

AN ABSTRACT OF THE THESIS OF

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(Name) (Degree)

in Oceanography presented on August 15, 1969
(Major) (Date)

Title: DIVERSITY AND SIMILARITY OF BENTHIC FAUNA OFF
OREGON

Abstract approved:

Redacted for privacy

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Samples of benthic organisms off the coast of Oregon, taken from depths varying from 50 to 2900 meters, have been analyzed in terms of diversity at a given station, and similarity and ecological distance to other stations. Estimates of epifauna abundance were also made. In the analysis an important distinction is made between diversity, abundance, and variety indices; the three measures are considered independent pieces of information relevant to the ecological structure of the population of interest.

Two types of sampling gear were used. Large epifauna were sampled with a beam trawl. Polychaetous infauna were sampled with an anchor-box dredge.

The diversity index chosen is Simpson's index; the measures of similarity and ecological distance are related. These measures

are preferred because of their ease in calculation and basic simplicity. In addition these measures may be interpreted as estimates of well-defined population parameters (as Simpson has pointed out) which have straightforward probabilistic interpretation.

A valid measure of diversity is one piece of relevant information necessary for elucidating the sufficient parameters of ecological systems. Therefore the methodology presented has broad application to studies of population structure.

Diversity and Similarity of Benthic Fauna off Oregon

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1970

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Date thesis is presented

August 15, 1969

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ACKNOWLEDGEMENTS

Many persons contributed directly and indirectly to the evolution and structure of this study. Much of the aid given me was of a philosophic nature; much was just lending a hand at the proper moment.

In particular I wish to acknowledge my major professor, Dr. Andrew G. Carey, Jr., who, besides providing the usual physical aids of laboratory facilities, ship time, and computer time, lent patient support and encouragement to my work.

I owe thanks to: Mr. Ronald Caplan and Mrs. G. Samuel "Mimi" Alspach for preliminary sorting of some of the specimens, Mr. Roger Paul for help in sampling and for making life enjoyable at sea, Miss Fran Bruce and Mr. Michael Kyte for aid in identifying some difficult species, and Mr. Danil Hancock for generously allowing me to utilize data from his Master's thesis.

I am especially grateful to Dr. Scott Overton of the Oregon State University Statistics Department. His insightful discussions have changed my outlook considerably.

Atomic Energy Commission contract AT(45-1)1750 supported this study by providing ship time and a two-year research assistantship.

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On her deathbed Gertrude Stein is supposed to have asked "What is the answer?" and hearing no reply she turned to those around her and said, "In that case, what is the question?"

DIVERSITY AND SIMILARITY OF BENTHIC FAUNA OFF OREGON

INTRODUCTION

Studies of population or community structure are significant when they can be used to support or generate insights into community ecology. Hence, one of the goals of ecological study is to identify and measure sufficient parameters for ecological systems (Levins, 1968). This identification is the prime function of ecological model-building. Levins (1968: p. 6) defines sufficient parameter as

an entity defined on a high level such as a population or a community which contains the combined relevant information of many parameters at a lower level.

The key phrase is "relevant information"; the objective is to determine which of the lower order parameters are important and which are not.

The purpose of this study is to set forth a statistical method for determination and analysis of diversity in terms of quantitative measures based on the proportional distribution of sample objects into qualitative categories. The techniques presented are useful for separating the relevant from the irrelevant information, and they are particularly helpful in analyzing the effectiveness of a sampling program.

These techniques are applied to certain data obtained from

dredge and trawl samples of the benthic fauna along a transect line due west of Newport, Oregon. The qualitative classification and proportional distribution of individual organisms by species gives the necessary information to make diversity studies. In the case of the benthic epifauna biomass by species was also determined to compute measures based on proportional distribution of biomass instead of individuals.

Diversity may be defined as a measure of the unlikeness within a collection of groups; similarity is a measure of likeness between two collections of groups. The diversity analysis used is based on Simpson's (1949) index.

It is intuitively appealing to define the geometric distance between two populations as a function of the diversity of each population and the similarity between them.

Distance does not refer to a spatial relation in nature. It is a measure of the ecological relationship suggested by the resemblance or similarity of two communities or samples thereof. The distance between two communities is the square root of the sum of the squared differences between the measures of each species. (McIntosh, 1967: p. 395)

Diversity, similarity, and distance, defined in terms of Simpson's measure, have this functional relationship mathematically described. These measures are understandable graphically, intuitively, and statistically, are easily calculated, and are all estimators of well-defined characteristics of the total population of interest and not just

of samples taken from the population (Overton, 1969). Unlike the diversity measure based on information theory (Margalef, 1958), these measures have a probabilistic interpretation which makes them particularly amenable to studies that involve the availability of items within certain categories (Horn, 1966).

MATERIALS AND METHODS

The samples from which data were obtained represent two major components of the invertebrate benthic community in the ocean: the large epifauna and the polychaetous infauna. The data were analyzed by station in terms of specific measures of diversity, similarity, and distance. An abundance estimate was calculated for the large epifauna.

Sampling

Data on the polychaetous infauna were derived from samples taken at selected stations from 800 to 2900 meters depth by use of a modified anchor-box dredge (Carey and Hancock, 1965). Samples of the large invertebrate epibenthos were taken at selected stations from depths of 50 to 800 meters using a quantitative beam trawl (Carey and Paul, unpublished manuscript). Both types of gear are quantitative samplers; they give an estimate of the surface area sampled, thus allowing computation of an abundance estimate.

Dredge and trawl samples were collected along the "Newport Line" regularly sampled and studied by researchers at Oregon State University. The transect line of stations lies due west of Newport, Oregon, along latitude $44^{\circ}-39.1'N$. Samples from fourteen stations form the basis for the polychaete data analyzed in this study (Hancock, 1969), and samples from five stations provide the epifauna data.

Byrne (1962) describes the sediment and geomorphology of the study area. The stations on the Newport line lie across the continental slope at 200 meter depth intervals from 200 to 2900 meters. Stations on the continental shelf less than 200 meters are spaced at 25 meter depth intervals. Individual stations on the western abyssal plain fluctuate in depth because of abyssal hills. Stations on the plain are spaced every 20 miles; four are considered in this study (see Figure 1 and Table 1 for station list and bottom profile of station line; see Appendix for detailed station list).

The fourteen samples of epifauna were taken with a quantitative beam trawl. This trawl consists of a rigid frame with broad skids and a hollow sealed aluminum pipe as the connecting beam (Carey and Paul, 1968). The beam maintains constant fishing width and the skids control the position of the net relative to the ocean bottom. For the samples used in this study a 1.5 inch (3.8 cm) mesh (diagonal stretch) otter trawl-type net was used. Paired odometer wheels and revolution counters are attached to the skids by pivoting arms to assure proper bottom contact. The counters count positively in either direction of rotation. A locking device prevents rotation in the water column during descent and ascent.

The area traversed by the gear is computed from the width of the net opening, the wheel circumference, and the number of revolu-

Figure 1. Bottom profile of station line (44°39.1'N.).

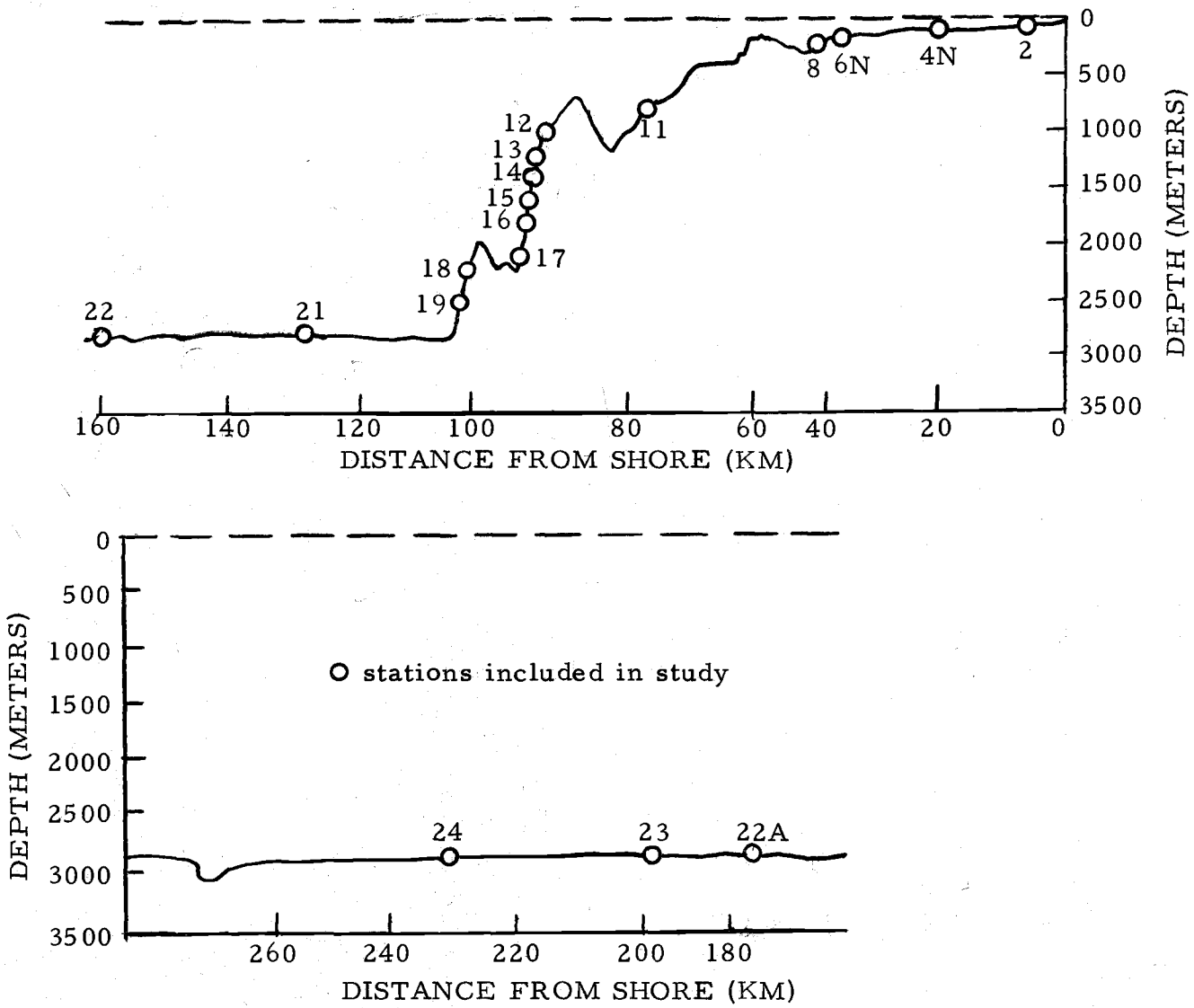


Table 1. Summary of Dredge and Trawl Collections

<u>Station</u>	<u>Depth</u>	<u>No. of trawls</u>	<u>Station</u>	<u>Depth</u>	<u>No. of dredges</u>
NAD 2	50	3	NAD 11	800	18
NAF 4N	100	3	NAD 12	1000	1
NAF 6N	150	3	NAD 13	1200	1
NAD 8	200	2	NAD 14	1400	3
NAD 11	800	3	NAD 15	1600	2
Total = 14			NAD 16	1800	1
			NAD 17	2000	2
			NAD 18	2200	1
			NAD 19	2400	1
			NAD 21	2800	7
			NAD 22	2800	4
			NAD 22A	2860	2
			NAD 23	2900	1
			NAD 24	2800	1
			Total = 45		

tions made during the sampling period. The highest reading recorded by either the right or left odometer was taken to be the number of revolutions used in computing the area traversed, since it is a reasonable assumption that the number of revolutions counted by any wheel will always underestimate the true distance. It is also assumed that the beam trawl actually travels one circumference in distance along the bottom per revolution of the wheel. Appreciable slippage or sinking into the mud would introduce other error factors, however, the wheels are probably not very heavy in water and observations by divers in Yaquina estuary indicate that the wheels appear to ride true upon the sediment surface. Slippage is minimized by spikes projecting from the circumference of the wheel.

Two models of beam trawl were used in collecting the data. Model I was the prototype, and it differs from Model II only in the shape of the counting wheels and net size opening (beam width). The sampling characteristics for the two trawls should be similar.

Samples of polychaetes were taken with an anchor dredge (Sanders, Hessler, and Hampson, 1965) or with an anchor-box dredge (Carey and Hancock, 1965). Samples were sieved, washed, preserved in 10% formalin-sea water, transferred to alcohol upon removal to the laboratory, and identified and enumerated (Hancock, 1969).

The dredge is designed to sample the upper 10 cm of the sediment; an estimate of the area sampled may be computed from the volume of sediment in the box.

All specimens of the large epibenthos were preserved on board ship in 10% neutral formalin and sea water for later study in the laboratory where they were sorted, counted, identified and wet weighed. The size range of the epibenthos sampled was restricted by the use of 1.5 inch mesh net. All specimens were counted in spite of probable operation within the selection range of the trawl. Selection range refers to the size range of the individuals of sampled species which may escape capture up to a maximum size which is sampled with uniform efficiency.

Wet weights by species of the epifauna were determined and were converted into ash-free dry weight values by use of specific conversion factors. Sufficient data for a similar analysis of the polychaete data were not available. Ash-free dry weights are a better measure of biomass than wet weights; they have a closer relation to metabolically active organic substance than dry or wet weights. The conversion factors were computed from previous data on wet weight, dry weight, and ash weight of the individual species (Carey, unpublished data). Of 46 species in the 14 samples analyzed, six species could not be converted to ash-free dry weight by specific data; data

from a similar organism (preferably of the same genus) were used. Data from a maximum of three separate ash-weight determinations were used for each species and an average value for conversion to dry weight and to ash-free dry weight computed. These values are listed in Table 10 in the Appendix. The large standard error of many of these values indicates biological variation and a lack of precision in the data. Wet weighing is imprecise but can be standardized within a study. Direct measurements of ash-free dry weights involves destructive analysis of the specimens; this is not always desirable because of the loss of valuable specimens and the impossibility of subsequent analysis or checking of identifications.

Basic guidelines set up for enumerating each species of epifauna are as follows:

- 1) Count all organisms with no restrictions to size class.
- 2) If organisms are fragmented, count only the anterior or basal portions.
- 3) Do not count epizooites or parasites.

Analysis

The number of trawl and dredge samples analyzed are summarized in Table 1 by station number and depth sampled. The stations for invertebrate macro-epifauna and polychaete infauna (referred

to hereafter as simply epifauna and polychaetes) overlap only at station 11.

Three major quantities are computed in the analysis of the raw data from these 18 stations and 59 samples. These quantities are diversity, distance, and similarity. An abundance measure is also computed for the epifauna. The derivation and relationships of these measures are presented in the Discussion section. The computational formulae and some of their properties are discussed below.

1. Diversity

Simpson's diversity index, λ , is a population parameter which characterizes the distribution of the proportions of individuals (or biomass, or any measure) in the entire population into species (or any other set of categories) (Simpson, 1949). The word population is used here and throughout the paper in the statistical sense to represent the body of data from which samples may be drawn. The diversity measure applied to the sample data in this study is Sd^2 , a biased estimator of λ , where Sd^2 is the sum of squares of the proportion of each species in the total sample.

$$Sd^2 = \sum_{i=1}^S p_i^2 = \sum_{i=1}^S \frac{n_i^2}{N^2} = \frac{\sum_{i=1}^S n_i^2}{N^2}, \quad (1)$$

where

$p_i = n_i/N =$ proportion of total individuals in i^{th} species;

n_i = number of individuals of i^{th} species in sample;

N = total number of individuals in sample;

S = number of species in sample.

Sd^2 is actually a measure of concentration, the complement of diversity. The value of Sd^2 has limits of $1/N$ and 1. The population is most diverse when Sd^2 is a minimum and is least diverse when Sd^2 is a maximum. $1 - Sd^2$ is used as a diversity index which varies in the same sense as diversity.

It is not necessary to have n_i and N in terms of individual organisms. They may represent, for instance, biomass of the i^{th} species and total biomass of the sample respectively. Species biomass diversity for the epifauna was computed for this study.

2. Similarity

Comparative studies of ecological systems require an objective measure of the similarity between different populations. Similarity is given in this study by the SIM and SIMI measures given below.

SIM_{12} is the similarity between collections 1 and 2. It is given by

$$SIM_{12} = \sum_{i=1}^S p_{1i} p_{2i} \quad (2)$$

where

p_{1i} = proportion of i^{th} species in first collection;

p_{2i} = proportion of i^{th} species in second collection;

S = number of species over both collections.

SIMI also represents similarity, but it is scaled by the factor (Sd_1) (Sd_2) and is thus called SIMI for similarity index. Thus,

$$SIMI_{12} = \frac{SIM_{12}}{(Sd_1)(Sd_2)}, \quad (3)$$

where the Sd values are the square root of the Sd^2 values defined by equation (1). This index has limits of 0 and 1 and is easier to make inferences from than the SIM index. SIMI values represent the probability that two individuals drawn randomly from each population will belong to the same species, relative to the square root of the probability of randomly drawing them from each population alone.

3. Distance

Distance is a comparison measure that is made between collections. It depends upon both similarity and diversity. The functional relation is

$$\begin{aligned} D_{12} &= \text{distance from collection 1 to collection 2} \\ &= Sd_1^2 + Sd_2^2 - 2(SIM_{12}). \end{aligned} \quad (4)$$

Distance is given by

$$D_{12} = \sum_{i=1}^S (p_{1i} - p_{2i})^2 \quad (5)$$

where p_{ji} = proportion of the i^{th} species in the total j^{th} sample;
 $j = 1, 2.$

4. Abundance

Abundance was defined in terms of individuals per unit area or biomass per unit area. An estimate of abundance was computed from the samples at each station by dividing total numbers of individuals or total ash-free dry weight in each sample by the area traversed by the gear. These values were averaged for each station to give the abundance index for that station.

This index underestimates the true abundance value for the population of fauna at each station by a large amount, but the factor cannot be determined without more knowledge of the sampling efficiency of the gear.

5. Averaging of samples at a given station

Diversity and abundance measures are reported by station and are based on an average distribution calculated from all samples at each station. More than one sample per station was available for each station with the exception of seven infaunal anchor-dredge samples (see Table 1). It was felt that each sample should carry equal weight, therefore an average distribution of p_i 's for a station was calculated by averaging p_i by species for all samples at each station. I. e., let \bar{p}_i ($i = 1, \dots, S$) represent the proportion of the i^{th}

species for the average of k samples taken at a given station. \bar{p}_i is then given by

$$\bar{p}_i = \frac{1}{k} \sum_{j=1}^k p_{ij}, \quad (6)$$

where p_{ij} = proportion of i^{th} species in j^{th} sample at the particular station.

\bar{p}_i was used to compute the diversity, distance, and similarity by equations (1), (2), (3), and (5) just as p_i was used. The information given in the RESULTS section by station was computed from averaged stations where the \bar{p}_i 's for the averaged station were determined by the above method. Computation of the abundance index for a given station also gave equal weight to each sample taken at that station.

6. Computation

The computation was done largely on the Oregon State Open Shop Operating System (OS3) using the CDC 3300 computer of the Oregon State University Computer Center with the AIDONE and AID-TWO programs developed by Overton (unpublished data) for the analysis of information and diversity ("AID").

When the OS3 system was not employed data were analyzed on the Olivetti Programma 101 desk calculator.

An n-dimensional geometric representation of diversity

Sd^2 as a measure of diversity is readily understood in terms of a simple graphical analogy. Consider a two-species community. Let p_i represent the proportion of the i^{th} species in the population ($i = 1, 2$). Then $\sum p_i = 1$, and each p_i assumes some value between 0 and 1. This is represented in Figure 2. p_i is plotted on the x-axis

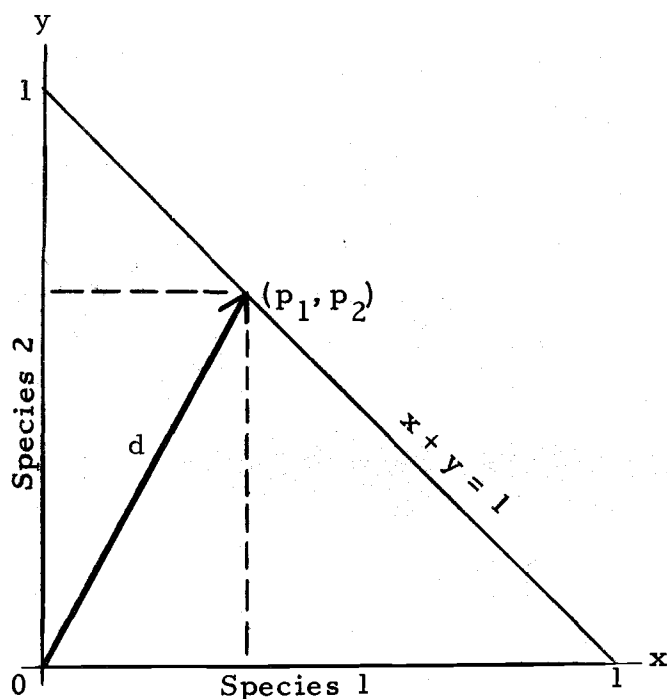


Figure 2. Two-dimensional geometric representation of diversity.

and p_2 on the y-axis. The diagonal 45° line (defined by $x + y = 1$, $x, y \geq 0$) represents all possible combinations of p_1 and p_2 .

Consider the vector from the origin to the point (p_1, p_2) . The vector length, d , is found by application of the Pythagorean theorem, thus

$$d^2 = p_1^2 + p_2^2 = \sum_{i=1}^2 p_i^2. \quad (7)$$

Equation (1) defines Simpson's d^2 as

$$Sd^2 = \sum_{i=1}^S p_i^2$$

In this case $S = 2$, and equations (7) and (1) are identical. Therefore, the square of the vector length d in Figure 2 represents Sd^2 .

The same representation is used for comparing two samples from two different populations. Let p_{1i} , p_{2i} represent the proportion of the i^{th} species in the first and second population respectively (Figure 3). d_1^2 and d_2^2 represent Simpson's d^2 -values for the first

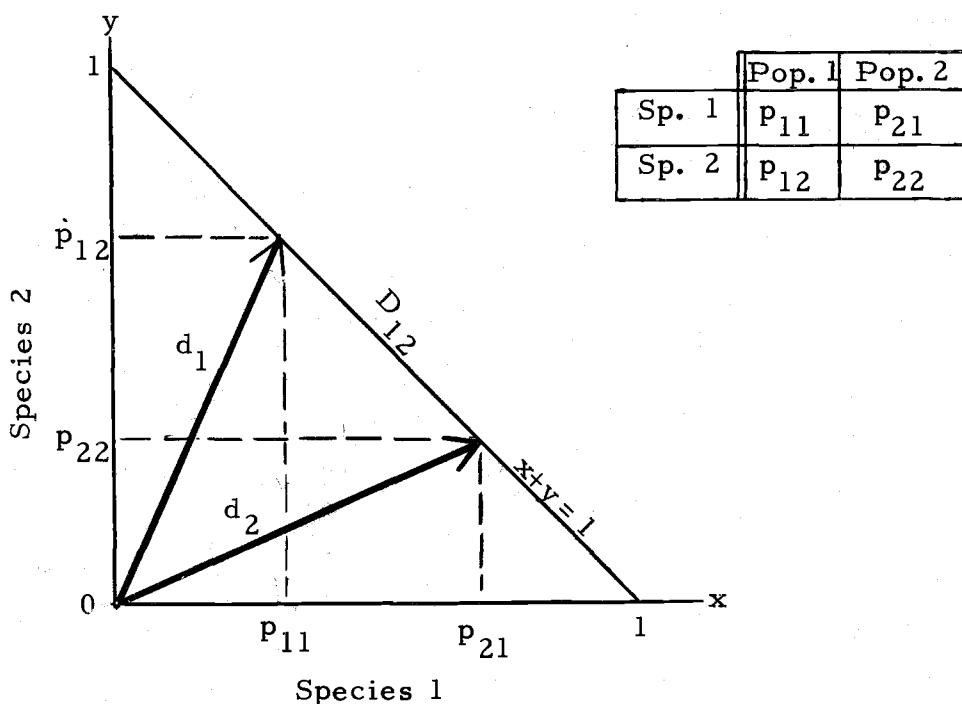


Figure 3. Two-dimensional geometric representation of distance and similarity.

and second population. D_{12} , the linear distance between the terminations of the two vectors \bar{d}_1 and \bar{d}_2 in Figure 3, is determined by pythagorean theorem from

$$D_{12}^2 = (p_{11} - p_{21})^2 + (p_{12} - p_{22})^2. \quad (8)$$

This is the same as equation (5) for the ecological distance. Rearranging and substituting gives

$$D_{12}^2 = d_1^2 + d_2^2 - 2 \sum_{i=1}^2 p_{1i} p_{2i}. \quad (9)$$

The general case for n species is analagous to the two-dimensional case and is treated in the same way. Consider a n -dimensional coordinate system with a hyperplane defined by

$$\sum_{i=1}^n x_i = 1, \quad x_i \geq 0, \quad (10)$$

where x_i is the variable along the i^{th} axis. As in the two-dimensional case, each p_i for $i=1, \dots, n$ varies along the i^{th} axis and takes values between 0 and 1. Simpson's d -value is the length of the vector from the origin to a point on the n -dimensional hyperplane given by coordinates $(p_1, p_2, \dots, p_i, \dots, p_n)$. The hyperplane is analagous to the 45° line in Figures 1 and 2 and represents all possible combinations of p_i 's ($i=1, \dots, n$). The Pythagorean theorem holds for n dimensions so that

$$Sd^2 = \sum_{i=1}^n p_i^2 \quad (11)$$

A comparison of two samples from two populations also yields a result analogous to the two-dimensional case. Distance measure, D_{12} , is simply the linear distance along the surface of the hyperplane between the two points terminating the vectors for samples 1 and 2. The result, by Pythagorean theorem, is

$$D_{12}^2 = \sum_{i=1}^n (p_{1i} - p_{2i})^2 \quad (12)$$

or, rearranging,

$$D_{12}^2 = \sum_{i=1}^n p_{1i}^2 + \sum_{i=1}^n p_{2i}^2 - 2 \sum_{i=1}^n p_{1i} p_{2i} \quad (13)$$

Distance is a summarization of the species points in a space with fewer dimensions than the original and is analogous to the similarity index in that it depends on both diversity and similarity. Distance values can be no larger than $\sqrt{2}$ (a case which occurs only with maximum degree of unlikeness between samples and minimum degree of unlikeness within samples) and no smaller than 0 (when the samples are identical).

The last term of equation (13) is equivalent to minus twice the SIM measurement defined by equation (2),

$$SIM_{12} = \sum_{i=1}^S p_{1i} p_{2i} ,$$

so equation (13) may be written as

$$D_{12}^2 = Sd_1^2 + Sd_2^2 - 2SIM_{12}, \quad (14)$$

thus deriving the relationship first given in equation (4).

Population parameters analogous to SIM, Sd^2 , and D^2

Sd^2 is only an estimator of Simpson's (1949) index, λ , a quantity defined on the entire population of interest.

$$\lambda = \sum_{i=1}^Z \pi_i^2, \quad (15)$$

where

π_i = proportional value of i^{th} species (or group) in the population;

Z = total number of species (or groups) in the population.

π_i is the population analog of p_i and so

$$\sum_{i=1}^Z \pi_i = 1.$$

λ is, theoretically, a constant parameter for a given population, and it represents the probability that two successive random samples of size = 1 from the population will belong to the same group. Simpson gives an unbiased estimator for λ :

$$l = \sum_{i=1}^S \frac{n_i(n_i - 1)}{N(N - 1)}, \quad (16)$$

where

S = number of species (or groups) in the sample;

n_i = number of individuals* in the i^{th} group;

N = total number of individuals* in all groups.

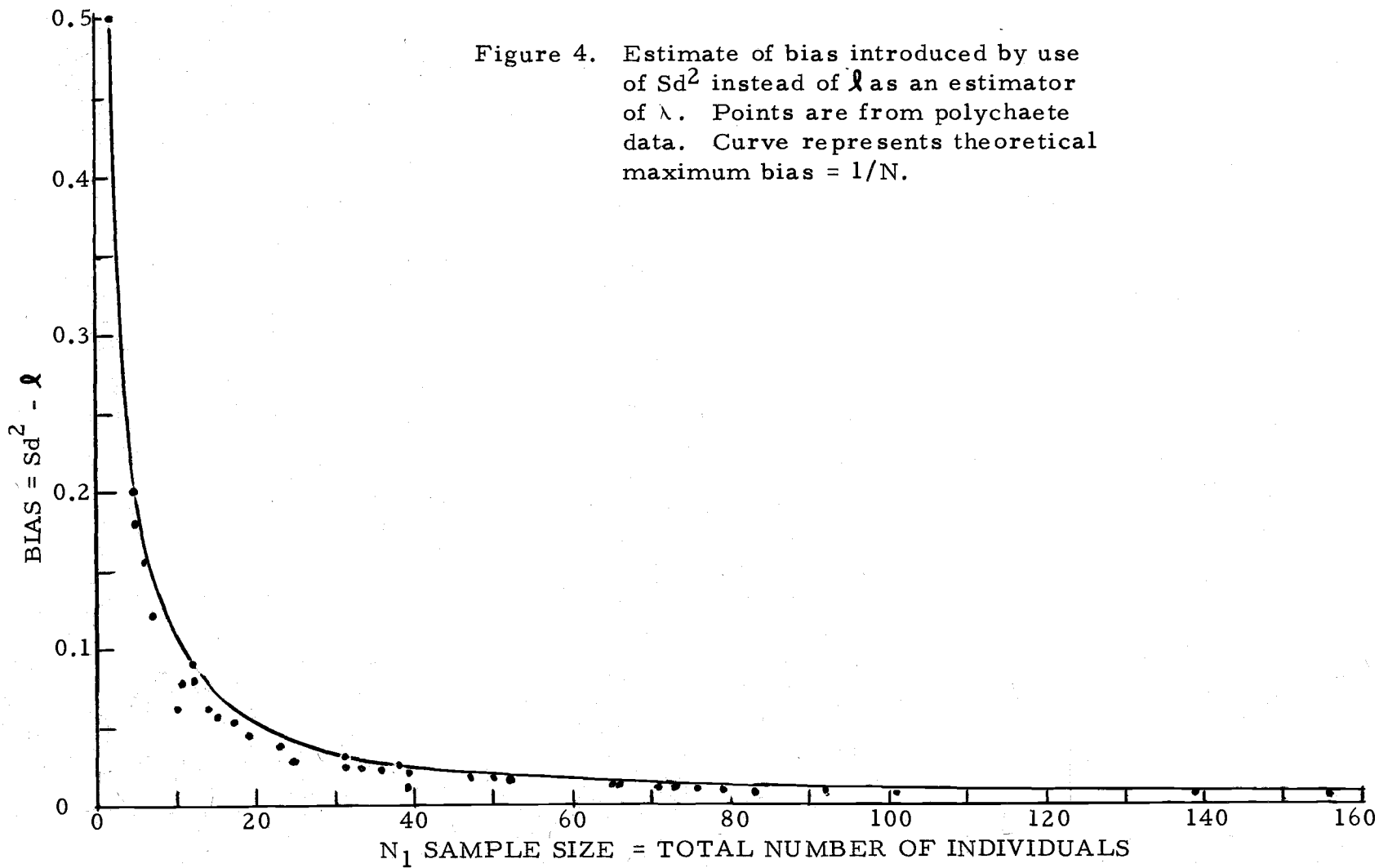
Sd^2 is also a consistent estimator of λ but is biased in that $Sd^2 \gg \lambda$ for all $N > 1$. To attempt to evaluate the bias the value of Sd^2 was subtracted from the value of λ for various sample sizes. Figure 3 shows this estimate of bias for actual data (polychaetes) and for a theoretical curve derived by maximizing $Sd^2 - \lambda$ for different sample sizes. In the notation of equation (16) this difference is

$$\frac{\sum_{i=1}^S n_i^2}{N^2} - \frac{\sum_{i=1}^S n_i(n_i - 1)}{N(N - 1)} \quad (17)$$

and the unconditional maximum value of this difference, for all $N > 1$, is equal to $1/N$.

Sd^2 is preferred over λ because of its mathematical relation to the distance and similarity measures. The rapid decrease of the difference curve in Figure 4 indicates that Sd^2 is nearly unbiased for larger values of N and thus can be a reasonable estimator of λ . The minimum N chosen will depend on the differences which must be resolved between samples. Thus, if a difference in diversity of less

* Note that this estimator is meaningless unless n_i and N are integers representing individuals.



than 0.04 will not significantly affect the accuracy of the work, a minimum sample size of 25 will be adequate.

In the same way that λ is analogous to Sd^2 we may define a population parameter analogous to SIM.

$$\text{Let } \rho_{12} = \sum_{i=1}^Z \pi_{1i} \pi_{2i} \quad (18)$$

where π_{ji} = proportion of the total j^{th} population in the i^{th} species,
 $j = 1, 2;$

Z = total number of species over both populations.

ρ_{12} is then a population constant that is interpreted as the probability that two random samples of size = 1, one from population 1 and one from population 2, will belong to the same species. SIM is now a consistent estimator of ρ .

The population value for distance measure, Δ_{12} , is then given by

$$\Delta_{12}^2 = \sum_{i=1}^Z (\pi_{1i} - \pi_{2i})^2 = \lambda_1 + \lambda_2 - 2\rho_{12}. \quad (19)$$

Statistical analog of diversity, similarity, and distance

The various population parameters can be interpreted in terms of the variance and covariance of the proportion, π_i . Population variance is defined, for a general measure, x , as

$$V(x) = \frac{1}{Z} \sum_{i=1}^Z (x_i - E(x))^2$$

where E means expected value, and Z is the true number of elements, in this case, the number of species. Thus

$$\begin{aligned} V(\pi) &= \frac{1}{Z} \sum (\pi_i - \frac{1}{Z})^2 && [E(\pi) = \frac{1}{Z}] \\ &= \frac{1}{Z} (\sum \pi_i^2 - 2 \frac{\sum \pi_i}{Z} + \frac{1}{Z}) \\ &= \frac{1}{Z} (\sum \pi_i^2 - \frac{1}{Z}) \\ &= \frac{1}{Z} (\lambda - \frac{1}{Z}). \end{aligned} \tag{20}$$

In the same way that λ is interpreted as the variance of the population of proportions, so may ρ_{12} be interpreted as the covariance of π_1 and π_2 . Covariance is defined as

$$\text{COV}(x, y) = E\{[x - E(x)][y - E(y)]\}$$

Thus

$$\begin{aligned} \text{COV}(\pi_1, \pi_2) &= \frac{1}{Z} \left[\left(\sum \pi_{1i} - \frac{1}{Z} \right) \left(\sum \pi_{2i} - \frac{1}{Z} \right) \right] \\ &= \frac{1}{Z} \left(\sum \pi_{1i} \pi_{2i} - \frac{1}{Z} \right) \\ &= \frac{1}{Z} \left(\rho_{12} - \frac{1}{Z} \right) \end{aligned} \tag{21}$$

Consider equation (20) for distance measure. Distance can be

interpreted by the statistical relationship,

$$V(x - y) = V(x) + V(y) - 2\text{COV}(x, y),$$

as the variance of the differences of the proportions, π_1 , π_2 , thus,

$$\begin{aligned} V(\pi_1 - \pi_2) &= V(\pi_1) + V(\pi_2) - 2\text{COV}(\pi_1, \pi_2) \\ &= \frac{1}{Z} [\lambda_1 + \lambda_2 - 2\rho_{12}]. \end{aligned} \quad (22)$$

SIMI, the similarity index

Two similarity parameters have been used in this study. SIM has already been discussed. The other value is SIMI, the similarity index, which is defined as

$$\text{SIMI}_{12} = \frac{\text{SIM}_{12}}{(\text{Sd}_1)(\text{Sd}_2)}. \quad (23)$$

The denominator acts as a scaling factor upon SIM so that the value of SIMI ranges from 0 to 1 with maximum similarity occurring at SIMI = 1, and minimum similarity at SIMI = 0. Maximum similarity will occur when the samples compared are identical. In this case SIM_{12} , Sd_1^2 , and Sd_2^2 are all equal (from equations 1 and 2), so SIMI = 1. Minimum similarity will occur when there are no species in common between the samples compared. In this case $\text{SIM}_{12} = 0$, and SIMI also equals zero. The SIMI quantity is analogous to a correlation coefficient for the proportions of species in sample 1 and sample 2.

The utility of SIMI is its use in measuring the similarity of one

population to another. I have applied it to the analysis of the epifauna and polychaete data to determine how similar any one station is to any other station on the transect, in terms of community structure. The resultant curve that can be drawn is useful as a rough check of correlations of fauna with environmental quantities such as temperature, oxygen, organic carbon, or sediment composition. The factors, or components of a factor (such as per cent sand, silt, or clay in sediments), may be analyzed exactly as the faunal samples to yield a SIMI table. If the factor of interest is a controlling factor, and strongly correlated with the change in population composition, then the similarity curve for the population composition should vary in a like manner to the similarity curve of the factor under consideration. This technique may be a useful tool for analyzing the relationship of environmental factors to faunal distribution.

RESULTS

Diversity

Diversity values of the epifauna and polychaetes by station are given in Tables 2 and 5 in terms of the diversity index, Sd^2 . Table 2 gives values of SIM for any polychaete station compared to any other polychaete station. Table 5 gives values of SIM for any epifauna station compared to any other epifauna station, both for numbers and biomass analyses. To determine diversity at a particular station, find the SIM value for that station compared with itself; i. e. $Sd_1^2 = SIM_{ii}$ (from equations 1 and 2). For example, to find the value of the diversity index for polychaete station 13 look at Table 2 and find the similarity value for station 13 compared to station 13, which is 0.1417. This low value implies a very diverse population. The probability of finding the same species in two successive random samples of size one at station 13 is estimated to be 0.1417.

A plot of polychaete diversity is presented in Figure 6. A similar plot of epifauna diversity and biomass diversity is presented in Figure 5. $1 - Sd^2$ is plotted so that a high diversity value would be indicated by a high data point. The polychaete diversity is generally higher than that of the epifauna. Even though there is only one station in common for polychaetes and epifauna in the data studied, I suspect that epifauna diversity is lower in general due to a lack of dominant organisms in the polychaete populations. The sea urchin Allocentro-

Table 2. Similarity (SIM) between stations for Polychaete numbers ($\times 10^4$).

STATION = NAD:	11	12	13	14	15	16	17
NAD 11	1049						
NAD 12	0075	2222					
NAD 13	0186	0145	1417				
NAD 14	0352	0022	0473	0708			
NAD 15	0103	0333	0000	0119	1750		
NAD 16	0312	0175	0503	0311	0000	0859	
NAD 17	0152	0213	0510	0367	0112	0336	0559
NAD 18	0278	0000	0471	0178	0083	0175	0245
NAD 19	0045	0000	0036	0247	0000	0373	0136
NAD 21	0143	0057	0046	0253	0124	0302	0202
NAD 22	0036	0054	0072	0093	0032	0092	0162
NAD 22A	0005	0238	0051	0078	0534	0031	0000
NAD 23	0140	0263	0046	0348	0000	0208	0369
NAD 24	0293	0000	0074	0284	0378	0032	0257
STATION = NAD:	18	19	21	22	22A	23	24
NAD 18	1250						
NAD 19	0000	1389					
NAD 21	0096	0415	0851				
NAD 22	0133	0089	0314	0647			
NAD 22A	0000	0049	0091	0265	1186		
NAD 23	0044	0307	0904	0370	0316	2023	
NAD 24	0356	0000	0245	0283	0219	0083	2144

Table 3. Similarity index (SIMI) between stations for Polychaete numbers ($\times 10^4$).

STATION = NAD:	11	12	13	14	15	16	17	18	19	21
NAD 11	10000									
NAD 12	0490	10000								
NAD 13	1527	9817	10000							
NAD 14	4079	0175	4718	10000						
NAD 15	0757	1690	0000	1069	10000					
NAD 16	3291	1270	4563	3987	0000	10000				
NAD 17	1983	1912	5734	5833	1133	4870	10000			
NAD 18	2423	0000	3538	1890	0563	1693	2929	10000		
NAD 19	0372	0000	0258	2489	0000	3414	1548	0000	10000	
NAD 21	1510	0413	0423	3264	1013	3554	2927	0929	3817	10000
NAD 22	0441	0451	0751	1369	0298	1236	2689	1474	0940	4229
NAD 22A	0046	1467	0394	0855	3703	0306	1160	0000	0382	0904
NAD 23	0962	1242	2971	2911	0000	1576	3466	0276	1831	6893
NAD 24	1955	0000	0426	2307	1951	0237	2348	2172	0000	1815
STATION = NAD:	22	22A	23	24						
NAD 22	10000									
NAD 22A	2319	10000								
NAD 23	3230	2040	10000							
NAD 24	2399	1373	4064	10000						

Table 4. Distance measure between stations (D_{ij}) for Polychaete numbers ($\times 10^4$).

STATION = NAD:	11	12	13	14	15	16	17
NAD 11	0000						
NAD 12	5588	0000					
NAD 13	4576	5788	0000				
NAD 14	3247	5372	3455	0000			
NAD 15	5093	5749	5628	4712	0000		
NAD 16	3583	5225	3563	3074	5108	0000	
NAD 17	3612	4853	3091	2309	4566	2726	0000
NAD 18	4177	5893	4154	4003	5323	4193	3633
NAD 19	4846	6009	5229	4004	5603	3876	4093
NAD 21	4018	5440	4663	3243	4851	3230	3171
NAD 22	2103	5255	4382	3420	4831	3636	2971
NAD 22A	4718	5415	5001	4168	4323	4453	3945
NAD 23	5284	6097	5786	4510	6142	4966	4295
NAD 24	5106	6608	5842	4779	5602	5421	4679
STATION = NAD:	18	19	21	22	22A	23	24
NAD 18	0000						
NAD 19	5137	0000					
NAD 21	4370	3754	0000				
NAD 22	4040	4310	2950	0000			
NAD 22A	4936	4977	4307	3609	0000		
NAD 23	5644	5289	3263	4394	5076	0000	
NAD 24	5180	5944	5005	4718	4379	6325	0000

Table 5. Diversity and similarity analysis between epifauna stations(x 10⁴).

STATION = NAD:		NUMBERS					ASH-FREE DRY WEIGHTS				
		2	4N	6N	8	11	2	4N	6N	8	11
DISTANCE MEASURE	2	0000					0000				
	4N	7419	0000				8367	0000			
	6N	8256	7110	0000			8645	6748	0000		
	8	8869	7762	5495	0000		10198	8645	7108	0000	
	11	7707	6413	7023	7652	0000	8880	7035	7280	9063	0000
"SIM"	2	3968					5035				
	4N	0307	2150				0072	2109			
	6N	0057	0028	2961			0005	0002	2449		
	8	0000	0011	1920	3897		0000	0000	1381	5365	
	11	0000	0004	0000	0007	1971	0000	0005	0000	0001	2851
"SIMI"	2	10000					10000				
	4N	1051	10000				0221	10000			
	6N	0166	0111	10000			0015	0009	10000		
	8	0000	0038	5652	10000		0000	0000	3810	10000	
	11	0000	0019	0000	0025	10000	0000	0021	0000	0003	10000

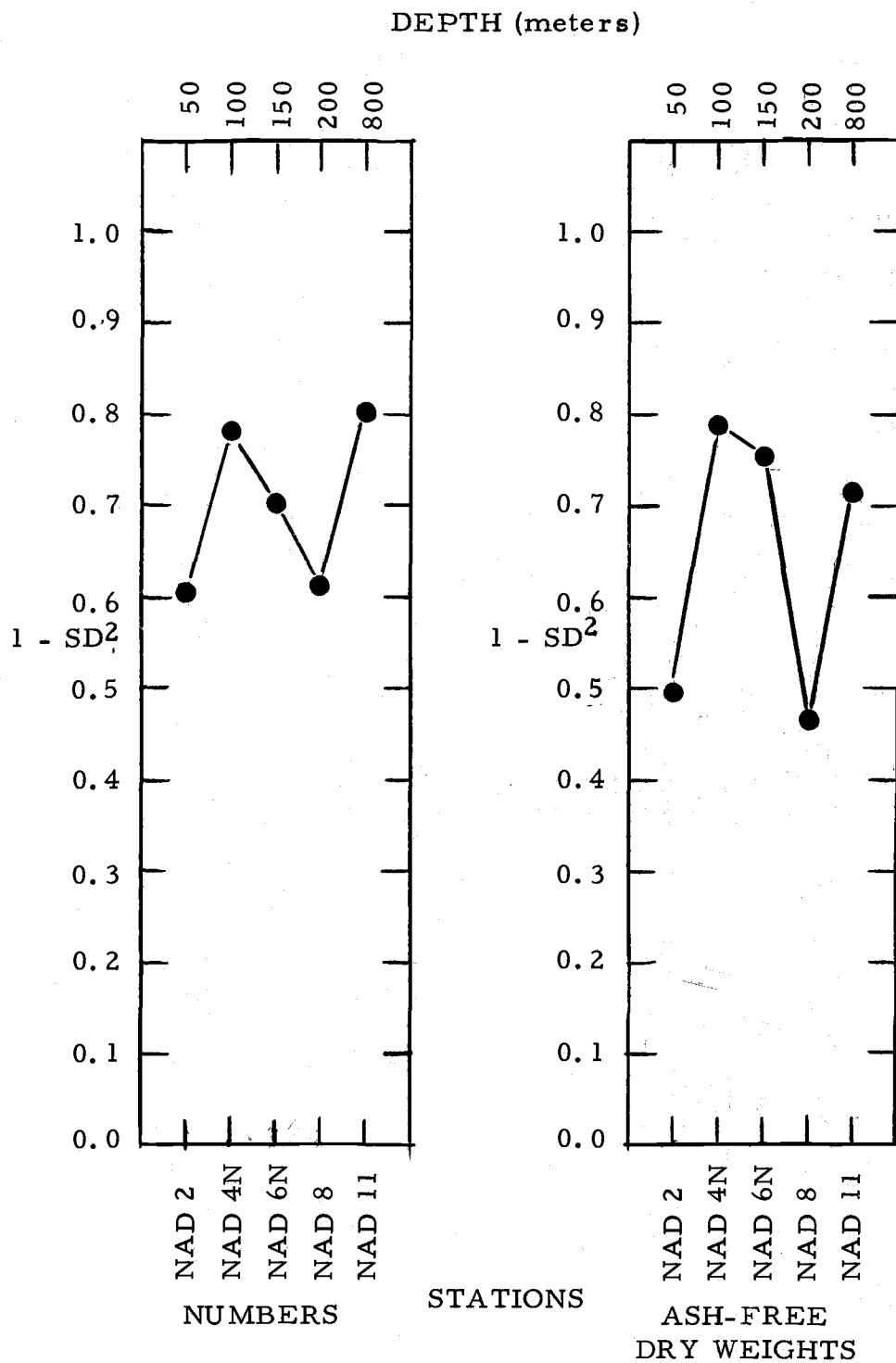


Figure 5. Epifauna diversity (50 to 800 m).

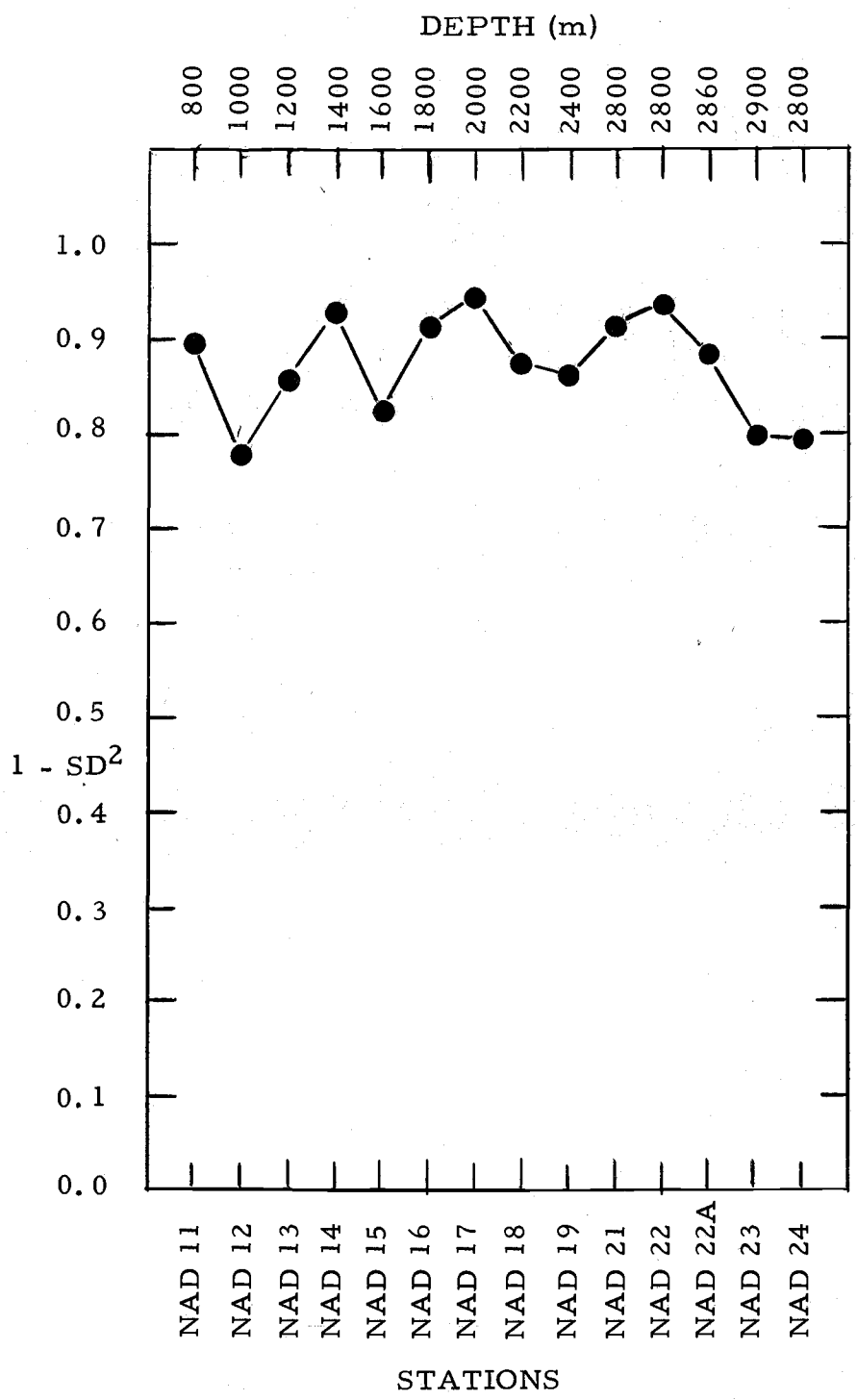


Figure 6. Polychaete diversity (800-2800 m).

tus fragilis dominates a large proportion of the beam trawl samples from 200 meters (station NAD 8), and many numbers of young tanner crabs, Chionecetes tanneri, are found in epifauna samples from 800 meters (station NAD 11). This increases the value of Sd^2 , and it decreases the diversity. Smaller sample sizes and smaller numbers of species sampled also account for the higher Sd^2 values of the epifauna.

Similarity (SIM)

Similarities between populations for epifauna and polychaetes are given in Tables 5 and 2 respectively.

Similarity Index (SIMI)

Values of SIMI for epifauna and polychaetes are given in Tables 5 and 3 respectively. Three pairs of stations, NAD 21-NAD 23 and NAD 13-NAD 17 for polychaetes and NAD 6N-NAD 8 for epifauna, have SIMI values greater than 0.5; no station pairs have values greater than 0.6. Thus, no stations show particular similarity to each other. This indicates the likelihood of a rapidly changing niche distribution along the depth gradient.

Similarity analysis of an environmental factor: sediment composition

If the change in organismic composition along a gradient such as depth depends primarily on some factor which also changes with depth, then, relative to a certain station, the similarity of species

distribution to the origin station should change in the same manner as the factor of interest.

The similarity index for polychaetes and epifauna falls off rapidly with change in depth, relative to any station chosen.

An analysis was made relating the similarity of sediment composition along the transect line to selected infauna station. The sediment data was obtained from A. G. Carey, Jr. (unpublished data, see appendix for data). The proportional distribution of sand, silt, or clay in the sediment at each station was used to compute a SIMI value for the sediment composition of each station as compared to stations NAD 11, NAD 14, and NAD 15.

The results are shown in Figures 7, 8, and 9 where SIMI values for both polychaete data and sediment data are plotted for measure relative to each of the three stations. No positive relationship between sediment composition and faunal distribution is apparent. This does not mean there is none; it may be masked by other, more important factors, by patchiness in the species distribution or the environment, or by inadequate sampling. At many of the anchor dredge stations only a single sample was taken.

Distance measure

Distance measure for one station relative to any other is given in Table 4 for polychaete data, and Table 5 for epifauna data.

Abundance

An abundance index is given for the epifauna data in Figure 10 and Table 6. Figure 10 is a plot of abundance values in terms of numbers per square meter and grams per square meter. Both the 50 and 100 meter stations are 100% sand substrate and support a relatively low density of animals. The peak at 200 meters, for both biomass and numbers, is due to a dominant organism, the sea urchin Allocentrotus fragilis. The sandy silt bottoms of the 150 and 200 meter stations support greater numbers and biomass of epifauna than the clayey silt bottom of station 11.

Abundance estimates for the polychaete data were not available from enough samples to make an analysis.

Table 6. Epifauna abundance index (estimate of abundance).

Station NAD	Depth m	#/10 ⁴ m ²	g/10 ⁴ m ²
2	50	14	17
4N	100	38	39
6N	150	272	251
8	200	390	773
11	800	163	236

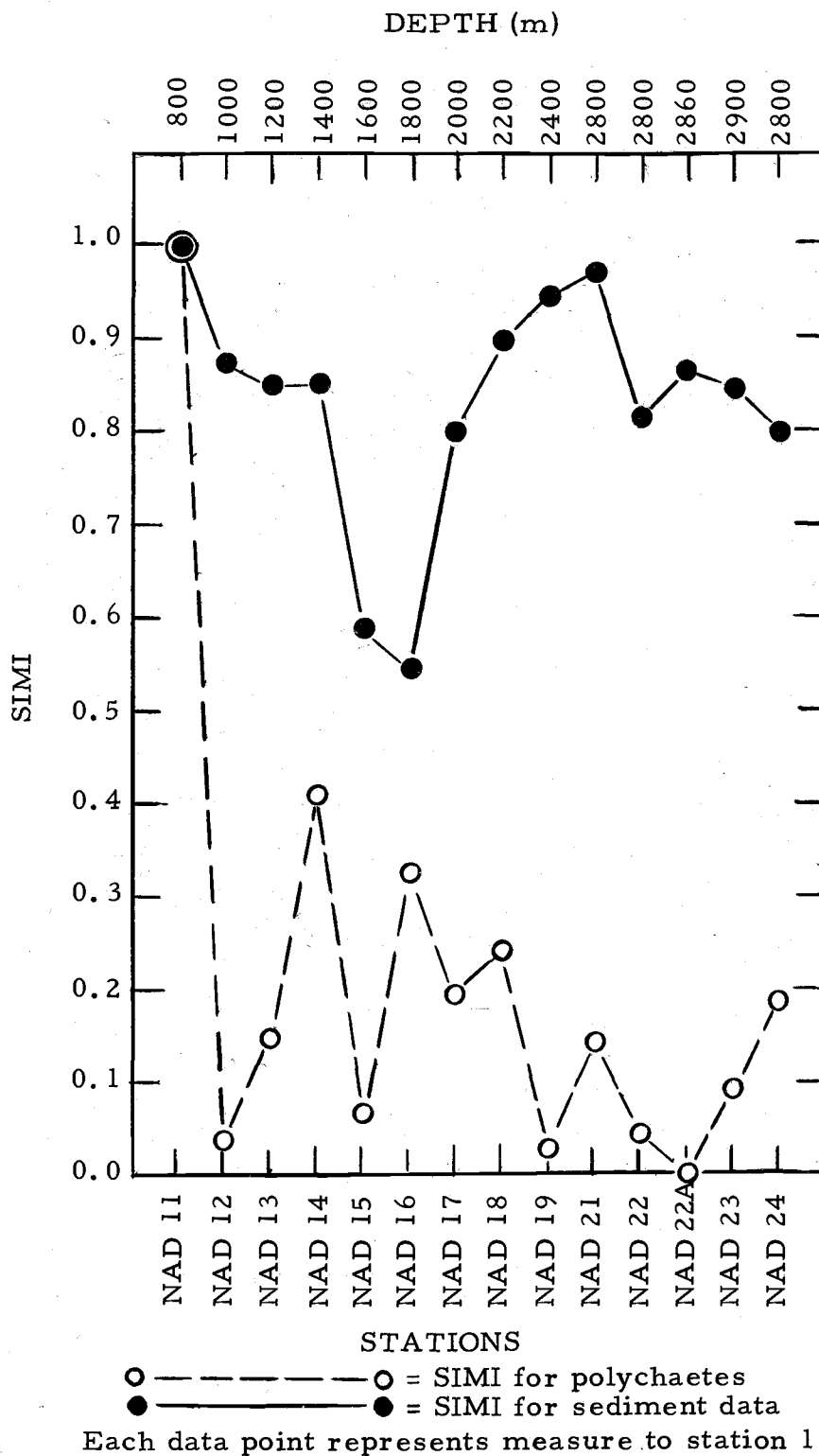


Figure 7. Similarity of sediment composition relative to station 11.

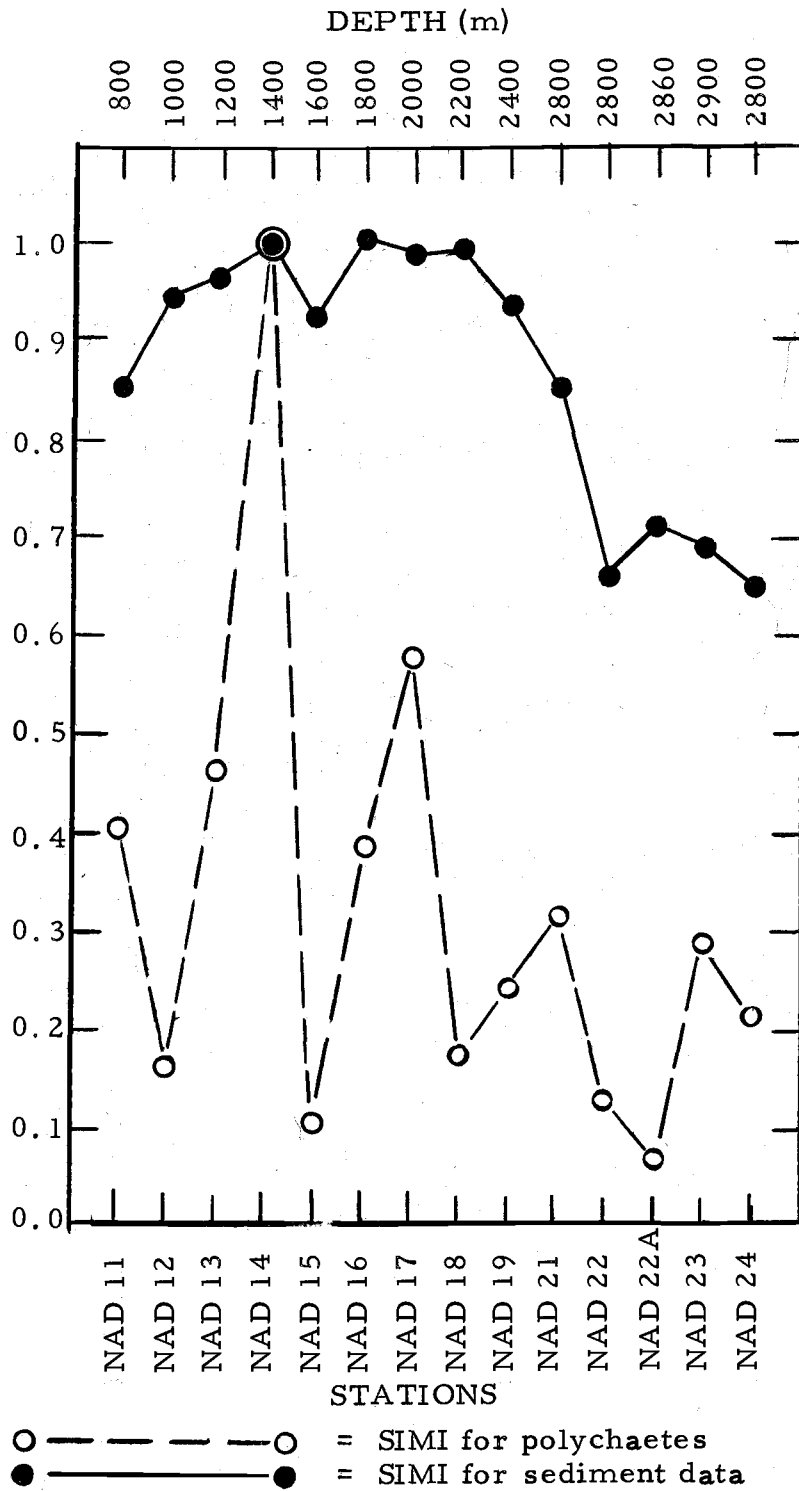


Figure 8. Similarity of sediment composition relative to station 14.

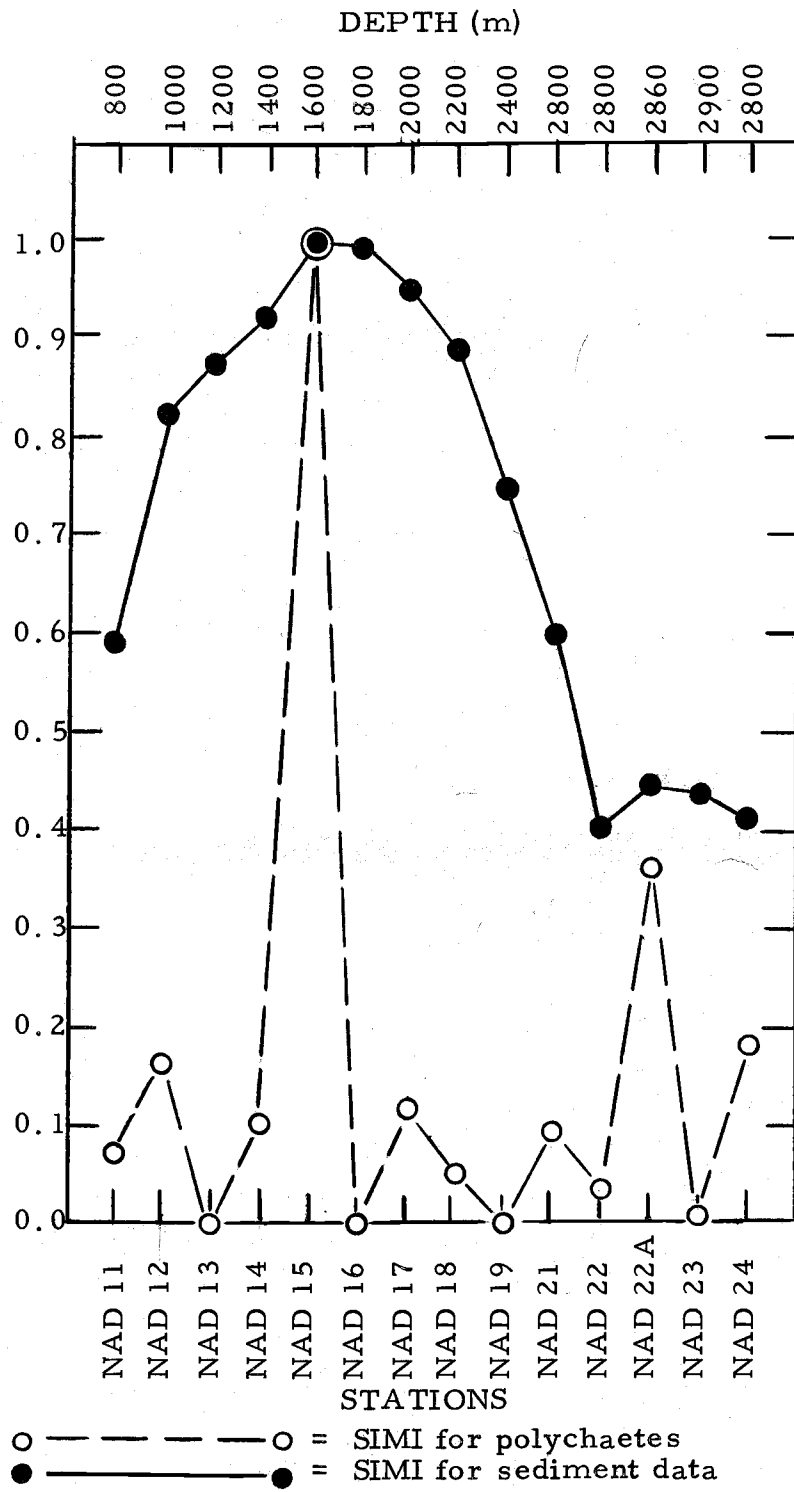


Figure 9. Similarity of sediment composition relative to station 15.

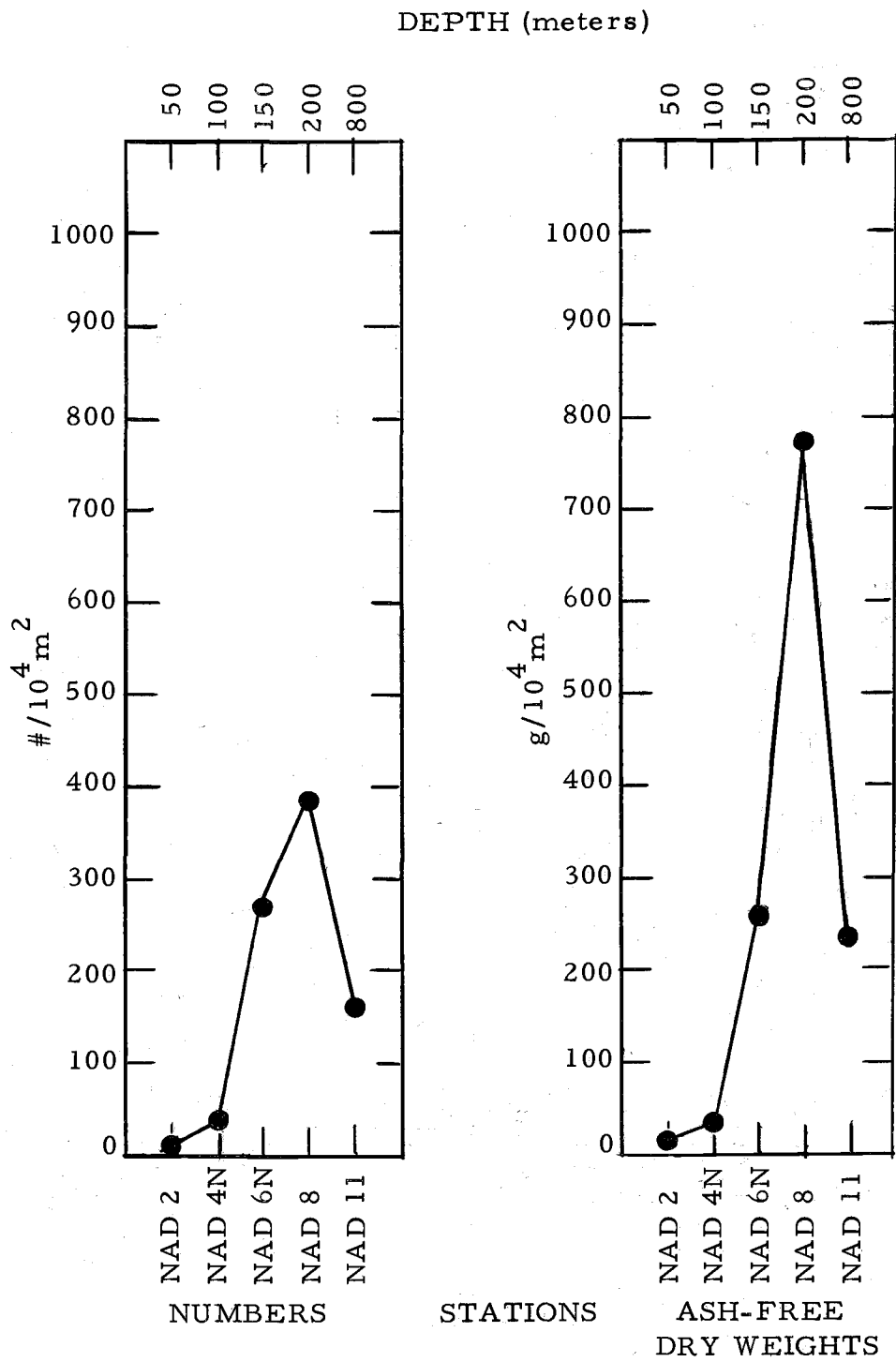


Figure 10. Abundance index for epifauna.

DISCUSSION

Measure and meaning of diversity

Many workers have used and defined many different diversity indices (Gleason, 1922; Fisher, Corbett, and Williams, 1943; Margalef, 1958; Patten, 1962; Lloyd and Ghelardi, 1964; Paine, 1966; Sanders, 1968; McIntosh, 1967; Simpson, 1949). Both McIntosh (1967) and Sanders (1968) give reviews and criticisms of previous work.

Diversity is defined as measuring the degree of unlikeness among groups of objects. In this project I have characterized the degree of unlikeness in terms of numbers of individual organisms grouped into species, and biomass (as ash-free dry weight) grouped into species. "Degree of unlikeness" is an intuitive definition that encompasses many other definitions, including those of Margalef, McIntosh, Simpson, and Lloyd and Ghelardi, in that it depends both on number of species (variety, or "richness") and distribution of individuals among the species, (Lloyd and Ghelardi's "equitability" component. *and number variety, etc. etc.*)

Sanders (1968) is rightfully concerned with the effect of sample size upon the bias of the various diversity indices. He feels that since the commonly used diversity measures are dependent on sample size that diversity should be measured simply in terms of variety,

and he proposes a measure based on total number of species and total number of individuals in a sample, the "rarefaction" method, which is "independent" of sample size only in that it reduces all samples taken to the lowest common denominator: the smallest sample. In fact, bias can only be defined in terms of a specific parameter, which in Sanders' case, must be the total number of species in the community. Sanders' method ignores distribution of individuals among the species and has a downward bias in relation to total species number. Since Sanders' method is to compare collections of "rarefaction curves", this bias is not apparent because it is cancelled out in the comparison. Information is lost in the artificial reduction, or "rarefaction", of a sample of large size to one of small size. Use of Simpson's measure or the commonly used diversity index based on information theory (Margalef, 1958) would make full use of the data, and it would also include the necessary equitability component of diversity.

Simpson's treatment is particularly significant as an attempt to estimate a population parameter, whereas most biological statistics "are defined as statistics to be calculated from sample data and not in terms of population constants" (Simpson, 1949).

Just as diversity must be distinguished from variety, so must it be distinguished from abundance. Direct estimates of abundance, although easy to calculate by dividing sample measures by sample

area, are difficult to interpret because of the difficulty in determining the sampling efficiency of the gear. McIntosh (1967) proposes an index of diversity derived as a special case of the distance measure of similarity. This index is $\sqrt{\frac{S}{\sum_{i=1}^S n_i^2}}$ where S equals number of species and n equals the number of individuals in each species. This index is not an estimate of a population parameter and is widely variable with sample size, since the n_i 's will increase as the sample size, N , increases. To be able to make comparisons between samples an index must represent a population constant. This can be done by using relative values such as proportions. McIntosh's index, simply divided by N , becomes equal to the square root of Sd^2 and then fulfills the criteria for a useful index. By itself it has little utility.

Both Simpson's index and the information measure are significant parameters in terms of estimating population constants. They are useful in that they vary within limits and are amenable to comparison between different populations. In fact the limits are similar. The information measure, $H = -\sum_S p_i \log_e p_i$, achieves a maximum when the individuals are distributed equally among the species in the population, i. e. $p_i = 1/N$ for each $1, \dots, N$. Then $H_{\max} = -\log_e 1/N = \log_e N$. Similarly, Simpson's index, $1 - Sd^2$, achieves a maximum value when $p_i = 1/N$ for N species, that is, when Sd^2 is at a minimum, and $Sd_{\min}^2 = 1/N$.

Both indices are of value, but I feel that Sd^2 is preferable because of its probabilistic interpretation and its relationship to distance and similarity measures.

Some thoughts on diversity and population biology

When a sample is taken it represents the end product, up to the time of sampling, of evolutionary and ecological processes operating upon the population of interest. In this sense it bears a relation to those processes, and insights into them may be derived from the information contained in the sample, provided this information accurately reflects what has occurred or is occurring in the population as a whole.

Levins' (1968) stimulating book, Evolution in Changing Environments, contains the seeds of many exciting insights into population biology. In his discussion of niche theory he presents five questions:

1. What determines the degree of specialization of a species, or inversely, its niche breadth?
2. What determines the species diversity of a community in relation to area, climatic region, size of organism, trophic level, etc. ?
3. How similar can species be and yet coexist?
4. How do similar species divide the environment among them?

5. How do species in the same community affect each others evolution? When do species alter their niches?

Levins proposes that "niche breadth", B , be defined as either

$$\log B = \sum p_i \log p_i \quad (24)$$

or

$$1/B = \sum p_i^2 \quad (25)$$

In this case p_i is the proportion of the species which is found in environment i , so equation (2) is not the same as Simpson's Sd^2 , although the form is identical and will have similar properties. Levins has no preference for either definitions, (24) or (25).

That there is a relationship of diversity to environment is obvious. What Sanders (1968) calls the time-stability hypothesis expresses it well. It requires time to evolve new species and since a highly diverse population contains many species, this condition is ordinarily found in a temporally stable environment; that is, an environment with constant physical conditions over time. Conversely, an environment where physical conditions are not uniform and constant will lead to low diversity. The relationship to evolution is direct. It requires a species with large variability to react to selective pressures imposed by a rapidly changing environment. This species will presumably have a large niche breadth. The specialized organisms with narrow niche breadth found in a diverse community

will not be capable of surviving in such a situation.

In a stable environment, particularly one limited in resources like the benthic, increased specialization of a species allows greater efficiency in utilizing existing resources, with the concomitant sacrifice of some genetic variability. This restricts that species' ability to live successfully in other environments, thus decreasing its niche breadth. Decreased niche breadth implies distribution of the resources among a greater number of species and, therefore, a higher diversity.

The relationship of Levin's niche breadth to Sd^2 may be interpreted as $1/B$ representing the proportional distribution of one species with respect to N environments, while Sd^2 represents the proportional distribution of N species with respect to a single environment.

It is not so easy to devise an estimator for B as it is for λ . Sampling would have to occur with equal intensity over the several environments in which the species occurs. The concept would, however, have particular use in food utilization studies over select environments. While a species parameter for B may not be forthcoming, the measurement of B over a range of differential resources would give numerical values for a limited niche breadth in the habitat under consideration.

Considerations on trawling

In this study it has been assumed that the beam trawl and

anchor-box dredge have been sampling each species with equal sampling efficiency, and that the distribution of organisms is random. It is likely that neither of these assumptions is correct. It is possible that the long duration of a trawl would reduce the effect of non-random distribution, but the differential sampling efficiency is still a problem. This subsection considers some of the effects of this problem for net trawls and a possible solution. The methods discussed were not applied, but are presented as an interesting comment on trawling.

In order to properly evaluate the results of beam trawling, or of any trawling, we wish to know what proportion of the population the trawl is sampling, and what the probability of selection is by age-class or size-class of the organism of interest. Since little or nothing is known about the age structure of the populations sampled in this study, we will restrict the discussion to that of size-class.

Most of this discussion is drawn from the work of R. J. H. Beverton and S. J. Holt, On the Dynamics of Exploited Fish Populations (1957). They develop a model for the commercial fisheries which also has application here. Two assumptions in the model are that there is a random element in the movement of the sampling gear and sampled organism relative to each other, and that the change in the probability of selection is a function of size. Organisms within the selection range of the gear have a chance of escaping through the meshes of the net, and this chance depends on their size. The proba-

bility of selection does not suddenly reach a maximum when it is plotted against size, but it bears a strong resemblance to an integrated normal curve; the implication being that the processes of escape within the selection range are of a random nature. This curve is called the selection ogive and a hypothetical example is illustrated in Figure 11.

In the commercial fisheries the parameter of interest is the fishing effort per unit area, or fishing intensity. It is a linear function of π_i , the fishing mortality coefficient, which is identical to the probability of selection (Beverton and Holt, 1957). In this discussion we are interested only in gear selection, not how it relates to commercial fishing; thus we choose the selection probability, π_i , as our parameter of interest.

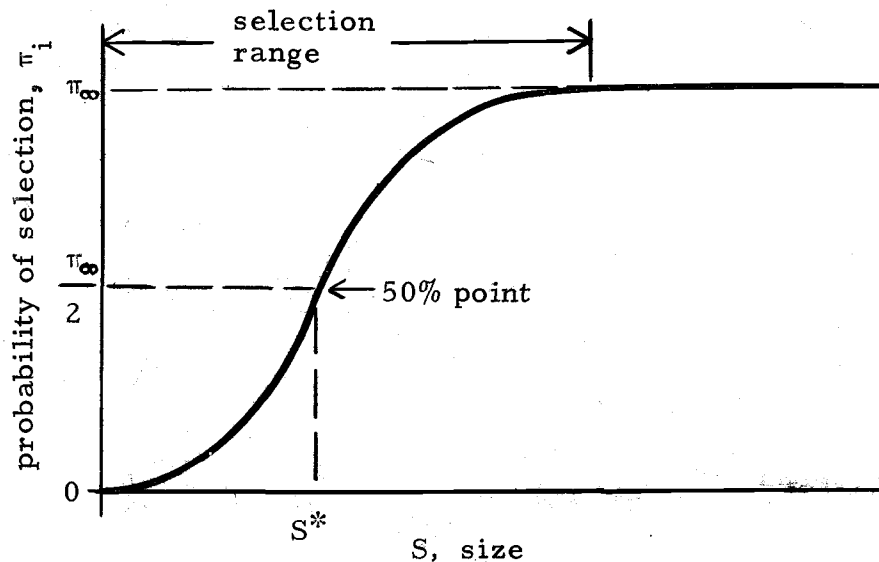


Figure 11. Hypothetical selection ogive.

The selection ogive is specific for a given species and a given piece of gear. The non-asymptotic portion of the ogive determines the selection range of the gear. When the size range of the organism under consideration falls within the selection range, the ogive becomes significant for the catch. It may become very important if that size range occupying the selection range is a large fraction of the size captured. If the size range falls below the selection range, no organisms are captured. If it falls above, the species is sampled at the maximum probability of selection (π_{∞} in Figure 4, the asymptotic portion of the curve).

The ogive is not open-ended, and the selection probability will decline once the animals are large enough to either avoid the net or not fit through the net opening. One must also keep in mind the effect of gear saturation, which is the tendency of a piece of gear to lose its fishing efficiency as the catch in it increases. For example, as the weight increases in a net the mesh changes from a characteristic diamond shape to a more square shape.

The main action of a trawl is in the cod end. Beverton and Holt describe a constant unit called the selection factor, b , where

$$\text{first retained size} = b \times \text{mesh size} . . .$$

Therefore, a change in mesh size gives a change in the age of first retainment and a change in the fishing power where fishing power = quantity caught/unit time/standard boat. There are other, more

complex factors involved in change of mesh size, but this is a good first approximation. The mesh selection ogive may be determined experimentally by running simultaneous paired trawls of different mesh sizes. Steps must be taken to assure that the variance between sample pairs is minimized. The mesh sizes are chosen so that the selection range of the larger mesh is included by the range of maximum selection probability of the smaller mesh trawl (see Figure 12).

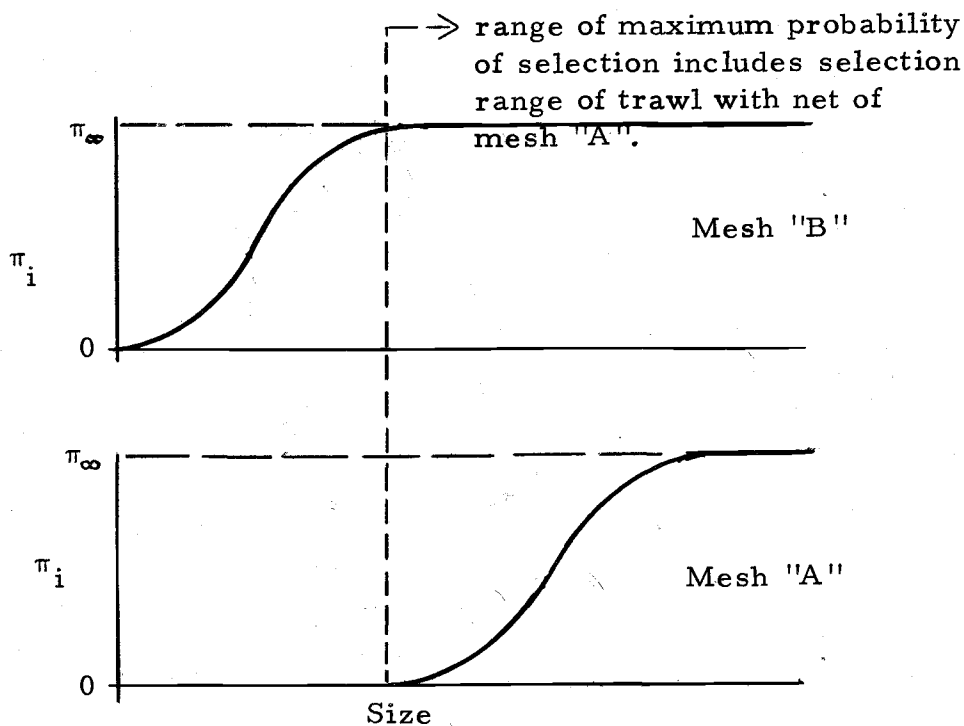


Figure 12. Hypothetical selection ogives of trawls with different mesh sizes.

In order to determine the selection ogive from the paired haul data the ratio of the number caught in each size class from net "A" to the number caught in each size class of net "B" must be computed.

This ratio, plotted against size, will give the selection ogive of the gear with mesh "A". There are refinements to this method, but this is the basic idea. The method is given in detail in Beverton and Holt (1957) for samples of plaice and haddock.

The mesh selection ogive is simply a relationship of the size of the organism to its probability of being captured by the net. The actual sample will depend on the mesh selection ogive and the probability of any one organism of size S being in the way of the net. This is essentially the size distribution of the animal in the sampling locality. The resultant catch curve is the product of these two curves. Figure 13 is a hypothetical example.

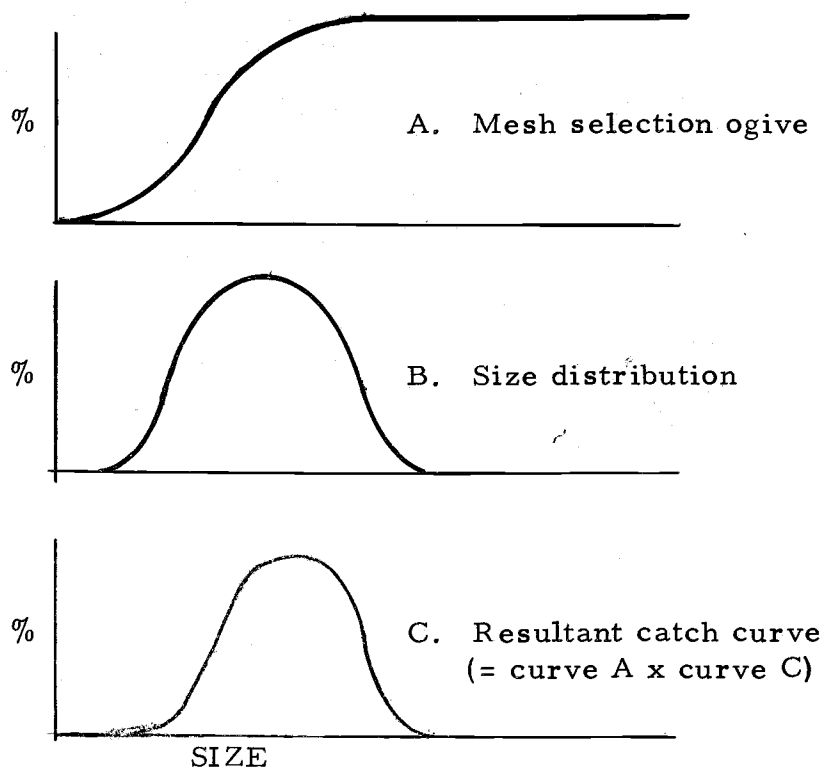


Figure 13. Resultant catch curve for size range overlapping selection range of gear.

If the mesh selection ogive is known one can determine the size distribution in the environment from the catch curve, since the mesh selection ogive is a constant for the gear and the particular species. However, if the selection range of the gear is greater than the size distribution nothing can be inferred below the size of first retainment for that piece of gear.

Once the selection ogive is known, decisions can be made on which size organisms to count in a quantitative sample as being representative of the population. The simplest method is that of knife-edge selection where no animals with size less than the size s^* , corresponding to the 50% selection point, are counted (Figure 11). There are more refined methods of linear and discontinuous approximation elaborated in Beverton and Holt (1957). The important point is that data in the selection range of the trawl need not be discarded but may be incorporated into the quantitative analysis by extrapolating with one of several methods so that they have equal weight as those data collected in the asymptotic range of the ogive. Future studies with the quantitative beam trawl and anchor-box dredge may yield superior data if the sampling characteristics of the gear can be studied in detail.

CONCLUSIONS

The purpose of statistics in laboratories should be to save labor, time, and expense by efficient experimental designs. The aim of basic research is not to produce statistically valid results but to study new phenomena. (Feller, 1969).

The methodology presented in this study is significant only if it leads to the generation of new insights concerning the populations under consideration. The definition of the statistical measures upon population parameters is a step in the right direction, for the results ought to apply to what is out in nature and not just to what is in the sample bag.

Benthic studies are difficult. The "sampling problem" cannot be much greater in any other area for communities and habitats change rapidly and irregularly in depth. Sanders and Hessler (1969) report that the faunal composition of a habitat type will change as much along a contour line thousands of kilometers long as it will for a change in depth of only a few hundred meters. The distance tables (Tables 4 and 5) show that along the length of the Newport transect line small changes in depth signify large changes in community structure.

The method of sampling discrete stations at large depth intervals has shown a broad pattern of high diversity and little similarity from station to station. To achieve the resolution necessary to define all changes in species distribution with depth would require increased

sampling along the length of the transect line - the holes between existing stations should be filled in. It would be useful to sample north and south along contour lines to see how similarity would change with constant depth.

An analysis of variance at each station was not done in this study because of lack of time and well-developed methods of analysis, but it would have shown a great variance within the samples at a particular station. This was due either to patchiness of the animals in the environment or variance or inaccuracy in reported sample depth. Accurate knowledge of the sampled depth is vital. If any patchiness that exists is fine enough to be filtered out by long sampling times then samples in the same area and depth ought to produce similar results. Each sample can then stand as representative of the precise depth sampled.

Only if one has inferential confidence that the data accurately characterizes what is present in the environment can the indices presented in this thesis be of use. Larger sample size will help; sampling at shorter depth intervals should improve the resolution of the analysis.

The fishing model of Beverton and Holt (1957) may well be applied to benthic ecology. Determination of the selection ogives for major species would enable them to be used as organismic indices for quantitative studies like this one without using a finer mesh net at

all times. This would make trawling and analysis easier and faster.

The significance of this thesis lies not so much in the results reported as in the methods applied to the data. A sampling program designed or modified to produce valid data with this method could aid greatly in increasing understanding of the benthic community.

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Table 7. Anchor dredge station list.

Anchor Dredge	Date	Depth (m)	Station	Start Latitude	Start Longitude	Finish Latitude	Finish Longitude
4	6-21-62	800	NAD 11	44-40.3	124-59.0	44-39.0	124-58.2
6	6- 6-63	2000	NAD 17	44-33.5	125-14.6	-----	-----
7	8-13-62	1800	NAD 16	44-38.8	125-12.1	-----	-----
9	8-13-62	2800	NAD 21	44-36.4	125-24.8	-----	-----
10	9- 4-62	800	NAD 11	44-40.3	124-59.0	-----	-----
10a	9- 4-62	800	NAD 11	44-40.3	124-55.9	-----	-----
11	9- 5-62	1600	NAD 15	44-39.2	125-11.0	-----	-----
13	9- 5-62	2200	NAD 18	44-39.0	125-13.2	-----	-----
16	10- 4-62	1200	NAD 13	44-39.0	125-10.0	44-38.0	125-10.0
17	10- 4-62	2000	NAD 17	44-39.1	125-19.6	44-39.1	125-18.8
18	10- 5-62	2900	NAD 23	44-39.1	126-31.0	44-36.5	126-31.8
19	10- 6-62	2900	NAD 22	44-39.7	126-0.03	-----	-----
20	12- 4-62	800	NAD 11	44-39.0	124-58.0	44-39.4	124-58.0
21	12- 4-62	800	NAD 11	44-39.4	124-58.0	44-39.7	124-58.0
22	12- 4-62	800	NAD 11	44-39.7	124-58.0	44-39.6	124-58.0
23	12- 4-62	800	NAD 11	44-39.6	124-58.0	44-40.1	124-58.3
24	12- 4-62	800	NAD 11	44-39.6	124-58.0	44-39.8	124-58.0

Table 7. Anchor dredge station list (continued).

Anchor Dredge	Date	Depth (m)	Station	Start Latitude	Start Longitude	Finish Latitude	Finish Longitude
25	12-05-62	800	NAD 11	44-39.8	124-58.0	44-40.6	124-58.5
28	1-25-63	800	NAD 11	44-40.3	124-57.0	-----	-----
29	1-25-63	800	NAD 11	44-39.3	124-57.0	-----	-----
30	1-25-63	800	NAD 11	44-39.3	124-57.4	-----	-----
31	1-25-63	1400	NAD 14	44-39.2	125-11.0	44-38.7	125-10.9
32	1-25-63	2400	NAD 19	44-38.6	125-20.1	44-37.6	125-21.0
33	1-25-63	2800	NAD 21	44-39.0	125-34.0	44-39.0	125-33.2
37	4-27-63	800	NAD 11	44-40.0	124-58.0	44-35.7	124-56.6
38	4-27-63	800	NAD 11	-----	-----	-----	-----
39	4-27-63	1420	NAD 14	44-39.1	125-11.0	44.39.5	125-11.1
41	6- 1-63	2800	NAD 21	44-39.3	125-34.2	44-40.9	125-35.2
42	6- 1-63	2800	NAD 21	44-40.6	125-35.5	44-43.3	125-36.0
43	6- 1-63	2800	NAD 22	44-40.0	126-03.0	44-38.0	126-03.0
44	6- 1-63	2800	NAD 22	44-38.0	126-03.0	44-38.5	126-03.8
47	5-15-63	800	NAD 11	44-39.2	124-57.0	44-37.7	124-57.6
48	6-16-63	800	NAD 11	44-38.7	124-57.5	44-37.6	124-55.7
53	8-14-63	2850	NAD 26	44-39.5	127-54.3	44-41.3	127-51.8

Table 7. Anchor dredge station list (continued).

Anchor Dredge	Date	Depth (m)	Station	Start Latitude	Start Longitude	Finish Latitude	Finish Longitude
55	8-15-63	2600	NAD 25	44-37.4	127-28.0	44-39.0	127-28.2
59	10-29-63	800	NAD 11	44-40.0	125-05.0	-----	-----
60	10-30-63	800	NAD 11	44-40.0	124-58.0	-----	-----
65	12-29-63	2750	NAD 21	44-42.0	125-37.8	44-40.9	125-36.9
74	2-20-64	1400	NAD 14	-----	-----	-----	-----
86	5-19-64	2865	NAD 21	44-38.4	125-35.0	44-38.4	125-36.3
88	5-20-64	2860	NAD 22A	44-39.1	126-16.8	44-39.0	126-17.8
89	5-20-64	2860	NAD 22A	44-38.5	126-16.1	44-38.1	126-16.4
110	8-11-64	2798	NAD 21	44-40.1	125-34.0	44-40.0	125-35.0
119	1-13-65	2800	NAD 22	44-38.0	126-02.2	44-38.0	126-06.0
139	2-10-65	2800	NAD 24	44-39.4	126-59.1	44-39.8	126-59.2
148	6- 5-65	1000	NAD 12	44-40.7	125-10.0	44-41.1	125-10.0
149	6- 5-65	1600	NAD 15	44-41.2	125-15.0	44-41.9	125-15.1
150	10-21-65	2560	NAD 26	44-39.1	127-55.5	44-39.0	127-56.6

Table 8. Beam trawl data summary and station list.

Trawl Station	Depth	# Species Observed	# of Individuals		Date	SD ² x10 ³
			S	N		
NAD	meters					
13	2	50	4	8	7/13/68	281
14	2	50	4	6	7/13/68	333
15	2	50	1	4	7/13/68	1000
16	4N	100	5	29	7/13/68	593
17	4N	100	6	17	7/13/68	232
10	4N	100	2	2	10/31/67	500
7	6N	150	7	38	10/31/67	341
8	6N	150	2	75	10/31/67	974
18	6N	150	10	34	7/13/68	204
5	8	200	5	91	10/30/67	446
6	8	200	7	92	10/30/67	463
3	11	800	16	242	10/30/67	254
4	11	800	12	191	10/30/67	241
24	11	800	12	122	7/14/68	178

Trawl	Start	Tow	Finish	Tow	Time	Area
	Lat	Long	Lat	Long	Towed mm	Traversed x1000 m ²
13	44-39.5	124-08.8	44-40.7	124-09.0	20	4.956
14	44-40.5	124-09.2	44-39.9	124-09.0	30	4.069
15	44-39.9	124-09.0	44-40.7	124-09.2	20	3.841
16	44-43.9	124-08.4	44-44.5	124-19.2	15	5.625
17	44-45.5	124-19.3	44-44.8	124-19.2	20	3.133
10	44-44.1	124-18.5	44-44.2	124-18.6	10	2.248
7	44-42.8	124-31.0	44-42.8	124-31.0	5	3.316
8	44-43.7	124-29.9	44-43.7	124-29.1	5	1.203
18	44-43.7	124-29.3	44-43.0	124-29.4	20	4.330
5	44-38.5	124-36.0	44-38.3	124-36.2	10	2.633
6	44-38.6	124-36.2	44-39.1	124-36.2	10	2.122
3	44-36.7	124-56.7	44-37.3	124-56.7	30	9.801
4	44-34.3	124-54.8	44-33.4	124-55.2	30	15.467
24	44-43.2	124-29.4	44-43.8	124-29.3	20	10.216

Table 9. Anchor-dredge data summary.

Data Block #	Station NAD	Dredge #	Species Obs.	# of Individuals	Sd ² x10 ³
1	11	4	12	50	138
2	11	10	30	192	147
3	11	10a	10	25	302
4	11	20	14	36	196
5	11	21	10	31	257
6	11	22	17	65	156
7	11	23	15	71	206
8	11	24	34	139	080
9	11	25	19	101	199
10	11	28	12	79	148
11	11	30	9	15	138
12	11	37	12	92	190
13	11	38	13	23	142
14	11	47	15	39	182
15	11	48	8	19	191
16	11	29	16	52	110
17	11	59	8	39	529
18	11	60	7	83	318
19	12	148	5	6	222
20	13	16	12	23	142
21	14	31	14	76	141
22	14	39	8	15	218
23	14	74	6	11	223
24	15	11	5	5	200
25	15	149	2	2	500
26	16	7	19	38	086
27	17	16	24	73	109
28	17	17	17	50	100
29	18	13	9	12	125
30	19	32	8	12	139
31	21	9	21	156	141
32	21	33	15	31	093
33	21	41	11	33	225
34	21	42	16	47	095
35	21	65	14	66	129
36	21	86	2	2	500
37	21	110	12	34	163
38	22	38	4	5	280

Table 9. Anchor-dredge data summary (continued).

Data Block #	Station NAD	Dredge #	Species Obs.	# of Individuals	$Sd^2 \times 10^3$
39	22	43	5	5	200
40	22	44	9	14	150
41	22	119	6	53	316
42	22A	88	4	7	265
43	22A	89	11	17	142
44	23	18	9	19	202
45	24	139	9	82	214

Table 10. Computed Conversion Factors for Epifauna.
(Wet Weight to Ash-free Dry Weight by Species)

Sp. #	Wet Wt. to Dry Wt.	S'	Wet Wt. to A.F.D.W.	S'	No. of Samples	Data From Similar Sp.
1	0.095	0.010	0.072	0.010	3	
2	0.097	0.017	0.082	0.010	3	
3	0.290	0.017	0.164	0.000	3	
4	0.329	0.042	0.193	0.024	3	
5	0.311	0.037	0.180	0.030	3	
*6 ^A	0.174	0.062	0.120	0.044	3	
J	0.160	0.046	0.073	0.024	3	
7	0.349	-----	0.162	-----	1	
8	0.332	0.087	0.232	0.073	2	
9	0.210	0.000	0.168	0.000	3	
10	0.240	0.037	0.161	0.045	3	
11	0.240	0.037	0.161	0.045	3	
12	0.237	0.000	0.172	0.000	3	
13	0.134	0.060	0.110	0.059	3	x
14	0.659	0.010	0.049	0.000	3	
15	0.583	-----	0.091	-----	1	
16	0.516	0.046	0.099	0.010	3	
17	0.455	0.056	0.109	0.021	3	
18	0.571	-----	0.086	-----	1	
19	0.571	-----	0.086	-----	1	
20	0.439	0.073	0.093	0.005	3	
21	0.688	0.015	0.080	0.005	3	
22	0.170	0.009	0.141	0.007	3	
23	0.455	0.056	0.109	0.022	3	x
24	0.439	0.073	0.093	0.005	3	x
25	0.382	0.019	0.021	0.003	3	
26	0.467	0.035	0.065	0.013	3	
27	0.323	0.058	0.091	0.016	3	
28	0.275	0.018	0.076	0.008	3	
29	0.024	0.042	0.073	0.023	3	
30	0.025	0.018	0.093	0.005	3	
31	0.307	0.027	0.117	0.015	3	
32	0.319	0.028	0.097	0.009	3	
33	0.393	0.070	0.129	0.042	3	
34	0.240	0.152	0.061	0.042	3	
35	0.133	-----	0.105	-----	1	
36	0.294	0.042	0.073	0.023	3	

Table 10. Computed Conversion Factors for Epifauna. (cont.)
 (Wet Weight to Ash-free Dry Weight by Species)

Sp. #	Wet Wt. to Dry Wt.	S'	Wet Wt. to A.F.D.W.	S'	No. of Samples	Data From Similar Sp.
37	0.486	0.014	0.063	0.007	3	
38	0.393	0.027	0.086	0.008	3	
39	0.413	0.019	0.044	0.009	3	
40	0.208	0.057	0.037	0.009	3	
41	0.131	0.259	0.044	0.000	3	
42	0.129	0.082	0.091	0.077	3	
43	0.208	0.063	0.032	0.013	3	x
44	0.136	0.008	0.073	0.003	3	
45	0.150	0.050	0.117	0.049	3	x
46	0.150	0.050	0.117	0.049	3	x

* A = Adult

J = Juvenile

Table 11. Summary of Percent Particle Size of Sediment (by weight).

NAD Station	Sand (%)		Silt (%)		Clay (%)		Sediment Type	Number of Samples
	Mean	Range	Mean	Range	Mean	Range		
2	100.0	-----	-----	-----	-----	-----	Sand	6
4	100.0	-----	-----	-----	-----	-----	Sand	3
6N	70.3	67.0-74.0	23.7	21.0-26.0	6.0	4.0- 7.0	Silty Sand	6
8	69.3	56.0-78.0	23.0	16.0-31.0	7.7	4.0-13.0	Silty Sand	7
11	2.2	0.9-10.3	67.5	56.8-80.1	30.4	9.5-40.0	Clayey Silt	16
12	26.1		39.6		34.3		Sand Silt Clay	1
13	30.0		40.1		29.9		Sand Silt Clay	1
14	32.1	21.1-49.7	50.0	43.5-63.5	18.0	0.0-30.7	Sand Silt Clay	3
15	54.6	31.2-78.0	36.5	28.1-44.9	8.8	0.1-17.5	Silty Sand	2
16	54.6		38.8		6.2		Silty Sand	1
17	37.5	24.2-45.5	49.2	43.5-53.0	13.3	3.3-22.8	Sandy Silt	2
18	25.66		47.2		27.09		Sand Silt Clay	1
19	-----		-----		-----		-----	-
21	7.3	1.2-12.8	52.5	45.8-64.7	40.2	23.8-52.1	Clayey Silt	8
22	1.4	0.6- 1.8	39.1	36.7-40.8	62.3	55.9-62.8	Silty Clay	4
22A	2.0	1.62-2.38	40.0	36.6-45.0	57.08	52.4-61.7	Silty Clay	2
23	2.1		38.3		59.6		Silty Clay	1
24	0.80		30.5		68.6		Silty Clay	1
25	2.4		30.2		67.4		Silty Clay	1
26	1.4	1.3- 1.5	30.6	30.2-30.9	68.1	67.6-68.5	Silty Clay	2

* All samples from NAD stations averaged (See Table 7 for dates and sample number) except beam trawl data.

Table 12. Species List of Epifauna Found in Beam Trawl Samples.

Code #	
1	unknown anemone a
2	unknown anemone b
3	<u>Pagurus tanneri</u> (Benedict)
4	<u>Pagurus ochotensis</u> Brandt
5	<u>Paguristes</u> sp.
6	<u>Chionecetes tanneri</u> Rathbun
7	<u>Lopholithodes foraminatus</u> (Stimpson)
8	<u>Spirontocarus macrophthalma</u> Rathbun
9	<u>Pandalus jordani</u> Rathbun
10	<u>Nectocrangon alaskensis</u> Kingsley
11	<u>Nectocrangon californiensis</u> Rathbun
12	<u>Crangon communis</u> (Rathbun)
13	unknown octopod
14	pelecypod, new sp.
15	<u>Mohnia frieli</u> Dall
16	<u>Neptunea pribiloffensis</u> (Dall)
17	<u>Buccinum</u> sp.
18	<u>Colus</u> sp. a
19	<u>Colus</u> sp. b
20	<u>Lischkeia</u> sp.
21	<u>Antiplanes</u> sp.
22	<u>Armina californica</u> (Bergh)
23	<u>Nassarius fossatus</u> (Gould)
24	<u>Polinices</u> sp.
25	<u>Laqueus californicus</u> (Kock)
26	<u>Dipsacaster anoplus</u> Fisher
27	<u>Zoraster</u> sp.
28	"Zorasteridae"
29	<u>Luidia foliolata</u> Grube
30	<u>Solaster borealis</u> Fisher
31	<u>Pisaster brevispinus</u> (Stimpson)
32	<u>Hippasteria spinosa</u> Verril
33	<u>Benthopecten</u>
34	<u>Thrissacanthus penicillatus</u> (Fisher)
35	<u>Patinopecten caurinus</u> (Gould)
36	unknown starfish
37	<u>Ophiura sarsi</u> Lütken
38	<u>Ophiura lütkeni</u> (Lyman)
39	<u>Brisaster latifrons</u> (A. Agassiz)
40	<u>Allocentrotus fragilis</u> (Jackson)
41	<u>Laetmophasma fecundum</u> Ludwig

Table 12. Species List of Epifauna Found in Beam Trawl
Samples (continued).

Code #	
42	unknown holothuroid sp. a
43	unknown holothuroid sp. b
44	<u>Aphrodite japonica</u> Marenzeller
45	<u>Cheilonereis cyclurus</u> (Harrington)
46	<u>Lurabrineris bicirrata</u> Treadwell

Table 13. Species List of Polychaete Annelids Found in Anchor Dredge Samples.

Code #	
101	<u>Chloeia pinnata</u> Moore
102	<u>Paramphinome "A" n. sp.</u>
103	<u>Anaitides groenlandica</u> (Oersted)
104	<u>Etone longe</u> (Fabricius)
105	<u>Eulalia "A" n. sp.</u>
106	<u>Eumida? sanguinea</u> (Oersted)
107	<u>Gyptis arenicola glabra</u> (Hartman)
108	<u>Ancistrosyllis breviceps</u> Hartman
109	<u>Ancistrosyllis (nr) hamata</u> (Hartman)
110	<u>Sigambra tentaculata</u> (Treadwell)
111	<u>Sigambra</u> sp.
112	<u>Ceratophale loveni pacifica</u> Hartman
113	<u>Nereis</u> sp.
114	<u>Nicon "A" n. sp.</u>
115	<u>Nephtys cornuta</u> Berkeley & Berkeley
116	<u>Nephtys longosetosa</u> Oersted
117	<u>Sphaerodorum brevicapitis</u> Moore
118	<u>Glycera capitata branchiopoda</u> Hartman
119	<u>Hemipodus borealis</u> Johnson
120	<u>Hemipodus "A" n. sp.</u>
121	<u>Glycinde? pacifica</u> Monro
122	<u>Goniada annulata</u> Moore
123	<u>Goniada brunneata</u> Treadwell
124	<u>Nothria geophiliformis</u> Moore
125	<u>Nothria iridescens</u> (Johnson)
126	<u>Nothria lepta</u> (Chamberlin)
127	<u>Nothria pallida</u> Moore
128	<u>Nothria stigmatis</u> (Treadwell)
129	<u>Onuphis vexillaria</u> Moore
130	<u>Onuphis "A" sp. n.</u>
131	<u>Paranorthia</u> sp.
132	<u>Eunice kubiensis</u> McIntosh
133	<u>Lumbrineris bicirrata</u> Treadwell
134	<u>Lumbrineris index</u> Moore
135	<u>Lumbrineris moorei</u> Hartman
136	<u>Lumbrineris similabris</u> Treadwell
137	<u>Lumbrineris</u> sp.
138	<u>Ninoe gemmea</u> Moore
139	<u>Arabella semimaculata</u> (Moore)
140	<u>Drilonereis</u> sp.

Table 13. Species List of Polychaete Annelids Found in
Anchor Dredge Samples (continued).

Code #	
141	<u>Califia</u>
142	<u>Haploscoloplos elongatus</u> (Johnson)
143	<u>Phylo nudus</u> (Moore)
144	<u>Scoloplos</u> (nr) <u>armiger</u> (Müller)
145	<u>Aedicira ramosa</u> (Annenkova)
146	<u>Aricidea lopezi</u> Berkeley & Berkeley
147	<u>Aricidea neosuecica</u> (Hartman)
148	<u>Aricidea uschakovi</u> Zacks
149	<u>Aricidea</u> sp. Hartman
150	<u>Paraonis gracilis oculata</u> Hartman
151	<u>Nerine foliosa occidentalis</u> Hartman
152	<u>Polydora</u> sp.
153	<u>Prionospio cirrifera</u> Wiren
154	<u>Prionospio malmgreni</u> Claparede
155	<u>Prionospio pinnata</u> Ehlers
156	<u>Prionospio "A"</u> sp. n.
157	<u>Prionospio "B"</u> sp. n.
158	<u>Pygospio</u> sp.
159	<u>Spiophanes anoculata</u> Hartman
160	<u>Spiophanes bombyx</u> (Claparede)
161	<u>Spiophanes cirrata</u> Sars
162	<u>Spiophanes fimbriata</u> Moore
163	<u>Spiophanes</u> sp.
164	<u>Magelona</u> sp.
165	<u>Phyllochaetopterus claparedii</u> McIntosh
166	<u>Telepsavus costarum</u> Claparede
167	<u>Chaetozone setosa</u> Malmgren
168	<u>Tharyx multifilis</u> Moore
169	<u>Tharyx "S"</u>
170	<u>Tharyx</u> sp.
171	<u>Cossura longocirrata</u> Webster & Benedict
172	<u>Brada glabra</u> Hartman
173	<u>Brada villosa</u> Rathke
174	<u>Brada "A"</u>
175	<u>Pherusa negligens</u> (Berkeley & Berkeley)
176	<u>Flabelligerid</u>
177	<u>Scalibregma inflatum</u> Rathke
178	<u>Ammotrypane aulogaster</u> Rathke
179	<u>Ammotrypane breviata</u> Ehlers
180	<u>Travisia brevis</u> Moore

Table 13. Species List of Polychaete Annelids Found in Anchor Dredge Samples (continued).

Code #	
181	<u>Travisia?</u> <u>forbesii</u> Johnston
182	<u>Sternaspis</u> <u>scutata</u> (Renier)
183	<u>Notomostus</u> (<u>Clistomastus</u>) <u>lineatus</u> Eisig
184	<u>Asychis</u> <u>similis</u> (Moore)
185	<u>Asychis?</u> <u>ramosus</u> Lerenstein
186	<u>Axiothella</u> <u>rubrocincta</u> (Johnson)
187	<u>Euclymene</u> <u>reticulata</u> Moore
188	<u>Maldane</u> <u>glebifex</u> Grube
189	<u>Maldane</u> <u>sarsi</u> Malmgren
190	<u>Nicomache</u> <u>lumbricalis</u> (Fabricius)
191	<u>Notoproctus</u> <u>pacificus</u> (Moore)
192	<u>Petaloproctus</u> <u>Quatrefages</u>
193	<u>Praxillella</u> <u>gracilis</u> (Sars)
194	<u>Rhodine</u> Malmgren
195	<u>Myriochele</u> <u>heeri</u> Malmgren
196	<u>Cistenides</u> <u>brevicoma</u> (Johnson)
197	<u>Amage</u> <u>anops</u> Johnson
198	<u>Amphicteis</u> <u>mucronata</u> Moore
199	<u>Amphicteis</u> <u>scaphobranchiata</u> Moore
200	<u>Anobothrus</u> <u>gracilis</u> (Malmgren)
201	<u>Anobothrus</u> sp.
202	<u>Lysippe</u> <u>annectens</u> Moore
203	<u>Melinna</u> <u>cristata</u> (Sars)
204	<u>Melinna</u> <u>denticulata</u> Moore
205	<u>Melinna</u> <u>heterodonta</u> Moore
206	<u>Melinna</u> sp.
207	<u>Artacama</u> <u>coniferi</u> Moore
208	<u>Lanicides</u> Hessle
209	<u>Pista</u> <u>fratrella</u> Chamberlin
210	<u>Streblosoma</u> sp.
211	<u>Terebellides</u> <u>eurystethus</u> Chamberlin
212	<u>Terebellides</u> <u>stroemi</u> Sars
213	<u>Trichobranchus</u> <u>glacialis</u> Malmgren
214	<u>Chone</u> <u>gracilis</u> Moore
215	<u>Euchone</u> <u>analis</u> Kröyer
216	<u>Potamilla</u> <u>acuminata</u> Moore & Bush
217	(Blank)
218	<u>Axiothella</u> sp.
219	<u>Euclymene</u> sp.
220	<u>Nicomache</u>
221	<u>Cistenides</u> sp.
222	<u>Amphicteis</u> sp.
223	<u>Pista</u> sp.