.0983	3.6489

APPENDIX IV

SEASON TO SEASON AIDN PARAMETERS BASED ON MOLLUSCAN FAUNA ONLY

SIMILARITY

	Fall	Winter	Spring	Summer
Fall	1.000			
Winter	.880	1.000		
Spring	.893	.951	1.000	
Summer	.934	.852	.850	1.000

DIFFERENCE

Fall	1.000			
Winter	1.081	1.000		
Spring	1.074	1.039	1.000	
Summer	1.055	1.097	1.093	1.000

WEIGHTED MEAN NICHE BREADTH

Fall	3.546	3.417
Winter	3.679	3.496
Spring	3.791	3.653
Summer	3.556	3.438

Appendix 5. Number of Individuals per Species

Species Code

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Station 2		1		1				1		1		5		1	52	59	4	13				13		18		3		3				5	15		
Station 6			1	1	2			6							42	90		2		1	1	6						2				2			
Station 7	5	2			8			1		11	5	19		6	21	26		16		31		16	50			3	3	5			1		1		
Station 8		1	1					1							4	7		7										1				1	1		
Station 10		2					9	110	89			2																		82				1	2
Station 15	11			17	6			37		22	10	29		6	14	22		104	2	16		3	12	13		4		1							
Station 22	247					1							17								16				72							4			
Station 23	10			2	16	1				2	5	70		2	14	7		3	3	53		88	17			3		5			1		1		
Total No.	273	6	2	21	32	2	9	156	189	36	20	125	17	15	147	211	4	145	5	101	17	126	79	31	72	13	3	16	1	82	2	12	18	1	2

	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70
Station 2							2			1	5										1	1						9	2					8	
Station 6						4					46							1			8		1		1					2				2	
Station 7		1		5	12	2		2			70		9	3		5	1		1		3	2	2	1	7	11		2	2	3	1			11	
Station 8									1		3							1										5						2	1
Station 10								1	1							2												1		8					1
Station 15				5	3	6					98		2	3		3	3	1	2	1	4		1		4	2	2	11		2		2		4	
Station 22			1								45	1		87							13	5	2			3				1					1
Station 23	2			4	13	2					40			6		2			1			2	1		5	8		11		2			1	9	
Total No.	2	1	1	14	28	14	2	3	2	1	307	1	11	99		13	4	3	4	1	29	10	7	1	17	24	2	39	4	18	1	2	1	36	3

	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	Total Number
Station 2	1	1									42			3	21		2	4	1		300
Station 6	1	4									43				10	2		10		3	294
Station 7				1	1	1				1	205		22		65		12	3		16	713
Station 8		1	5								10				1	4	1	5	1	2	67
Station 10														7	2			6		3	429
Station 15		1					1			1	18		27		14		4	4		21	579
Station 22				1				1	1			29					2			6	556
Station 23					1	1				1	180		12		52	7	13	1		6	686
Total No.	2	7	5	2	2	2	1	1	1	3	498	29	61	10	165	13	34	33	2	57	3624

*No species for number 50

Appendix 6. Percent Frequency of Occurrence

Species Code

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Station 2		5		5				5		5		25		5	50	65	10	35				30		45		15		10				10	40		
Station 6			5	5	5			30							65	90		5		5	5	20						10				10			
Station 7	25	10			30			5		40	20	55		25	65	60		85		60		30	70			15	15	20			5		5		
Station 8		5	5		5			5							15	25		20											5			5	5		
Station 10		5					35	75	35			10											10							70				5	10
Station 15	15			70	5			90		55	40	65		25	30	50		85	10	45		10	40	45		20		5							
Station 22	100					5							60								60				90							10			
Station 23	20			10	55	5				10	15	100		10	40	10		15	15	85		30	40			15		20			5		5		
% of Total Grabs	20	4	1	11	9	1	4	26	4	14	9	24	7	8	33	37	1	31	3	24	8	15	20	11	11	8	2	8	1	9	1	4	7	1	1

	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50*	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70
Station 2							10			5	20					5		5			5	5						35	5					40	
Station 6						20					85										40		5		5					5				10	
Station 7		5		15	30	10		10			80		40	15		25	5		5			10	10	5	25	45		10	10	15	5			55	
Station 8									5		15								5									25						10	5
Station 10								5	5							10												5		30					5
Station 15				15	5	25					100		10	5		15	10	5	10	5	5		5		20	10	10	40	20	10		5		20	
Station 22			5								85	5		80							45	25	10			10				5					5
Station 23	5			15	40	10					80			20		10			5			10	5		25	25		40		5			5	45	
% of Total Grabs	1	1	1	6	9	8	1	2	1	1	58	1	6	5		8	2	1	3	1	12	6	4	1	9	11	1	19	4	9	1	1	1	22	2

	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	% of Species Present
Station 2	5	5									70			10	65		10	20	5		37.1
Station 6		5	20								65				40	10		40		15	30.3
Station 7			5	5	5						95		60		85		50	15		55	56.2
Station 8		5	15								40				5	20	5	25	5	10	27.0
Station 10															25	10		20		15	21.3
Station 15		5					5			5	60		70		55		20	20		70	52.8
Station 22				5				5	5			65					10			25	24.7
Station 23					5	5				5	100		30		65	45	45	5		45	50.6
% of Total Grabs	1	2	4	1	1	1	1	1	1	1	54	8	20	4	41	9	17	18	1	29	

* No species for Number 50