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## Animal-Sediment Relationship Study of the Western Branch of the Lynnhaven River

Charles Perry Seymour  
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ANIMAL-SEDIMENT RELATIONSHIP STUDY  
OF THE WESTERN BRANCH  
OF THE LYNNHAVEN RIVER.

by

Charles Perry Seymour  
B.S. June 1974, Fairleigh Dickinson University  
Madison, New Jersey

A Thesis Submitted to the Faculty of  
Old Dominion University in Partial Fulfillment of the  
Requirements for the Degree of

Master of Science

Biology

OLD DOMINION UNIVERSITY  
1979

Approved by:

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Daniel M. Dauer (Committee Chairman)

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ABSTRACT

ANIMAL-SEDIMENT RELATIONSHIP STUDY  
OF THE WESTERN BRANCH  
OF THE LYNNHAVEN RIVER

Charles Perry Seymour  
Old Dominion University, 1979  
Committee Chairman: Dr. Daniel M. Dauer

The animal-sediment relationships of the marine benthic infauna of an estuarine river system, Lynnhaven River, Virginia Beach, Virginia, were studied at six sites, sampled bimonthly for one year. Six species were found to dominate all of the sampling periods and sites for the year. The greatest number of individuals, biomass, and species were found at the sand sites. Deposit feeders were recorded in greater number than suspension feeders at both the sand and the mud sites.

Cluster and nodal analyses were successful in demonstrating animal-sediment relationships for the intertidal regions of the river system.

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## I. Introduction

A benthic organism's distribution and abundance are governed by the hydrodynamic and sediment properties associated with its environment. These properties will inhibit or encourage the recruitment of individuals into an area. Once an organism has settled in the area, again hydrodynamic and sediment properties of the marine ecosystem will influence the natality, mortality, and biomass (i.e., growth or loss of weight) of these individuals.

Petersen (1924) conducted the earliest benthic ecology studies investigating the North Sea. His study proposed to establish the major benthic communities, to characterize their environment, and to delimit their distribution.

Howard Sanders (1958), after examining the relative proportions of deposit feeders and suspension feeders in specific benthic communities, developed the basic concept demonstrating the relationship between the benthic infaunal distribution of the macroinvertebrates and the sediment particle size distribution parameters, median grain size and percentage silt-clay. The proportion of deposit feeders increased as the percentage of silt-clay increased with the greatest number of deposit feeders being found in sediments containing a silt-clay fraction of 78-91%. A suspension feeder's distribution was not controlled by the sediment character itself, but rather by the hydrodynamic processes which would determine that sediment's character.



The largest populations of suspension feeders were found in well-sorted sediments.

This approach to studying the interaction between the water column, the sediment, and the benthos was employed by McNulty et al. (1962), Bloom et al. (1972), O'Connor (1972), and Kinner et al. (1974) in the marine environment. All of the investigators concluded that a definite assemblage of marine benthic organisms would be associated with a particular sediment type, but these same groups of organisms would be found in a wide range of sediments containing silt-clay.

Kinner et al. (1974) showed that sediment containing 51-100% silt-clay was characterized mostly by deposit feeders and not by suspension feeders. Bloom et al. (1972), on the other hand, found that the assemblages most dominated by deposit feeders had a high variance in the silt-clay fraction, 1.3 to 22%. Johnson (1971) reached conclusions similar to Sanders (1958), that the greatest concentrations of deposit feeders were found in those sediments high in the percentage of silt-clay. Johnson (1970) found, for certain areas, that more species of deposit feeders were found than suspension feeders in an area of low silt-clay concentration but these deposit feeders did not dominate in total number. All of the above investigations demonstrate that spatial variation of the concentrations of deposit feeders and of suspension feeders are affected directly or indirectly by the physical properties of the sediment.

As a result of the large quantities of numerical data obtained from these types of animal-sediment relationship studies, mathematical methods have been devised to measure these relationships. Hughes and Thomas (1971) used classification by a hierarchical cluster analysis to

analyze their data. Day, Field, and Montgomery (1971) also used a classification analysis for their benthic research to explain the distribution of faunal assemblages. Boesch (1977b) has explained and showed from studies the usefulness of applying nodal analysis to analyzing ecological studies.

This study was undertaken to collect data on the benthic macro-invertebrates from six stations in the Lynnhaven River, Virginia Beach, Virginia. Two mutivariate analyses--hierarchical classification and nodal analysis--were utilized to analyze the data obtained and to define the benthic faunal assemblages (groups of species that occur in the same habitat) present. The hierarchical classification was used to determine what clustering of species and sites were present in the data. Nodal analysis attempts to explain and interpret the cluster groups that are formed by hierarchical classification. These two methods of analysis were also chosen because of the previous success other researchers have had with them; to see if their application can be used to elucidate patterns in the data collected from this study; and to determine to what extent the benthic faunas' numbers, biomass, and species were affected by sediment types and hydrographic factors of the river. Species diversity was calculated using the Shannon-Weaver Index, Margalef Richness Index, and Pielou's Evenness Index to explain further the seasonal variation in species and numbers between sites.

## II. Site Description

The Lynnhaven River complex is a tidal estuary that empties into the Chesapeake Bay five miles west of Cape Henry (Figure 1). The site is ten miles east of Norfolk, Virginia. The Lynnhaven River complex is composed of several small bays and branches: the Lynnhaven Inlet, Lynnhaven Bay, Long Creek Channel, Broad Bay, and the Eastern and Western Branches.

For the purpose of this study, the Western Branch was selected as the site for the intertidal research. The Western Branch, like the Eastern Branch, is approximately four miles in length from its inlet to the headwaters (Oswalt, 1975). The Western Branch is a relatively shallow body of water with an average mean low water depth of four to six feet and with a mean tidal range of approximately two feet (Johnson et al., 1974).

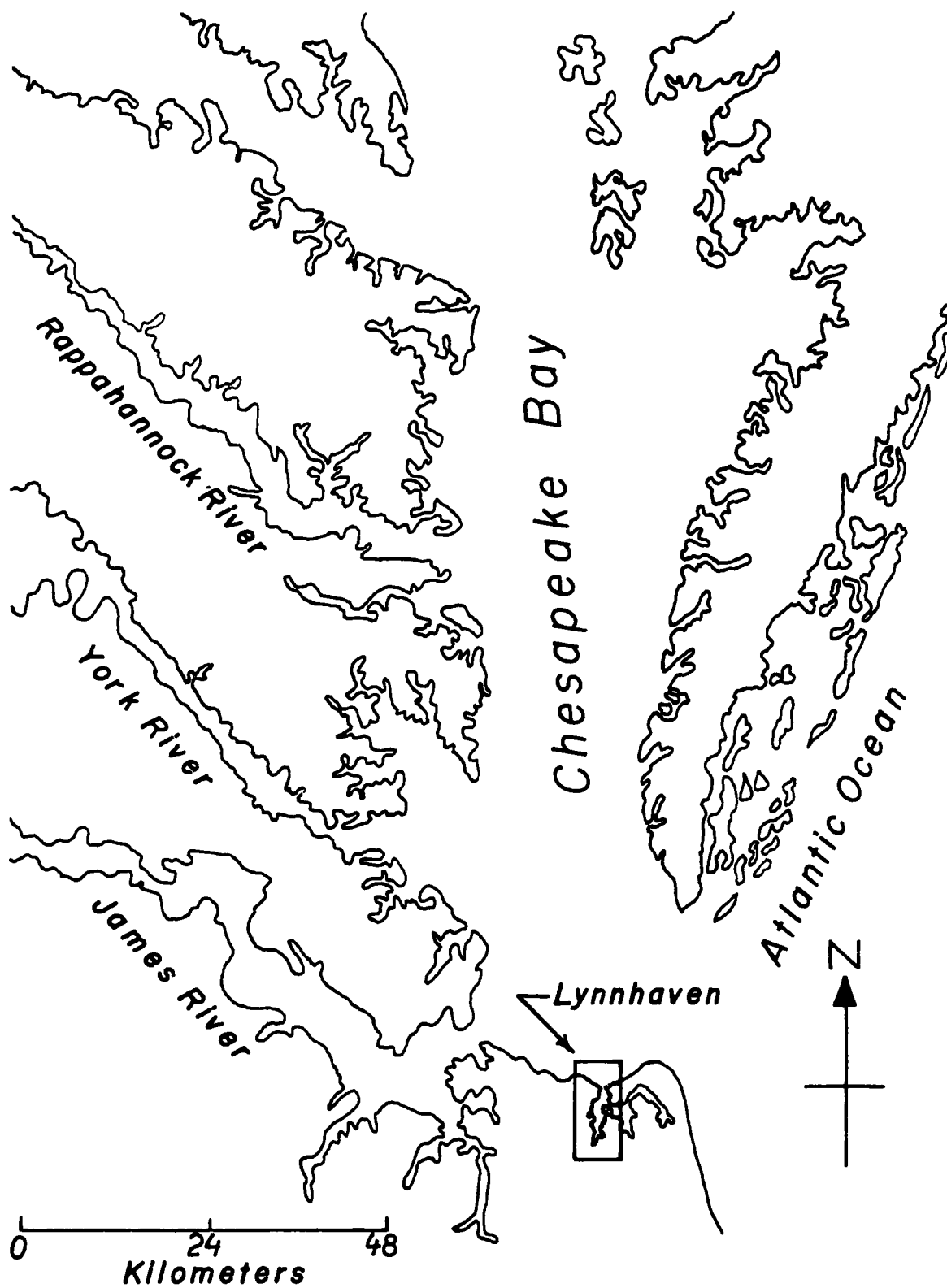


Figure 1. Map Showing the Lynnhaven River System on the Chesapeake Bay, Virginia.

### III. Materials and Methods

#### Collecting Procedures

Six intertidal study sites were sampled from the Inlet to the headwaters of the Western Branch (Figure 2). The six sites studied were in conjunction with a non-point pollution study of the total Lynnhaven River system conducted by Dr. Daniel M. Dauer. Since the river was examined for the effects of possible pollutants on the macro-benthic infauna, sites were located to minimize the effect of sediment type within the two major types of sediment studied.

Sites 1, 2, and 3 were all sand sites. These three sites were chosen from preliminary trips because their sediments were all medium to fine in texture. Site 1 was located near the Inlet of the Lynnhaven, while site 3 was the farthest penetration into the headwaters where medium to fine sands were found. Site 2 was located approximately halfway between sites 1 and 3.

Sites 4, 5, and 6 were selected to represent the upper reaches of the river. These sites have a high proportion of silt-clay. Site 6 was chosen because it was as far up the headwaters of the Western Branch as a motorboat could reach at high tide. Site 4 was located up a shallow creek near a sewage treatment plant. This site was chosen to observe if the outflow from the plant would have a noticeable effect on the area. Site 5 was located approximately halfway between sites 4 and 6.

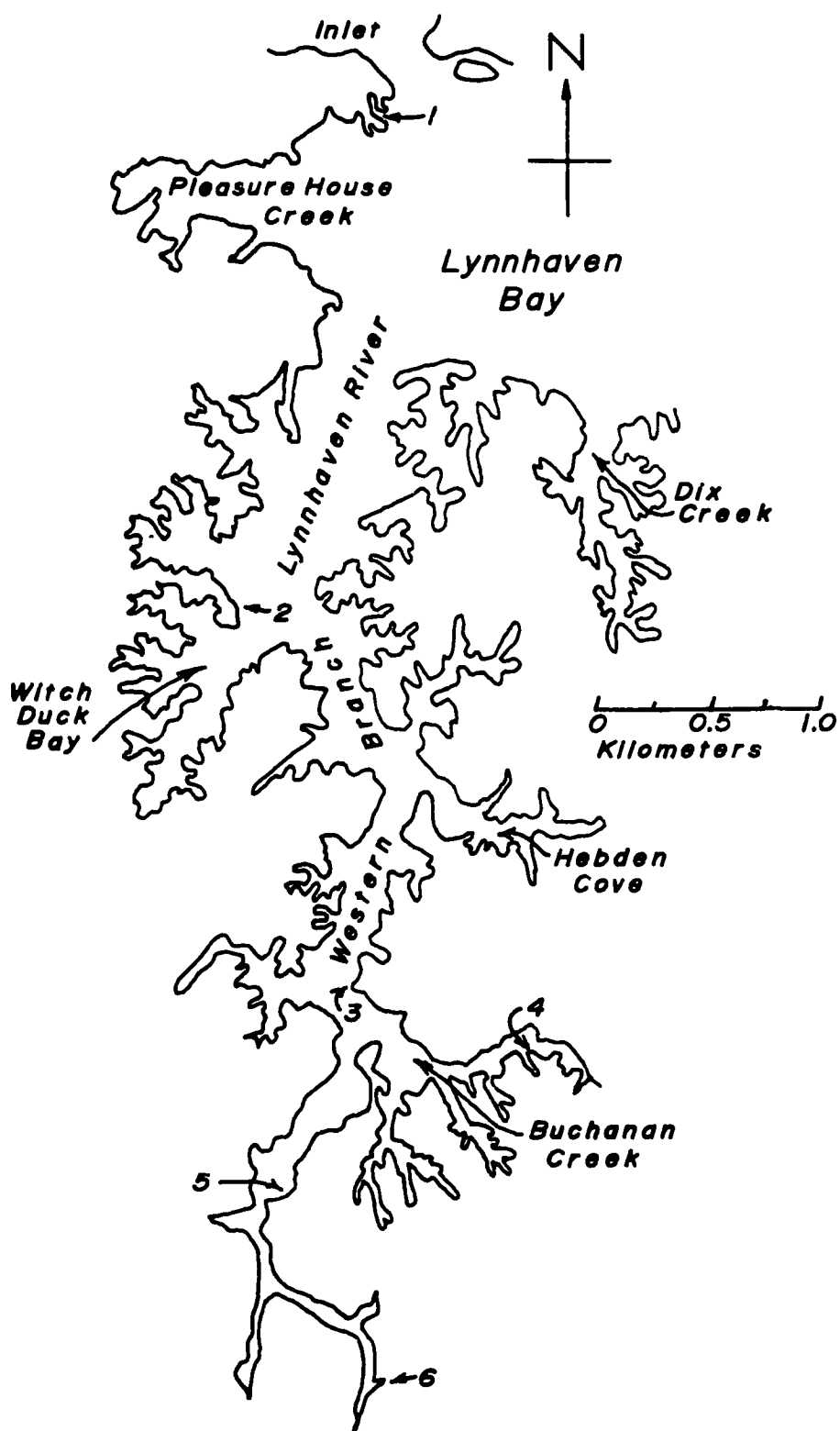


Figure 2. Map of the Western Branch of the Lynnhaven River System.

Samples were taken bimonthly from August 1976 to June 1977. All samples were collected at the mid-tidal level. Ten random samples were taken per site. The samples were obtained by using a 20 cm deep corer with an internal diameter of 8.5 cm.

The samples were sieved through a 0.5 mm screen. The retained organisms were flushed into a jar, relaxed with isopropyl alcohol, stained with rose bengal, and then preserved with a 5% solution of formalin.

In the laboratory, organisms were identified, counted, and placed separately by species in aluminum drying pans. These pans were then dried at 60° C for more than 48 hours and ashed at 550° C for 4 hours to determine the ash-free biomass of the organisms.

Sediment was analyzed by techniques described by Folk (1974). A series of Wentworth sieves from 2 mm to 63µm was used to determine the various sand fractions by dry sieving. Pipet-analysis of the fine fraction (<63µm) was used for those sediments composed mostly of silt-clays. Sediment analyses were performed on samples collected in August 1976 and December 1976. Salinity and temperature were taken during each of the sampling periods. A rarefractometer was used to determine the salinity of the water at each site, and a stem thermometer was used to record the temperature of the surface water.

## Species Diversity

Species diversity of an assemblage can be defined as a function of the number of species present (species richness) and the evenness with which the individuals are distributed among these species (species evenness).

Only the numbers of individuals were used for testing the patterns of diversity and not their respected biomass. Although Dickman (1968) and Wilhm (1968) both felt that a more meaningful measure of diversity could be obtained if the index was based on biomass, Bloom et al. (1972) showed that this diversity could be greatly influenced by one individual which had a high biomass value and overshadow the importance of a species that is very small in biomass but high in total number of individuals. The Shannon-Weaver Index for Diversity was used. The formula is

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

where  $p_i$  = proportion of the abundance of the  $i^{\text{th}}$  species, and  $s$  = number of species. Margalef's formula,

$$r = \frac{(\text{number of species} - 1)}{\log_e \text{no. of individuals}}$$

was used to determine species richness. The distribution of the individuals among species or evenness of "H" was determined by

$$E = H' / H_{\max}$$

where  $H_{\max} = \log_2 s$  (Pielou, 1966).



## Multivariate Analysis

Two multivariate analysis techniques were used: 1. the classification of the species by a cluster analysis and 2. nodal analysis.

The cluster analysis was selected because it produces a classification of the variables (sites and/or species) that can be readily interpreted and more easily understood than other multivariate analyses (Boesch, 1977a). The Bray and Curtis similarity index was used to cluster log transformed density and untransformed biomass data. The species and sites were then clustered using group average sorting (Boesch, 1977b)

Nodal analysis rearranges the original data matrix formed from cluster analysis and creates a two-way table arranged by sites and species groups (Boesch, 1977b). The two-way table is helpful in aiding in the interpretation of the classifications. It uses the classic ecological concepts of dominance, constancy and fidelity.

#### IV. Results

##### Environmental Data

Of the six sites examined, two distinct classes of sediments could be defined on the basis of their physical properties. Sites 1, 2, and 3 were generally well-sorted, with low silt-clay contents. Throughout the year, the silt-clay fraction never exceeded 2.1% (Table 1). The silt-clay content at sites 4, 5, and 6 for the year averaged from 81% to 95%, and these sediments were poorly sorted.

The sediment analyses are summarized in Table 1. There was little variation in physical parameters within the sand and the mud sites between the two sampling periods, August 1976 and December 1976. The median grain phi size at the sand sites ranged from 1.678 $\phi$  to 1.919 $\phi$  for August and 1.716 $\phi$  to 1.959 $\phi$  for December. The sorting properties of the sediment for the sand sites ranged from 0.790 $\phi$  to 0.881 $\phi$  for August and 0.763 $\phi$  to 0.880 $\phi$  for December. The mean and sorting phi values for the mud sites were significantly greater. Median grain phi size for August ranged from 6.017 $\phi$  to 7.264 $\phi$  and 6.086 $\phi$  to 7.265 $\phi$  for December. The median phi values when referred to the scale devised by Krumbein describe the sand sites as having a medium sand texture and the mud sites a medium to fine silt texture (Folk, 1974).

Table 2 shows the average water salinity and temperature recorded from the six sites. The temperature, which averaged from 13.2 $^{\circ}$  C to 18.5 $^{\circ}$  C, and the salinity, which averaged from 11.3% to 20.7%, fluctuated

SITES	MEAN ( $\phi$ )		SORTING ( $\phi$ )		% SAND		% SILT-CLAY	
	A	D	A	D	A	D	A	D
Sand								
1	1.678	1.745	0.796	0.796	99.3	99.6	0.7	0.4
2	1.572	1.716	0.881	0.880	99.3	98.1	0.7	1.9
3	1.919	1.959	0.790	0.763	99.0	97.0	1.0	2.1
Mud								
4	7.264	7.265	2.795	2.711	6.7	2.0	93.3	98.0
5	6.926	6.704	2.774	2.729	4.7	2.8	95.3	97.2
6	6.017	6.086	2.862	2.662	18.5	21.5	81.5	78.5

TABLE 1. Physical Recordings of the Sediment from the Western Branch of the Lynnhaven River for August 1976 (A) and December 1976 (D).

SITES	1	2	3	4	5	6
Average Temperature	15.3	18.5	16.4	14.6	14.6	13.2
Average Salinity	20.7	20.0	17.3	15.5	16.0	11.3

TABLE 2. Temperature ( $^{\circ}\text{C}$ ) and Salinity ( $^{\circ}/\text{oo}$ )  
Recordings from Each Site for the Western Branch  
of the Lynnhaven River during August 1976 to  
June 1977.

greatly at the six sites depending on the time of the year the samples were taken.

### Spatial Relations

During 1976 - 1977, 360 samples were collected from the river's six sites. In these 360 samples, 9416 individuals were counted and 30 species identified. Sixteen polychaete species accounted for 66% of the total number of organisms collected and 93.5% of the total biomass. The oligochaete Peloscolex gabrielliae represented 31% of the total number of organisms collected. All of the species collected were deposit feeders except for four species of bivalves, two species of amphipods, and one species of decapod. The amphipods and decapod occurred infrequently during the study and did not contribute significantly in numbers or biomass. The bivalves were mentioned only as being present because the core used was unable to penetrate as deep as the burrowing bivalves and quantitative sampling was not possible.

Table 3 lists the species encountered during the study and the sites at which they were found. The habitat preferences shown by each species and their feeding mode are also included in the table. Habitat preference was broken into three categories--surface crawlers, those spending the majority of their time feeding at the surface or just below the surface interface; burrowers, those capable of burrowing below the surface for purposes of feeding; and sedentary, those that remain stationary throughout their life. A total of 11 species--7 polychaete species, 1 oligochaete species, 1 bivalve species, 1 isopod species, and 1 amphipod species--were found in both the sandy sites and the muddy sites. (Refer to the Appendices for the number of individuals and

TABLE 3. Species List and Classification of the Macrofaunal Invertebrates and the Sites with Which They Were Associated Between 1976 and 1977.

SPECIES	SITES						Habitat Preference			Feeding				
	Sand				Mud		Surface Crawler	Burrower	Sedentary	Deposit Feeder	Surface Deposit Feeder	Filter Feeder	Omnivore	Scavenger
	1	2	3	4	5	6								
I. ANNELIDA														
Polychaete														
<u>Capitella capitata</u>	x	x	x	x	x	x		x			x			
<u>Chaetozone sp.</u>	x	x	x				x				x			
<u>Drilonereis magna</u>		x						?					x	
<u>Eteone heteropoda</u>	x	x	x	x	x		?						?	
<u>Glycera dibranchiata</u>		x					x						x	
<u>Heteromastus filiformis</u>	x	x	x	x	x	x		x			x			
<u>Laeonereis culveri</u>	x	x	x	x	x	x		?					x	
<u>Loima viridis</u>		x							x		x			
<u>Lysippides grayi</u>				x		x		x			x			
<u>Microphthalmus aberrans</u>				x			x						x	
<u>Nereis succinea</u>	x	x	x	x	x			x					x	
<u>Polydora ligni</u>	x	x	x	x	x	x			x		x			
<u>Scoloplos fragilis</u>		x						x			x			
<u>Spiophanes bombyx</u>					x				x		x			
<u>Streblospio benedicti</u>	x	x	x	x	x	x			x		x			
Oligochaete														
<u>Pelosclex gabrielliae</u>	x	x	x	x	x	x		?			?			
Hirudinea														
<u>Myzobdella lugubris</u>	x	x							x		Parasitic			
II. NEMERTEA														
Mollusca														
		x	x	x	x	x		x						?
III. BIVALVIA														
<u>Gemma gemma</u>	x	x	x					x					x	
<u>Macoma balthica</u>	x	x	x					x			x		x	
<u>Mya arenaria</u>	x	x	x	x		x			?				x	
<u>Tagelus plebeius</u>	x	x	x						?				x	
Gastropoda														
<u>Nassarius obseletus</u>	x	x					x							x
IV. ARTHROPODA														
Isopod														
<u>Cyathura polita</u>			x	x	x		x				x			?
Amphipod														
<u>Corophium tuberculatum</u>		x	x	x	x	x			x				x	
<u>Gammarus mucronatus</u>	x								x				x	
Decapod														
<u>Palaemonetes pugio</u>	x						x				x			x
V. HEMICHORDATA														
<u>Saccoglossus kowalevski</u>		x						x		x			x	
VI. INSECT LARVAE														
<u>Diptera sp.</u>		x					?	?					?	

biomass listed according to species.) Polychaetes comprised 50% of the sand species and 67% of the mud species.

Figures 3, 4, and 5 show summaries of the following biological data for the six sites: A. the average number of individuals / sampling period / 10 cores; B. the average biomass for total individuals / sampling period / 10 cores; and C. the average number of species / sampling period / 10 cores.

The average density of the individuals per site (Figure 3) illustrated the gradual decrease within the sand sites from 1 to 3. The mud sites, 4 and 5, had the lowest density values. An increase in density occurred, within the mud sites, towards the headwaters.

The average biomass was greater at the sand sites than at the mud sites (Figure 4). The same trend for the average total number of species (Figure 5) was shown between the sand and mud sites. The greatest number of species were found at the sand sites, except site 1 which had fewer species than mud site 4. The mud sites showed a gradual decrease in number of species when approaching the headwaters. Site 1 had the lowest number of species for the sand sites, and site 6 had the lowest number of species for the mud sites.

Four polychaetes (Capitella capitata, Heteromastus filiformis, Laeonereis culveri, and Streblospio benedicti), and one oligochaete (Peloscolex gabrielliae) were found consistently at all six sites and Nereis succinea, a polychaete found at sites 1 through 5, comprised the majority of the total individuals and biomass for the year (Figure 6). Each species' relationship to overall density and biomass for all species sampled for the year at each of the six sites is shown in Figure 7 and Figure 8.

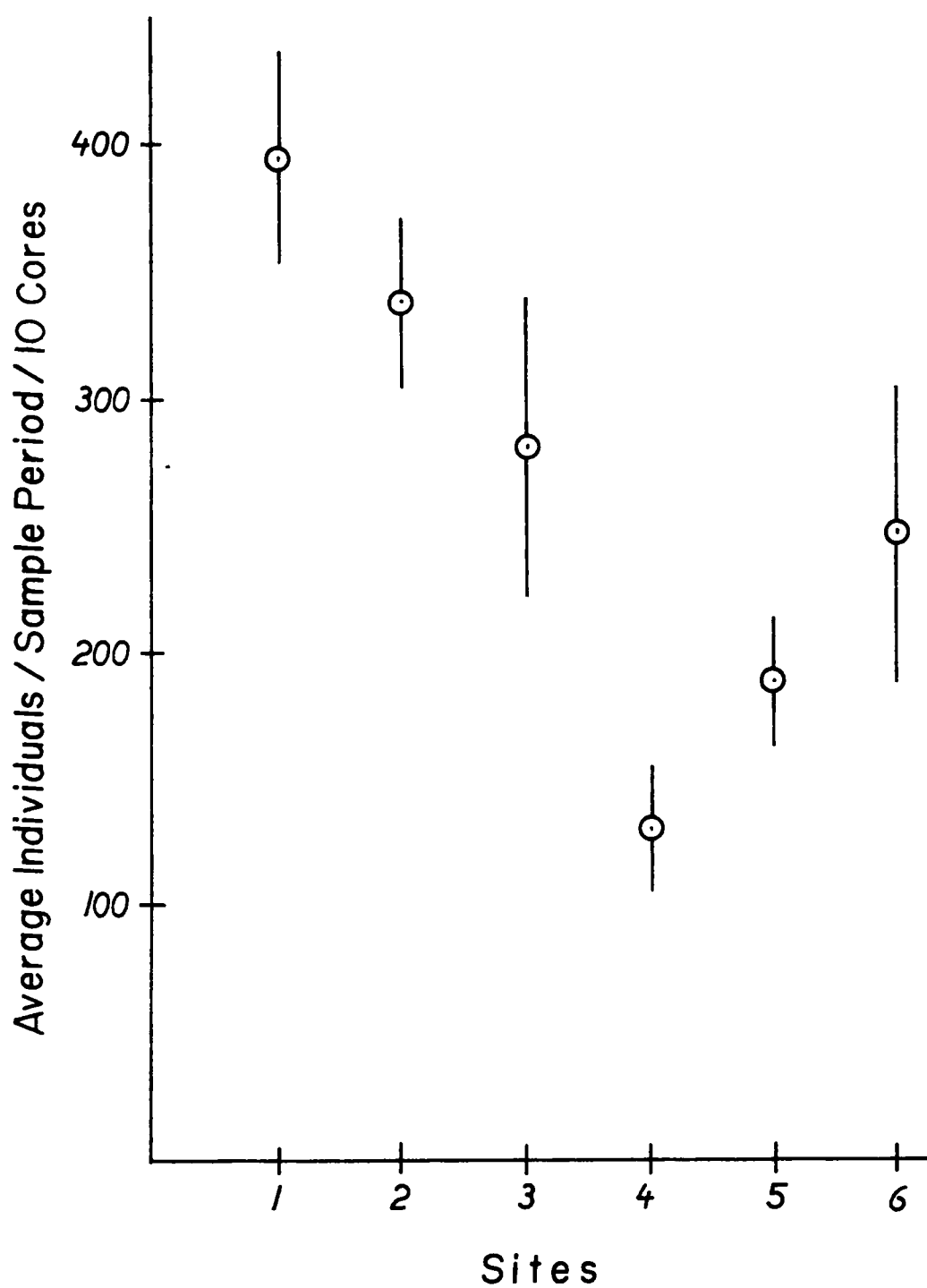


Figure 3. Summation of the Biological Data for Average Number of Individuals per Site Per Sampling Period Per Ten Cores and Range of Standard Error for Each Site.



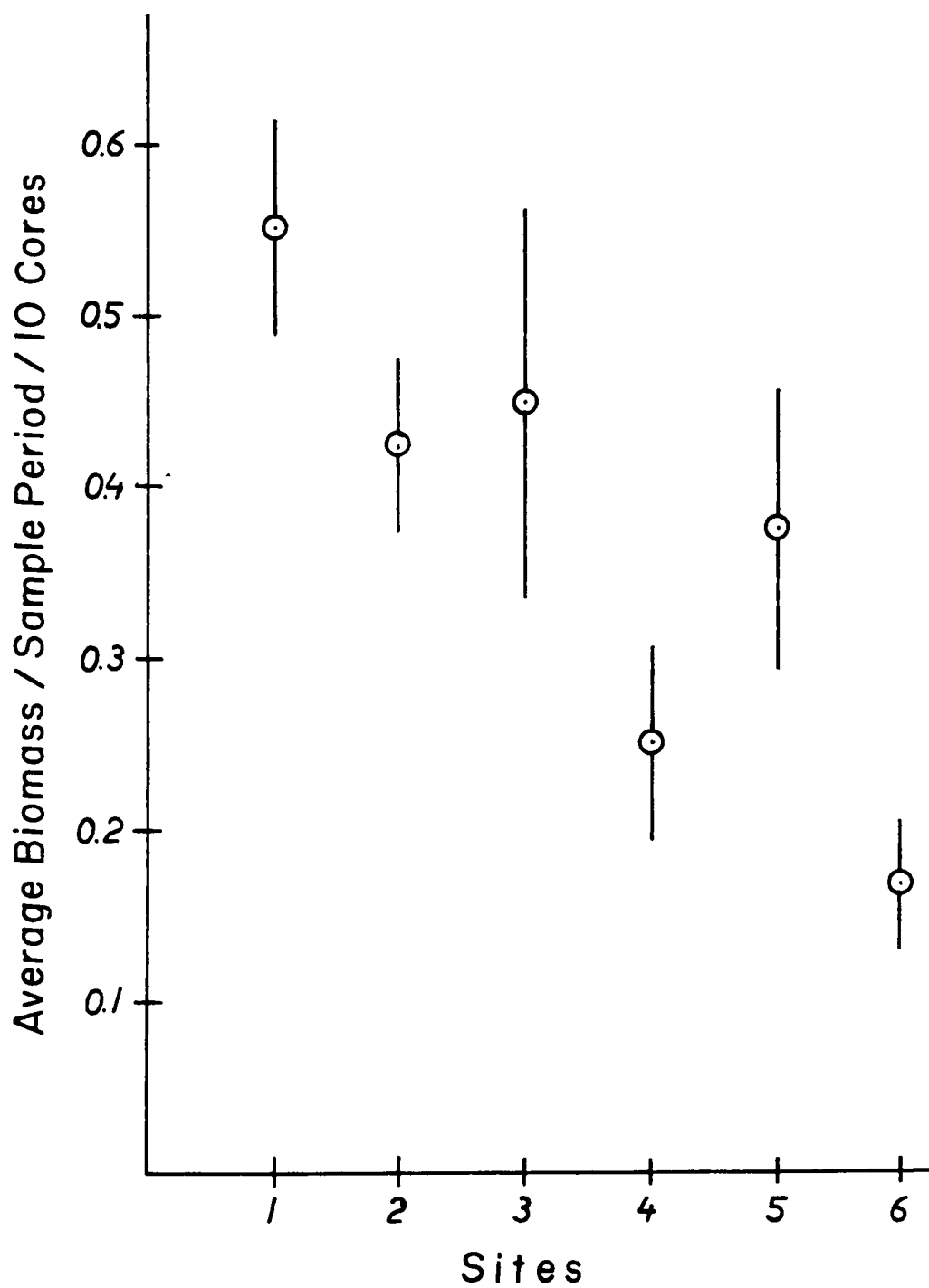


Figure 4. Summation of the Biological Data for Average Biomass Per Site Per Sampling Period Per Ten Cores and Range of Standard Error for Each Site.

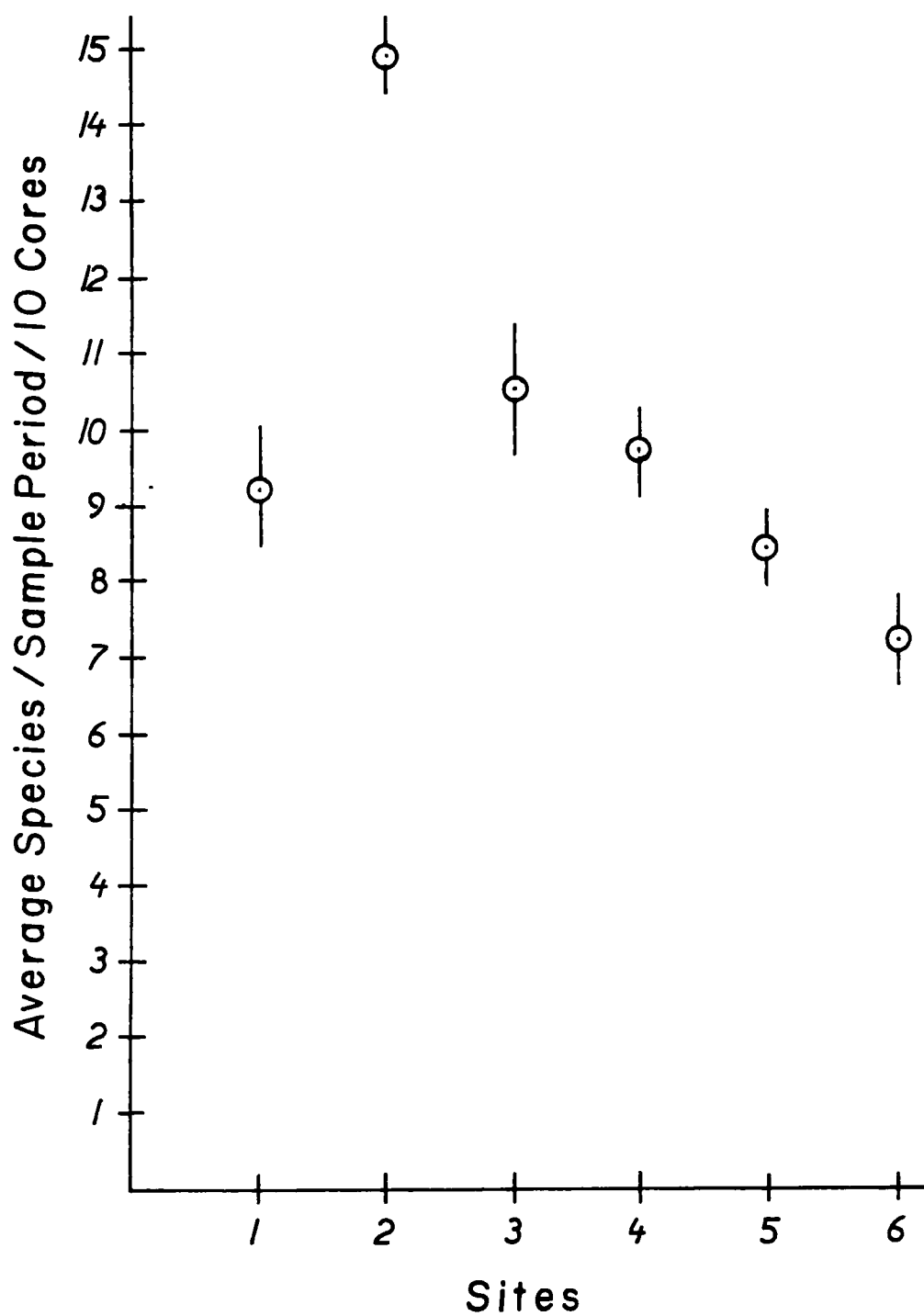


Figure 5. Summation of the Biological Data for Average Number of Species Per Site Per Sampling Period Per Ten Cores and Range of Standard Error for Each Site.

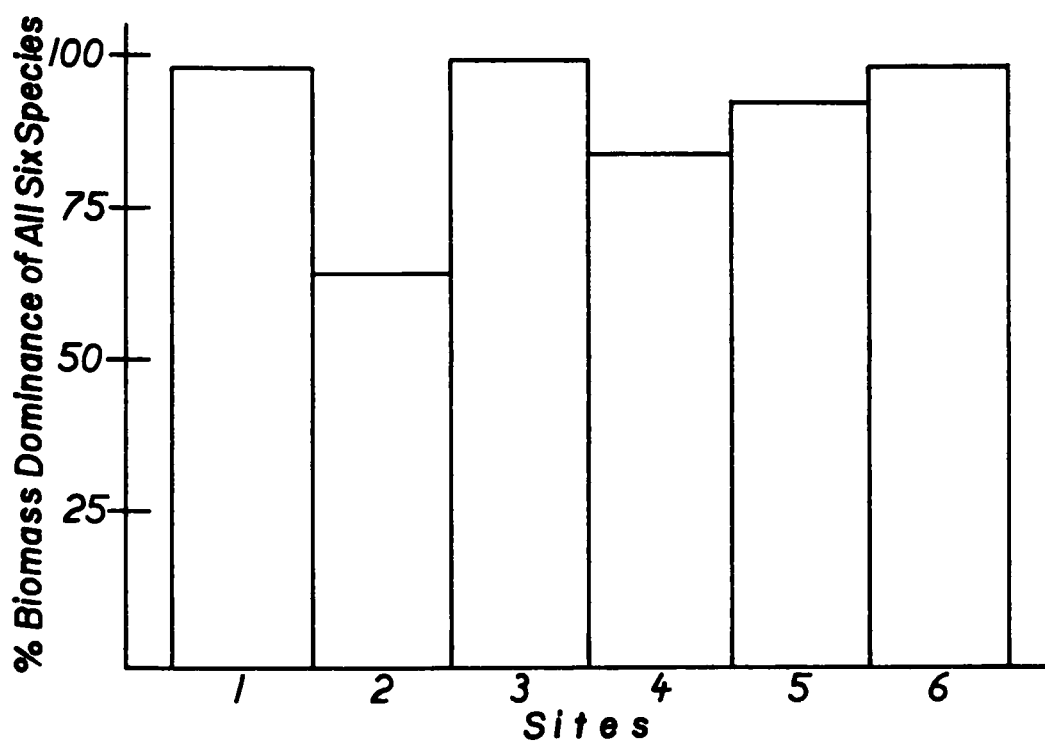
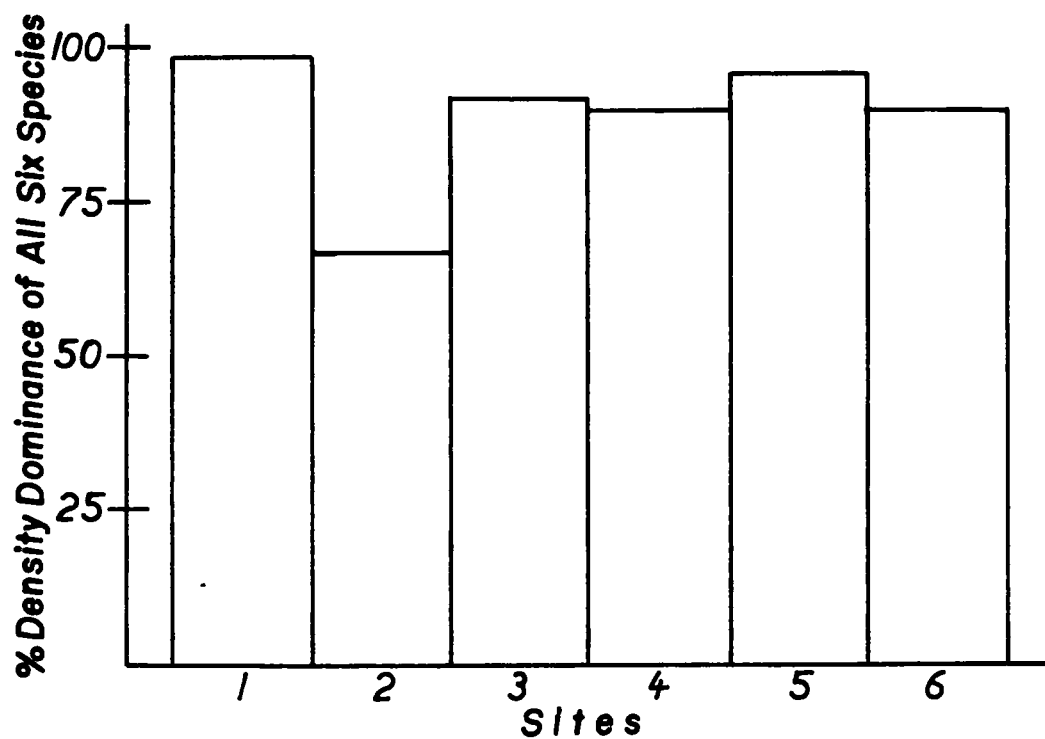


Figure 6. The Total Percentage Density and Biomass Dominance Shown by Six Dominant Species - Capitella capitata, Heteromastus filiformis, Laeonereis culveri, Nereis succinea, Peloscolex gabrielliae, and Streblospio benedicti - for All Six Sites.

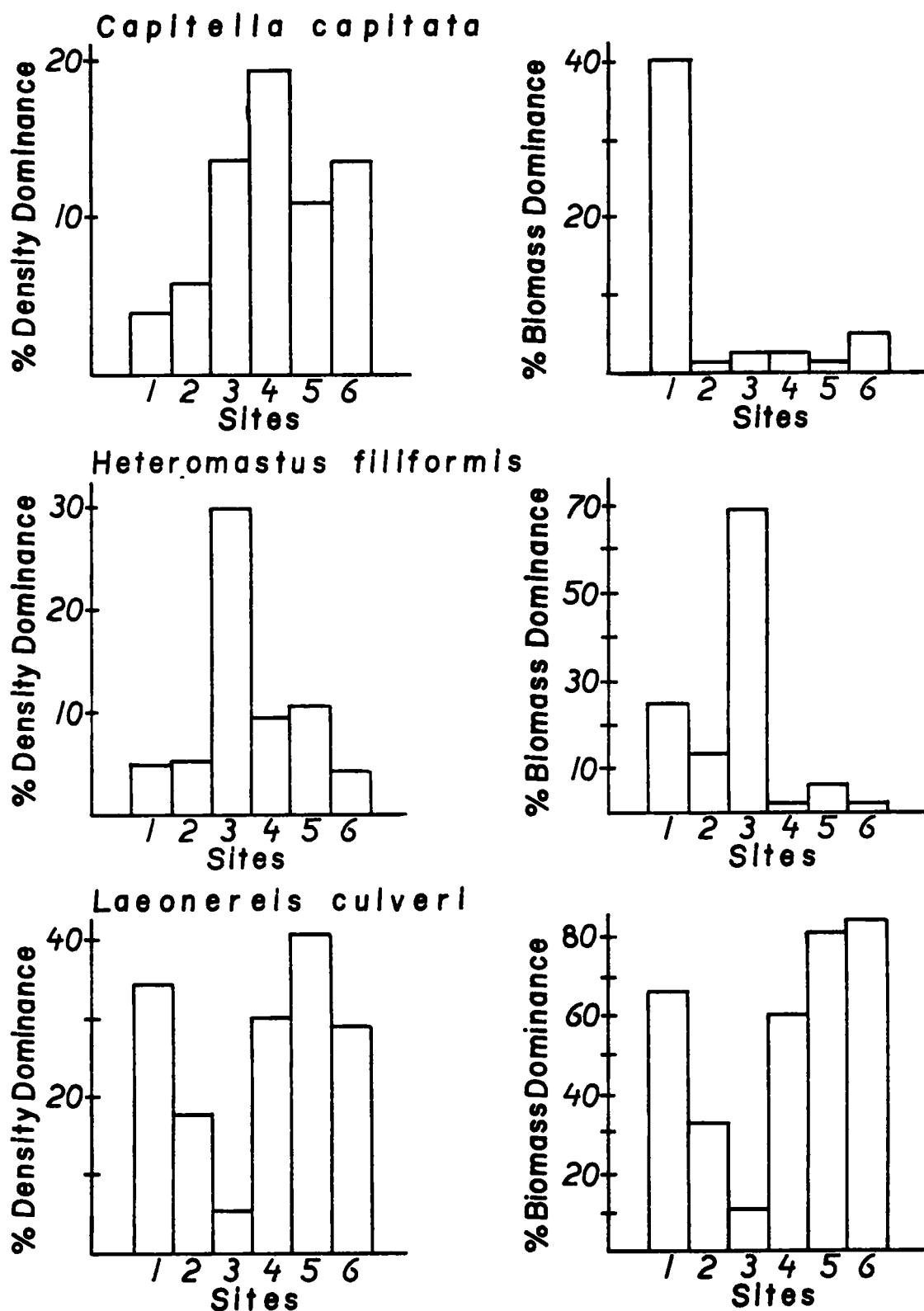


Figure 7. The Percentage Density and Biomass Dominance Displayed by Three Species - Capitella capitata, Heteromastus filiformis, and Laeonereis culveri, for the Six Sites.

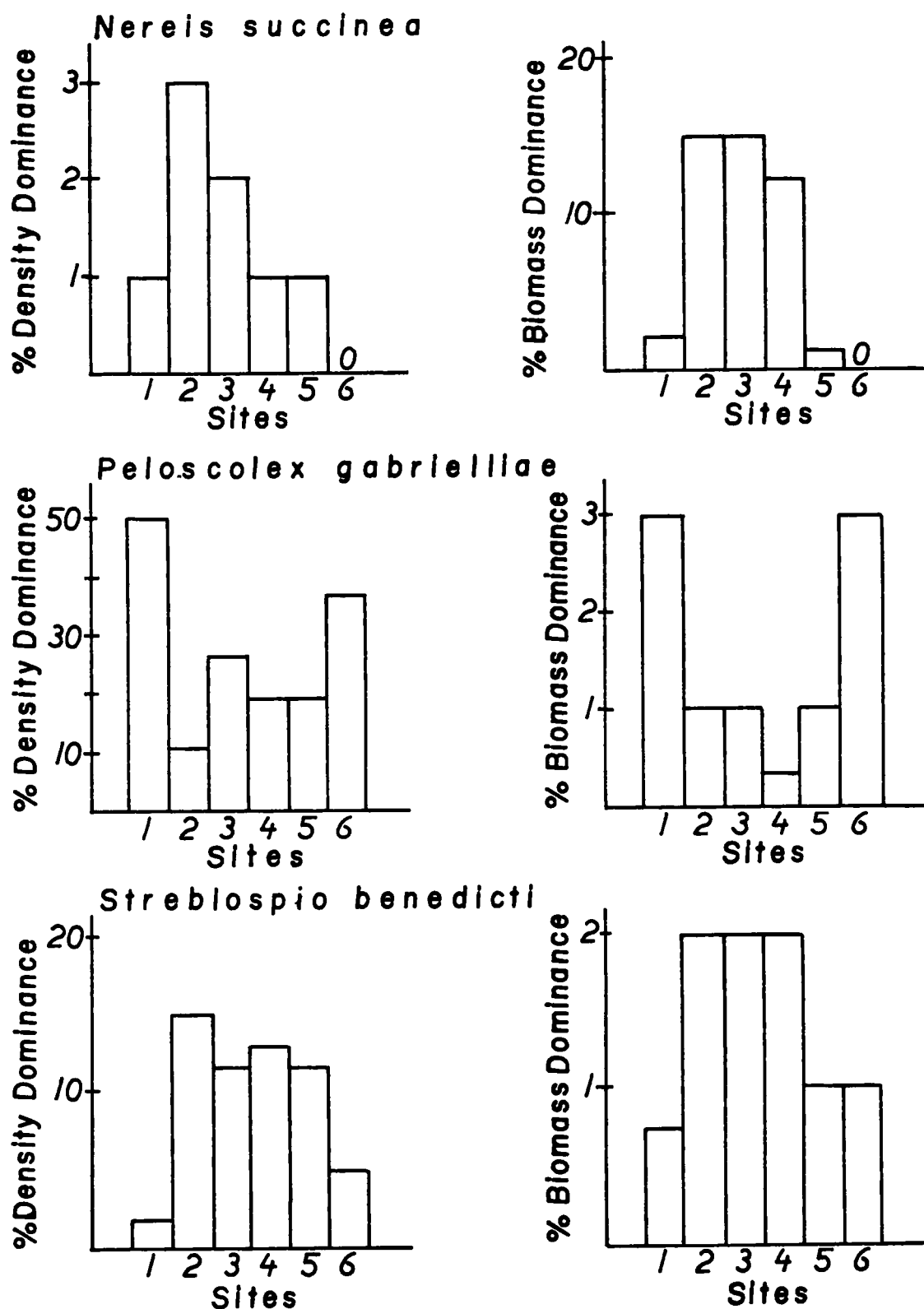


Figure 8. The Percentage Density and Biomass Dominance Displayed by Three Species - *Nereis succinea*, *Peloscolex gabrielliae*, and *Streblospio benedicti* - for All Six Sites

## Temporal Variation

Figure 9A shows the pattern of temporal variation in the average number of individuals and biomass between the sand and the mud sites. Because of the similarity in sediment properties shown within the sand parameters and within the mud parameters, the three sand sites, and then the three mud sites, were examined collectively. A cyclic trend was shown by the density of the individuals. The greatest concentration of individuals for the mud sites was during the early winter and spring months. The sand sites densities were lowest during the summer months and highest during the cooler seasons of the year. The average biomass (Figure 9B) showed an upward seasonal trend, except for the mud sites during the winter, until the spring. A noticeable drop was recorded for overall biomass for the summer months.

## Species Diversity, Richness, and Evenness

Figures 10, 11, and 12 show the temporal pattern of species diversity ( $H'$ ), evenness ( $E$ ), and richness ( $R$ ). Species diversity (Figure 10) and evenness (Figure 11) for the sand sites showed no fluctuations except between the months of February and June. On the other hand, for the mud sites, species diversity and evenness had a greater variability between August and December. In other words, the sand sites were influenced by temporal conditions during the "spring" months, February to June, while the mud sites were influenced by temporal conditions during the "fall" months, August to December. The sand sites showed a slight drop in species richness values (Figure 12) during the winter months, August to April, while the mud sites showed little variation over the year except for a slight rise during the summer month of June.

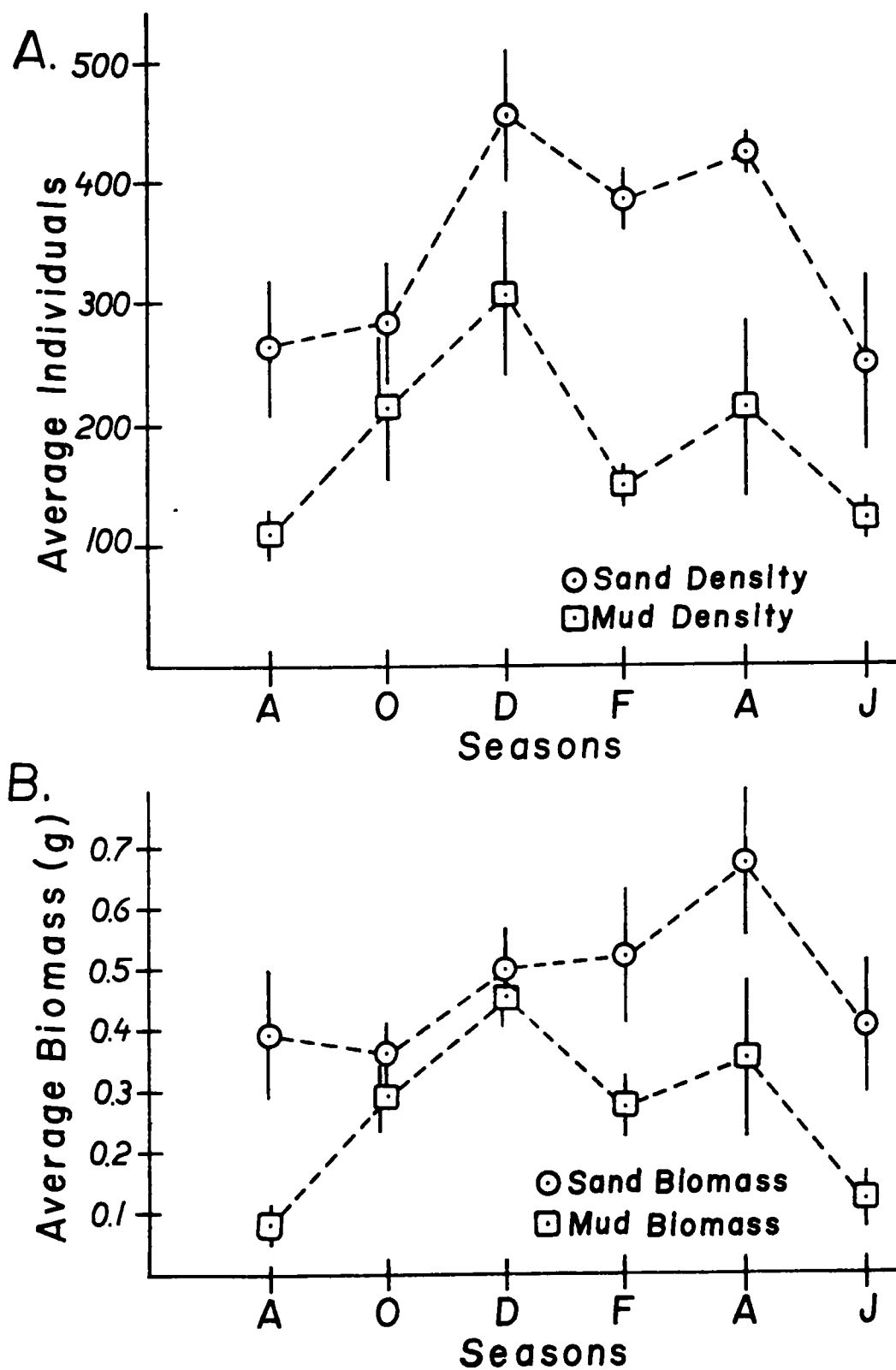


Figure 9. Seasonal Variation for the Average Number of Individuals and Their Biomass Per Season.

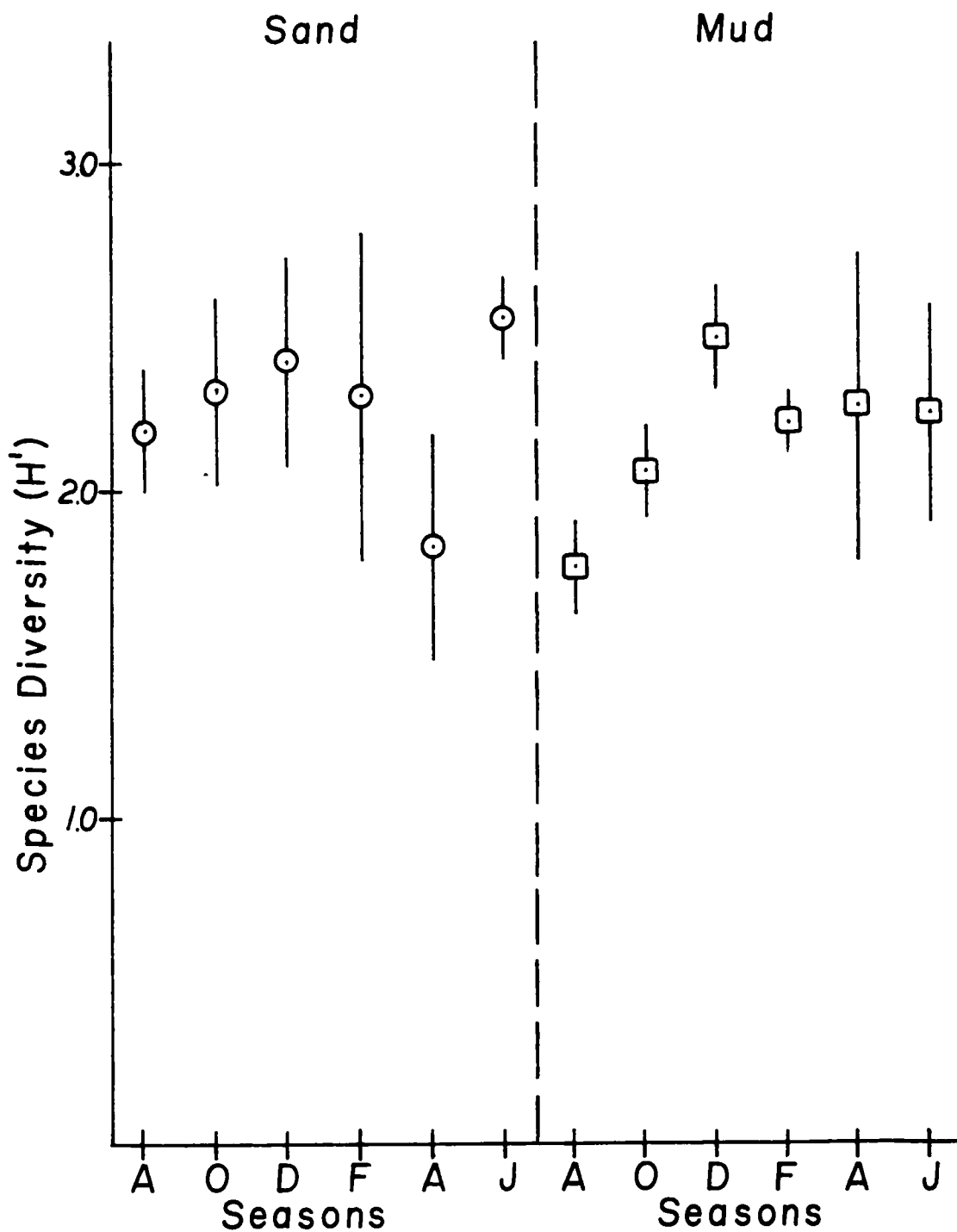


Figure 10. Temporal Patterns Explained by Species Diversity ( $H'$ ) Showing Their Mean and Range of Standard Error for Each Sampling Period.



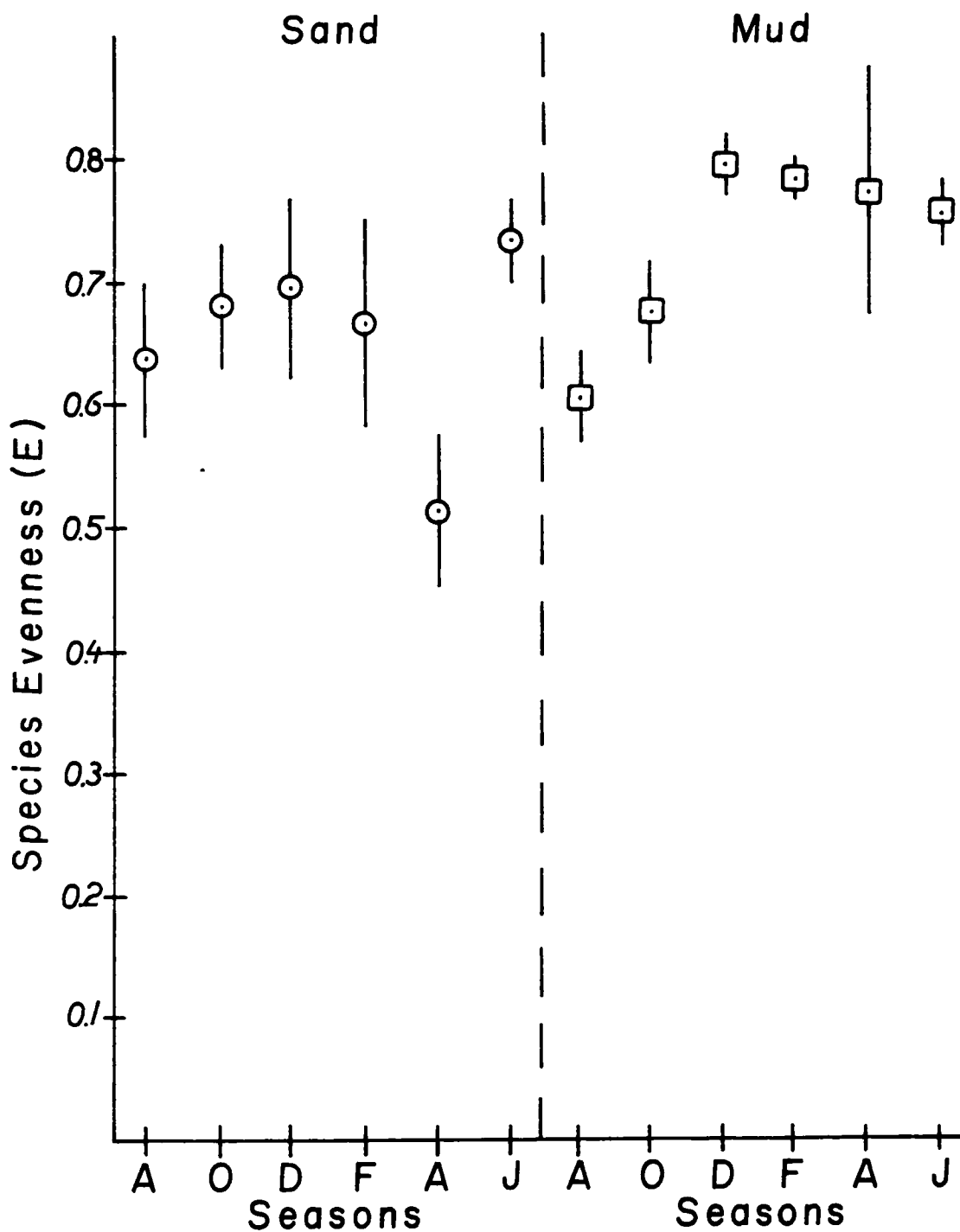


Figure 11. Temporal Patterns Explained by Species Evenness (E) Showing Their Mean and Range of Standard Error for Each Sampling Period.

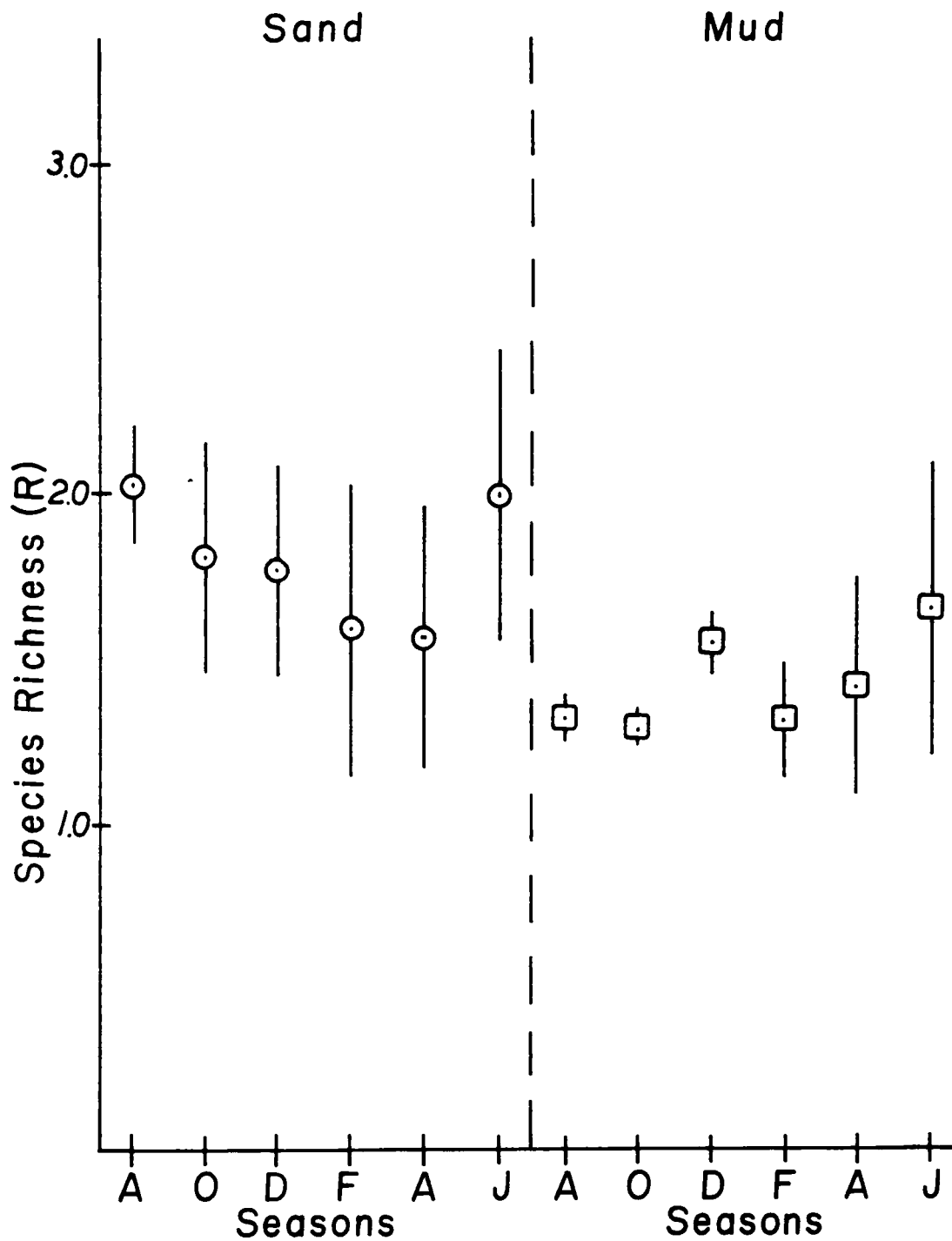


Figure 12. Temporal Patterns Explained by Species Richness (R) Showing Their Mean and Range of Standard Error for Each Sampling Period.

Spatial patterns of diversity (Figure 13) between the sand and mud sites for the year sampling periods were very similar between all the sites for species diversity, evenness, and richness. Within sites, site 2 (sand) and site 4 (mud) had the greater values.

#### Cluster Analysis

The hierarchical grouping of stations is shown in Figures 14 A and 14 B. For the purpose of this analysis, average seasonal data was used. Thirteen species were selected from all six sites based on their total contribution to total individuals and biomass which was 98.9% and 95.3% respectively. The calculated similarity coefficients determined by the classification Q-mode analysis split the sites into two main groups related to the percentage of silt-clay found at each site--i.e., splitting them into sand and mud sites. In Figure 14 A, sites 1 and 2-3 ("A") were classified together with a 75% similarity. The sites occurred in the lower half of the river where the mean salinity and temperature averaged the greatest for the year, and the percentage silt-clay was the lowest (see Tables 1 and 2). Sites 4-5 and 6 ("B") were classified together with an 88% similarity. These sites were found in the upper half of the river where the salinity and temperature mean values were lower than "A's," but the silt-clay percentage was higher. "A" was comprised of the sand sites and "B" the mud sites.

Similar results were seen after examining the biomass of the benthic organisms for each site (Figure 14 B). The cluster analysis grouped the same sites together as were grouped when individuals per site were examined.

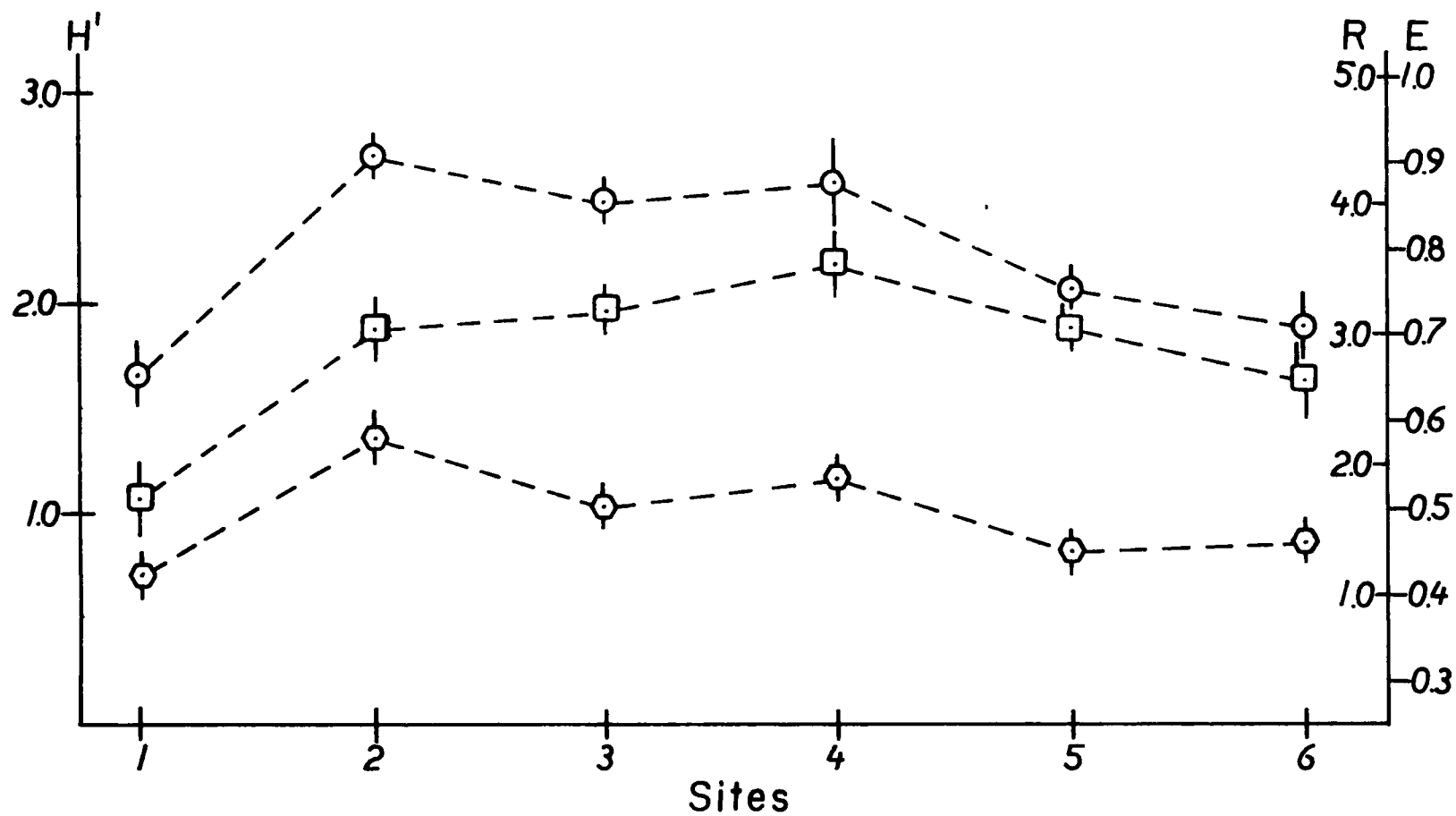


Figure 13. Trends and Standard Error for the Three Species Indices Between Sites.  $H'$ : Shannon-Weaver Index for Species Diversity (○);  $R$ : Margalef Species Richness Index (◻);  $E$ : Pielou's Evenness Index (⊙).

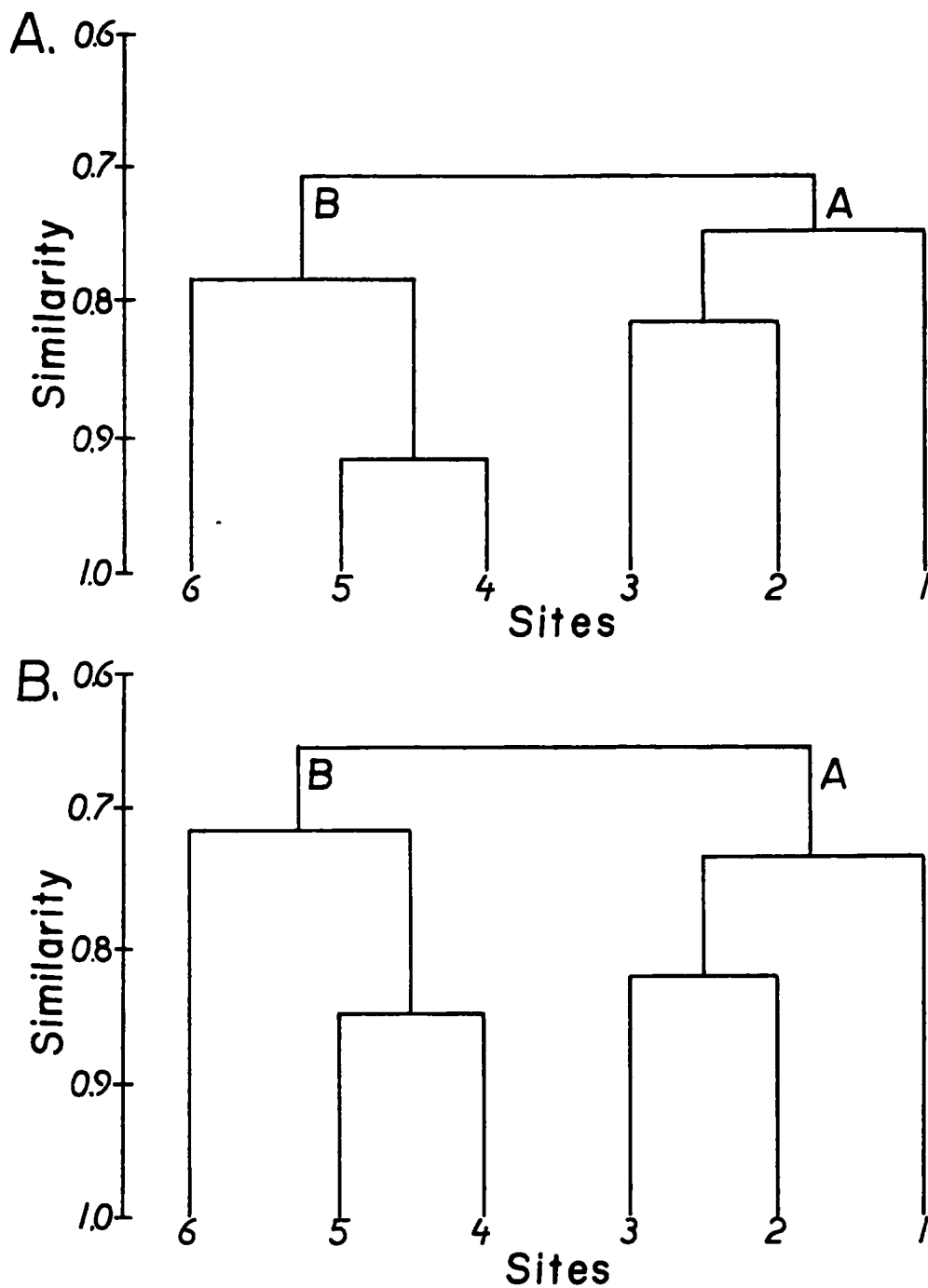


Figure 14. Similarity Dendrogram Based Upon Density (A) and Biomass (B) for Six Sites. Sites 1, 2, 3 Are Sand Sites and Sites 4, 5, 6 Are Mud Sites.

When examining the species by R-mode analysis, shown in Figure 15, subdivision "a" was comprised of two subsets, "d" and "e." Subset "d" represented those species that were found in greatest abundance in the sand sites, while subset "e" was comprised of species found in the greatest numbers and percentage (Figure 6) throughout all six sites. Subdivision "b" and "c" were species found only at two of the mud sites which accounts for the low similarities displayed by them to the other species.

Figure 16 represents the classification of the species by their biomass. As with the dendrogram representing the individuals, biomass for the individuals were divided into several groups. The dendrogram shows that "a" was only 21% similar to the biomass of all the other species. This was due to the restriction of the bulk of this species to one site. Subset "c" was composed of those species biomass that contributed the most similarity for the sand sites. "b" were those species whose biomass influenced the total biomass at all six sites the most.

#### Nodal Analysis

For the purpose of nodal analysis, the groups of species and sites resulting from the hierarchical cluster analysis were used. Three species groups were determined by the cluster analysis. One group had a total similarity of 57% and was composed of the species Polydora ligni, Nereis succinea, Eteone heteropoda, Gemma gemma, and Chaetozone species. The second group was composed mostly of the opportunistic species at a similarity level of 57%. They were Capitella capitata,

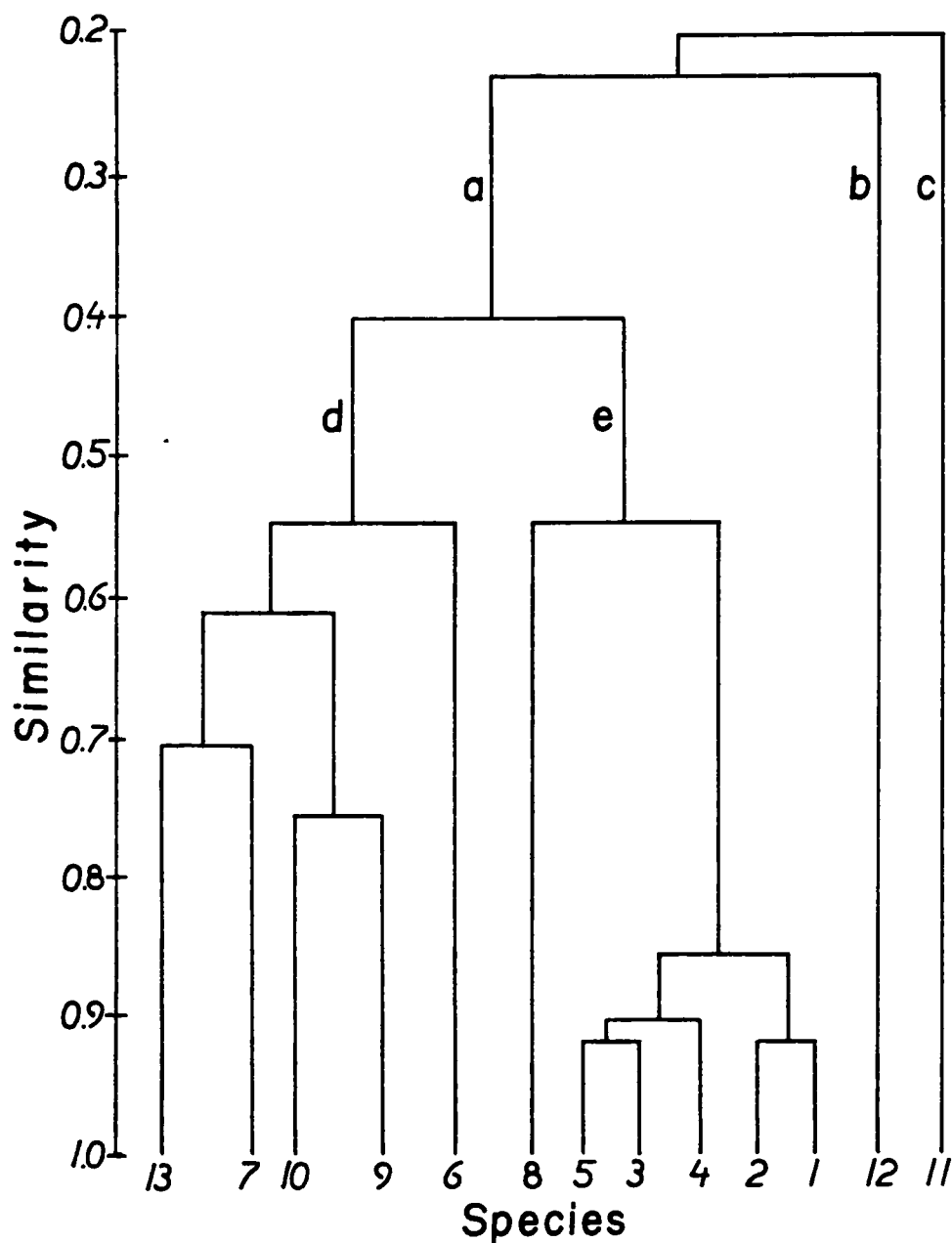


Figure 15. Similarity Dendrogram Based Upon Density for Thirteen selected species. 1. Peloscolex gabrielliae; 2. Laeonereis culveri; 3. Heteromastus filiformis; 4. Streblospio benedicti; 5. Capitella capitata; 6. Chaetozone sp.; 7. Nereis succinea; 8. Nemertea; 9. Gemma gemma; 10. Eteone heteropoda; 11. Lysippides grayi; 12. Cyathura polita; 13. Polydora ligni.

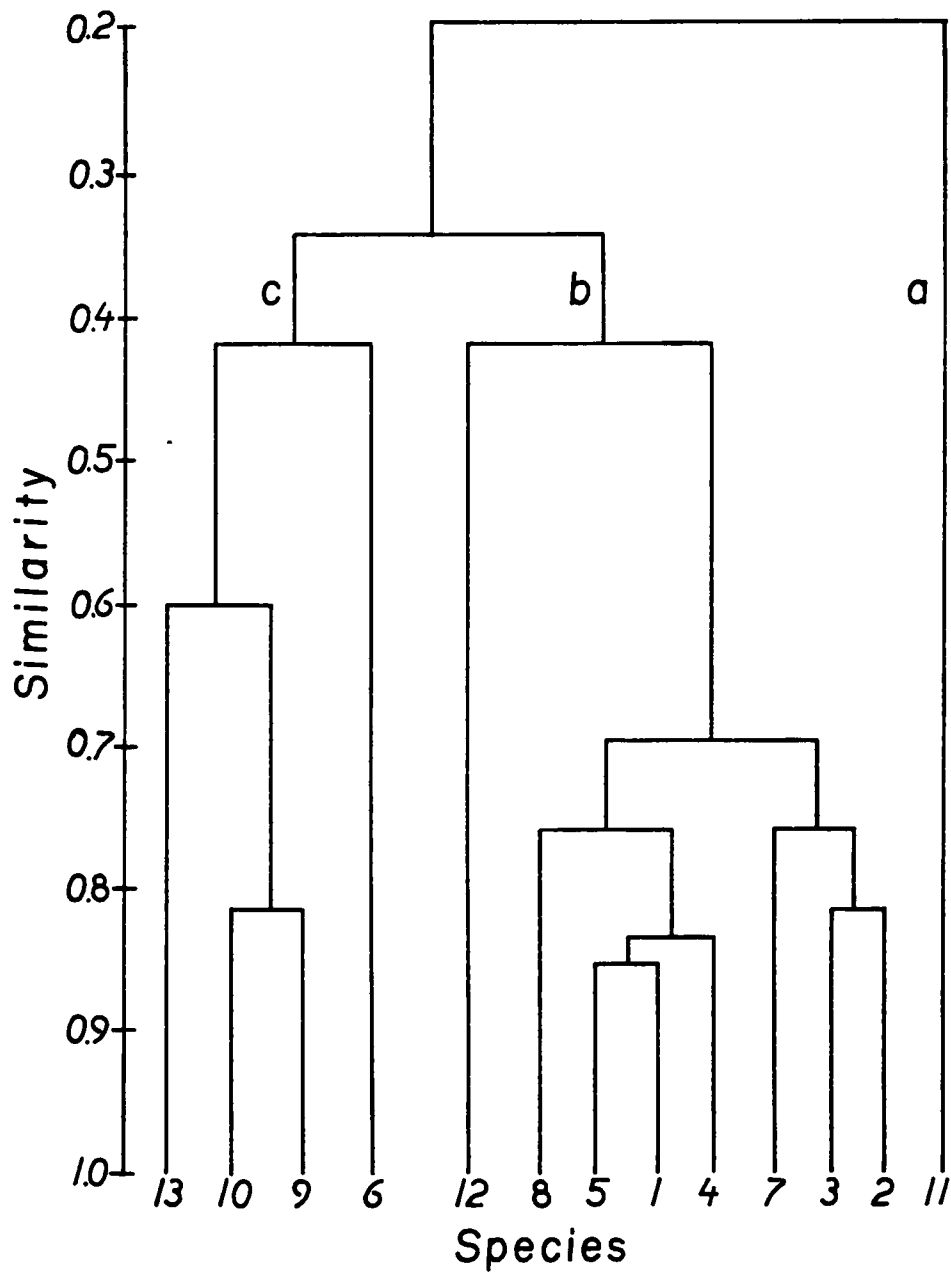


Figure 16. Similarity Dendrogram Based Upon Biomass for Thirteen Selected Species. 1. Peloscolex gabrielliae; 2. Laeonereis culveri; 3. Heteromastus filiformis; 4. Streblospio benedicti; 5. Capitella capitata; 6. Chaetozone sp.; 7. Nereis succinea; 8. Nemertea; 9. Gemma gemma; 10. Eteone heteropoda; 11. Lysippides grayi; 12. Cyathura polita; 13. Polydora ligni.



Heteromastus filiformis, Streblospio benedicti, Laeonereis culveri, Peloscolex gabrielliae and nemerteans. The third and last group, Cyathura polita and Lysippides grayi, were lumped together because of their greatest dominance at the mud sites.

Cluster analysis, however, did not group these two species together. For nodal analysis, the two species were grouped as one. The raw data, found in the appendices A and B, supports the justification that they be grouped together in this manner. Significant values for total individuals and biomass were observed at the mud sites for Cyathura polita and Lysippides grayi. However, Cyathura polita did occur once during sampling period four, February, but did not contribute significantly to justify splitting these two species into the two separate groups.

The sites were grouped two ways. Since the three sand sites--1, 2, and 3--were all grouped by the cluster analysis with a 75% similarity, these sites were grouped together as site group A under nodal analysis. The three mud sides--4, 5, 6--which were grouped together by cluster analysis with a 79% similarity will be referred to as site group B under nodal analysis.

Constancy, a term used to describe a collection of species from the total assemblage that are always grouped together in particular collection groups, and fidelity, an indicator of the degree to which species "select" or are limited to certain collection types (habitats, seasons, etc.), were examined by the nodal analysis.

The constancy index values (see Appendix) ranged from 0.08 to 1.00. The values for fidelity (see Appendix) ranged from 0.40 to 1.60.

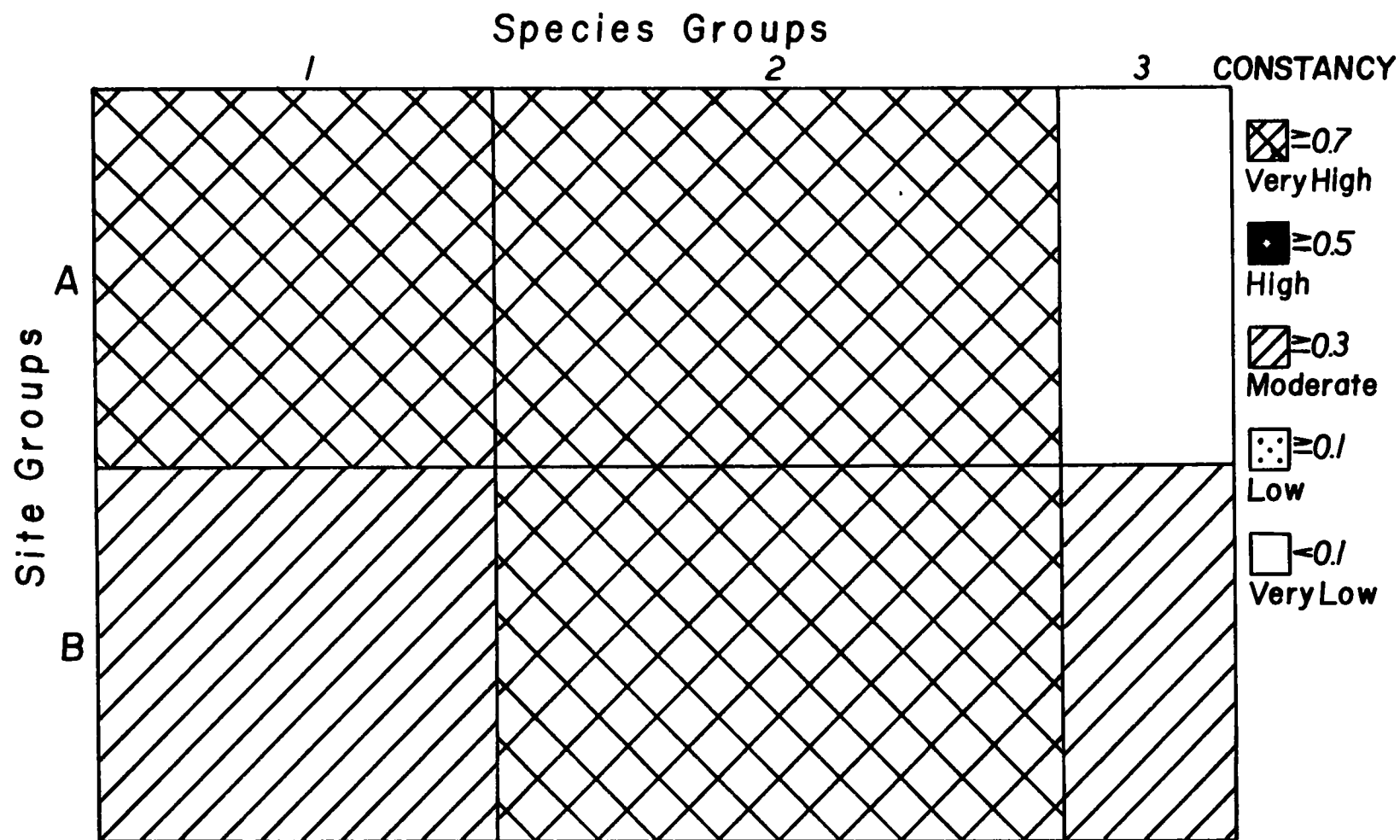


Figure 17. Nodal Constancy in a Two-way Table of Species Groups in Site Groups of Macrobenthos from the Western Branch of the Lynnhaven River.

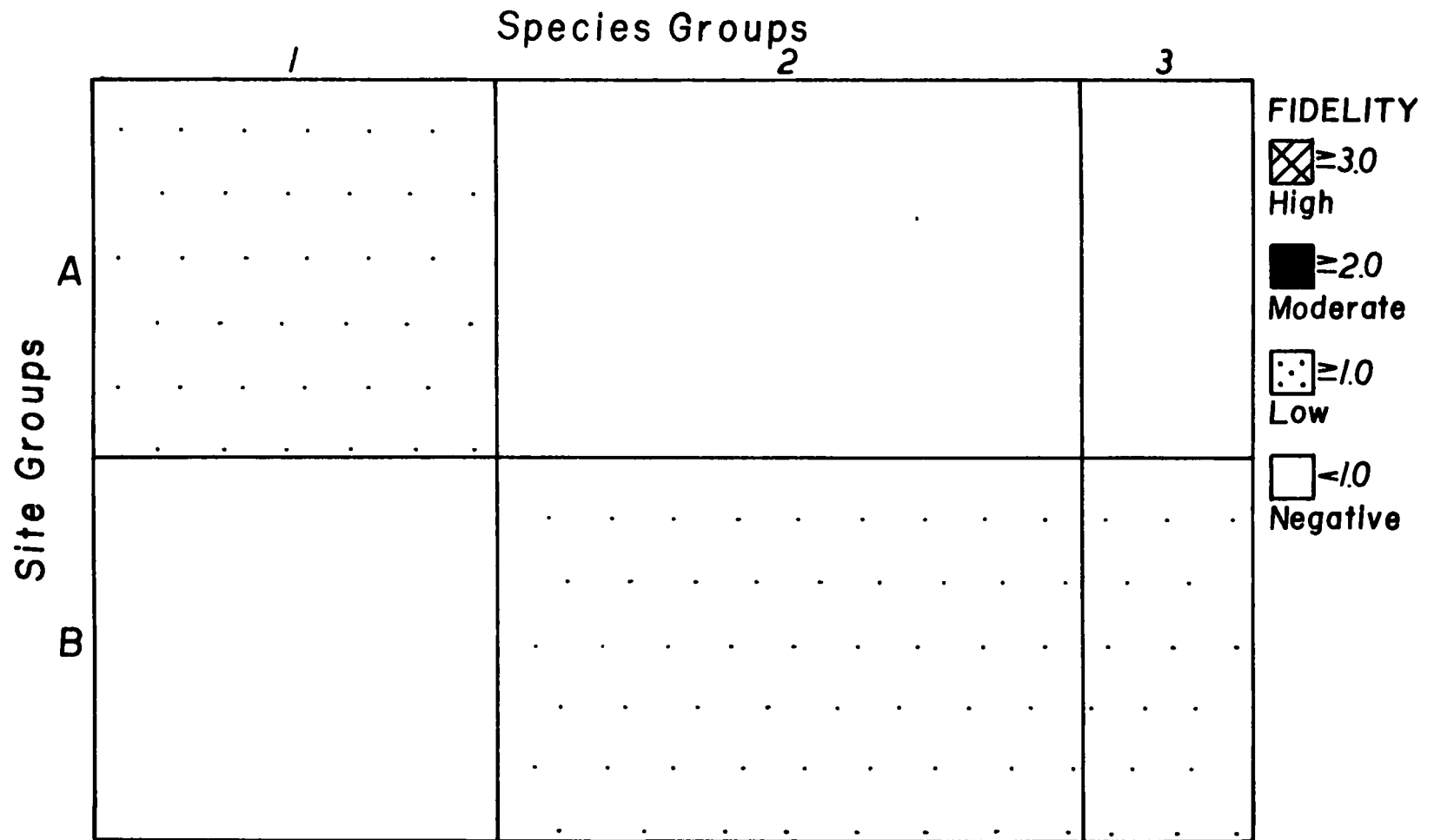


Figure 18. Nodal Fidelity in a Two-way Table of Species Groups in Site Groups of Macroenthos from the Western Branch of the Lynnhaven River.

Figure 17 is a two-way nodal constancy diagram of the data for species groups and site groups. The nodal constancy patterns show the faunal difference between collection groups. The figure shows that at sand group site A two species groups, 1 and 2, were constant. Groups 1 and 2 of the species had constancy throughout the site group B. Species group 3 was moderately constant at mud site group B.

Figure 18 showed nodal fidelity patterns for the sites and species groups defined by hierarchical cluster analysis. Although the species groups 1 and 2 were highly constant to the collection groups A and B (Figure 17), they were not faithful to any of the site groups. Species group 3, which was moderately constant to mud group B, showed low fidelity to site group B.

## V. Discussion

A community, as stated by Sanders (1960), is a group of species that shows a high degree of association by tending to reoccur together. The community, in other words both in organisms present and by biomass, is an association of organisms in a given region in which the various species are more or less interacting among each other.

Since the study did not examine any degree of dependence between or within the species present, the term community cannot be used in this study to describe the congregations of species in the sand or in the mud sites or those organisms found in both. Rather, the term "assemblages" should be used to explain the grouping of the organisms associated with the various sediment types. The usage of the word does not attempt to suggest that any degree of interdependency or interaction exists among the species.

Intertidal areas of the Lynnhaven River system composed of sand and mud were examined. Sanders (1968) characterized intertidal areas as a "physically controlled community"; but, for my purposes, I shall refer to this area as a physically controlled assemblage. This area is characterized by widely fluctuating physical conditions which would place an extreme physiological stress upon the organisms that try to settle here. The surviving benthic invertebrates located at these sites must be able to tolerate a broad range of physical fluctuations (temperature, salinity, and oxygen availability). This would result in these

communities being characterized by a small number of eurytopic species (Sanders, 1968).

Six species dominated the total number of individuals and biomass, accounting for an overall average of 89% of the total individuals and 88% of the total biomass. They were Capitella capitata, Heteromastus filiformis, Laeonereis culveri, Nereis succinea, and Streblospio benedicti, all polychaetes, and one oligochaete, Peloscolex gabrielliae. The six species were found to be non-selective in sediment type and distributed throughout all six sites except N. succinea which was found at sites 1 through 5. These species are classified as highly eurytopic opportunists that are physiologically adapted to survive stressed or physically disturbed environments (Grassle and Grassle, 1974; Rosenberg, 1976; Boesch, 1977a).

For a system that is constantly being disturbed because of natural or man-made causes, the species mentioned are ideally suited to adapt to environmental changes. The six species above possess some or all of the following characteristics that allow them to survive intertidally. They are capable of responding to a disturbance by reproducing very rapidly (Reisch, 1971; Grassle and Grassle, 1974; Kaplan et al., 1975; Watling, 1975; Dauer and Simon, 1976); of surviving extreme salinity and temperature gradients (Dean and Haskin, 1964; Tenore, 1972; Grassle and Grassle, 1974; Grey, 1976); of tolerating man-made disturbed environments (Tenore, 1972; Buchanan and Warwick, 1974; Grassle and Grassle, 1974; Grey, 1976; Scherba and Gallucci, 1976); and of invading a wide range of sediment types (Grassle and Grassle, 1974; Kinner et al., 1974; Boesch, 1977a). The dominance in density and biomass of the six

species was very high throughout all six sites on the river system (Figures 6, 7, and 8). Even though Figures 6, 7, and 8 do not show the influence of oxygen stress, available organics, and seasonal changes, these environmental factors probably also had an effect on regulating total density and biomass of the species.

When examining the river system for variations in sediment types, two regions of different silt-clay content were seen (Table 1). Differences were shown between the mud and sand sites for average number of individuals (Figure 3), average biomass (Figure 4), and average number of species (Figure 5). Generally, there was a greater concentration of individuals and biomass (Figures 3 and 4) and a greater number of species (Figure 5) at the sand sites. The exception was site 1, a sand site, which had fewer number of species than site 4, a mud site, but still a greater number than found at sites 5 or 6, mud sites. Sanders (1968) has indicated that, within given areas, the sand bottom fauna is generally more diverse in species and individuals than that of mud bottoms, presumably because of the greater variety of microhabitats available. Moreover, an organism's presence at sand or mud sites in number and biomass could be affected directly by oxygen availability, deposition rates of the sediment, sediment type characteristics, and food availability.

Oxygen content in mud sediments is much less than at sand sites because of the reduced water permeability of the mud sites. Generally, a redox potential layer is formed just below the surface of the mud and the anaerobic conditions that exist below this layer would prevent oxygen breathing organisms from penetrating. This would limit the

number of organisms and species that could inhabit this environment. On the other hand, sand sites which have a greater permeability to water have a deeper redox layer which allows for greater vertical movement. This in turn permits more individuals and species to survive.

Another element that would allow more suspension feeders to survive at sand sites than mud sites would be the higher rate of deposition of sediments at mud sites. In benthic areas where there is very little current to allow the flushing of the overlying waters, as at the mud sites, organic matter and sediment run-off from land erosion would settle at a greater rate, smothering any sedentary organisms and clogging the feeding mechanisms of suspension feeders. Again the sand sites would offer more optimum conditions for greater survival of species and density than the mud sites.

The sands, which contained few grain size categories, would allow for more interstitial spaces between the grains than the muds, which contained many sediment grain sizes. At the sand sites a more diverse assemblage of species and individuals would be able to burrow through and migrate vertically to deeper levels to avoid unfavorable surface water conditions than at the mud sites.

The availability of food in the water interface would be greater for the suspension feeders and selective deposit feeders at the sand sites than at the mud sites because the constant current flow is continuously replenishing the food supply.

The total species per site (Figure 5) was lowest at site 1 when examining the sand sites and at site 6 when examining the mud sites. However, these sites had the greatest number of individuals per sand or



mud sites respectively (Figures 3 and 5). The six opportunistic species, Capitella capitata, Heteromastus filiformis, Laeonereis culveri, Nereis succinea, Peloscolex gabrielliae, and Streblospio benedicti, contributed the greatest total density, 95.6% (site 1) and 90.6% (site 6), and biomass, 98.4% (site 1) and 96.1% (site 6), at these two sites than all of the remaining species (see Appendices). The high dominance and presence of these opportunistic species could suggest that sites 1 and 6 were stressed more than were any of the other sand or mud sites causing the physical conditions, not competition between species, to be the limiting factor in total species. Adverse physical conditions would cause low numbers of species and allow the species present to utilize the resources present to the fullest and occur in high densities. Grassle and Grassle (1974) showed that for intertidal areas, such as sites 1 and 6, that have less predictable environments, a greater number of opportunistic species and individuals would occur.

The pattern of temporal variation (Figures 10, 11, and 12) for the year showed that the variation in density of the species and the actual number of the species used to calculate  $H'$ ,  $E$ , and  $R$  depended on the sites being examined. The probable reason the mud sites showed more variability in species diversity,  $H'$  (Figure 10), and in species evenness,  $E$  (Figure 11), with the lower values occurring during the summer months, was that environmental conditions such as high temperatures and lower oxygen availability were unfavorable to sustain large numbers of individuals and biomass. Another factor may be that the mud sites afford less protection from predation by fish and macroinvertebrates (Young, et al., 1976).

The drop shown in April for the sand sites' species diversity ( $H'$ ) and evenness ( $E$ ) was due to their density and to the effect of the winter environmental conditions on the species present. The winter is more detrimental to species in sand sites than those in the mud sites. The upper layers of the sand sites may be more easily disturbed physically by harsh winter conditions such as water currents than the mud sites with their heavier consistency. This would also explain the gradual drop from August to April in the total number of species,  $R$  (Figure 12) at the sand sites while those species at the mud sites remained fairly constant from August to April. During the summer months both sand and mud sites showed a slight increase in the total number of species because of the recruitment of new species settling and surviving from the planktonic stages of the infauna.

For the winter month February, a decline at the mud sites was recorded for both average number of individuals and biomass (Figure 9). Seasonal changes such as observed in this study were recorded by Tenore (1972), Beukema (1976) and Holland et al. (1977). However, further studies will have to be conducted on the Lynnhaven system to verify conclusively that the above factors controlled the temporal variation of the macroinvertebrates in the intertidal areas.

Any disturbance or stress induced by climatic fluctuations, salinity regime, sediment grain size or man-made disturbances will cause the species diversity to be low (Copeland, 1970; Boesch, 1972). The above factors probably affected the diversity, evenness, and richness values shown among the six sites (Figures 10, 11, and 12). Sanders, et al. (1965) showed for the Pocasset River, Massachusetts, that species

diversity was lowest at the station with the lowest salinity highest up the estuary and diversity was highest at the station with the greatest salinity.

Unlike studies by other investigators with higher diversity values in sand than in mud (Sanders, 1968; Young and Rhoads, 1971; Kinner et al., 1974), my values for  $H'$ ,  $E$ , and  $R$  were very nearly the same for all sand and mud sites (see Figures 10 - 13). When compared to a study by Boesch (1972) conducted in the Virginia area, my average median values were much lower, 2.3 (sand) and 2.2 (mud), than his values, 3.9 (sand) and 3.3 (mud), for species diversity ( $H'$ ). On the other hand, my evenness values were higher, 0.65 (sand) and 0.72 (mud), compared to Boesch's 0.48 (sand) and 0.56 (mud). However, the species richness values were lower than observed by Boesch, 1.8 (sand) and 1.4 (mud), compared to Boesch's 7.5 (sand) and 5.7 (mud). When differences in diversity between sand and mud sites were seen by the above investigators, these differences were attributed to competition, predation, absence of suspension feeders in areas of high silt-clay, higher spatial heterogeneity in sand, and the stability of sand over mud, thus offering a more favorable site for the settlement and survival of larvae. Further research should be done to determine whether or not these factors play a role in this study and if these effects could be the cause of the lower and similar values as recorded in this study.

From the multivariate methods used, i.e., cluster analysis and nodal analysis, several interesting results were obtained.

The cluster analysis grouped the sites and species into three distinct assemblages. The group - average sorting method of analysis

divided the six sites into sand and mud sites based upon density and biomass data (Figures 14 A and 14 B).

The cluster analysis for the species for both total individuals and biomass depicted what assemblages prevailed for the Western Branch. It created three groups - 1. individuals found concentrated at the sand sites, 2. individuals found dispersed heavily throughout all six sites, and 3. individuals found only at the mud sites whether based upon density (Figure 15) or based upon biomass (Figure 16). The degree of similarity for the individuals concentrated most heavily at the sand sites (group 1) was due to the infrequent and seasonal occurrence (see Appendices) of these species throughout the study sites and a stronger preference to congregate at the sand sites. Group 2 showed the greatest degree of similarity because they dominated the samples for the total study for density and biomass. Group 3, those species found only at the mud sites, were 20% similar for density and 21% similar for biomass to all other species. These values can be attributed to the occurrence of these two species at two of the mud sites and to the low densities and biomass they contributed to the study.

Constancy (Figure 17) of the site groups A was very highly characterized by species group 1. Species group 1 was moderately constant at the mud group site B. Both study sites were strongly characterized by species group 2. The individual species comprising species group 2 were found throughout all six study sites. Species group 2 was comprised mostly of the eurytopic, opportunistic species. Site group A's constancy was characterized low by species group 3. Species group 3 was moderately constant at the mud group site B.

Figure 18 shows nodal fidelity patterns for species groups. It can be shown that group 2, although highly constant in some collection groups, was not very faithful in any of the group sites. This tendency could be attributed to the frequent occurrence of the species throughout all six sites. Species group 2 did not dominate only one site group in total density for the study, but instead occurred constantly throughout all two site groups for the complete study.

Species group 1, highly constant in collection group A, and species group 3, moderately constant in site group B, were not faithful to the two site groups. These species groups (1, 3) support the evidence that, like species group 2, both groups cannot be characterized by any particular site group. The species groups 1 and 3 occurred often enough at site group A and site group B, respectively, to be low in fidelity but not often enough in density to be characterized by that particular site group. The nodal constancy and fidelity results show that the Western Branch of the Lynnhaven River system has no clear-cut species-sediment relationship to any particular sand or mud group sites. Instead these species groups constantly occur often enough in all sites to disallow any faithfulness to one sediment type, but, instead, possessed some degree of constancy to continually occur together in their particular species group throughout the time of the study.

It can be stated that the nodal analysis supports the grouping of species and collection types by cluster analysis. Nodal analysis can be used as a means to explain through constancy and fidelity the ecological significance assigned to each cluster group. This has been shown through the use of the data accumulated from the study and from the multivariate tests.

## VI. Summary

1. The benthic populations of macrofauna were studied for one year at six stations located on the Western Branch of the Lynnhaven River, Virginia Beach, Virginia, U.S.A. Sampling depths were taken just at mean low tidal level. Relatively lower densities, biomass and total species were shown by the mud sites.
2. Six opportunistic species, Capitella capitata, Heteromastus filiformis, Laeonereis culveri, Nereis succinea, Streblospio benedicti (all polychaetes) and Peloscolex gabrielliae (oligochaete), dominated the samples for the year for total densities and biomass.
3. Species diversity, richness, and evenness were similar in value between all sand and mud sites.
4. Cluster analysis successfully grouped the sites and species into distinct assemblages.
5. The grouping of the sites and species by cluster analysis was further examined by nodal analysis. The latter successfully explained the species groups constancy and/or fidelity to the site groups.

## LITERATURE CITED

- Beukema, J. J., 1976. Biomass and species richness of the macro-benthic animals living on the tidal flats of the Dutch Wadden Sea. *Neth. J. Sea Res.*, 10: 236-261.
- Bloom, S. A., J. L. Simon, and V. D. Hunter, 1972. Animal-sediment relations and community analysis of a Florida estuary. *Mar. Bio.*, 13: 43-56.
- Boesch, D. F., 1972. Species diversity of marine macrobenthos in the Virginia area. *Ches. Sci.*, 13: 206-211.
- \_\_\_\_\_, 1977a. A new look at the zonation of benthos along the estuarine gradients. In *Ecology of Marine Benthos*. B. C. Coull, ed., pp. 245-266, Belle W. Baruch Library in Marine Science, U. South Carolina Press, Columbia.
- \_\_\_\_\_, 1977b. Application of numerical classification in ecological investigations of water pollution. EPA Report 600/3-77-033. U.S. Environmental Protection Agency, Corvallis, 115 pp.
- Buchanan, J. B. and R. M. Warwick, 1974. An estimate of benthic macro-faunal production in the offshore mud of the Northumberland coast. *J. Mar. Biol. Assoc. U.K.*, 54: 197-222.
- Copeland, B. J., 1970. Estuarine classification and responses to disturbances. *Trans. Amer. Fish. Soc.*, 99: 826-835.
- Dauer, D. M. and J. L. Simon, 1976. Lateral or along-shore distribution of the polychaetous annelids of an intertidal sandy habitat. *Mar. Bio.*, 31: 363-370.
- Day, J. M., J. G. Field, M. P. Montgomery, 1971. Use of numerical methods to determine distribution of benthic fauna across continental-shelf of N. Carolina. *J. Anim. Ecol.*, 40: 93-126.
- Dean, D. and H. H. Haskin, 1964. Benthic repopulation of the Raritan River estuary following pollution abatement. *Limnol. Oceanogr.*, 9: 551-563.
- Dickman, M., 1968. Some indices of diversity. *Ecology*, 49: 1191-1193.
- Folk, R. L., 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, Texas.

- Grassle, J. F. and J. P. Grassle, 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. *J. Mar. Res.*, 32: 235-284.
- Grey, J. S., 1976. The fauna of the polluted river Tees estuary. *Estuarine Coastal Mar. Sci.*, 4: 653-676.
- Holland, A. F., N. K. Mountford, and J. A. Mihursky, 1977. Temporal variation in Upper Bay mesohaline benthic communities: I. The 9-m mud habitat. *Ches. Sci.*, 18: 370-378.
- Johnson, R. E., L. J. Baer, J. C. Barlow, W. M. Crouse, F. R. Frisbie and W. J. Comerly, 1974. Mapping survey of the marine wetlands of the Rudee and Lynnhaven areas of Virginia Beach, Virginia. Tech. Report No. 10, Inst. of Oceanography, Old Dominion University, 20 pp.
- Johnson, R. G. 1970. Variation in diversity within benthic marine communities. *Am. Nat.*, 104: 285-300.
- \_\_\_\_\_, 1971. Animal-sediment relations in shallow water benthic communities. *Marine Geology*, 11: 93-104.
- Kaplan, E. M., J. R. Welker, M. G. Kraus and S. McCourt, 1975. Some factors affecting the colonization of a dredged channel. *Mar. Biol.*, 32: 193-204.
- Kinner, P., D. Maurer and W. Leathen, 1974. Benthic invertebrates in Delaware Bay: Animal-sediment association of the dominant species. *Int. Revue ges. Hydrobiol.*, 59: 685-701.
- McNulty, J. K., R. C. Work and H. B. Moore, 1962. Some relationships between the infauna of the level bottom and sediment in South Florida. *Bull, Marine Sci. Gulf Carribbean*, 12: 322-332.
- O'Connor, J. S., 1972. The benthic macrofauna of Moriches Bay, New York. *Biol. Bull*, 142: 84-102.
- Oswalt, D. W., 1975. Urbanization and environmental change in Lynnhaven Estuary, Norfolk, V.: Old Dominion Univ., 1975. Thesis (M.S.).
- Peterson, C. G., 1924. A brief survey of the animal communities in Danish waters. *Amer. J. Sci.*, 7: 343-354.
- Reish, D. J., 1971. Seasonal settlement of polychaetous annelids on test panels in Los Angeles-Long Beach Harbors 1950-1951. *J. Fish. Res. Board Can.*, 28: 1459-1467.
- Rosenberg, R., 1976. Benthic faunal dynamics during succession following pollution abatement in a Swedish estuary. *Oikos*: 414-427.



- Sanders, H. L., 1958. Benthic studies in Buzzard Bay. I. Animal-sediment relationships. *Limnol. and Ocean.*, 3: 245-258.
- \_\_\_\_\_, 1960. Benthic studies in Buzzard Bay. III. The Structure of the soft-bottom community. *Lim. and Ocean.*, 5: 138-153.
- \_\_\_\_\_, P. C. Mangelsdorf, and G. R. Hampson, 1965. Salinity and faunal distribution in the Pocasset River, Mass. *Limnol. and Ocean.*, 10: 216-228.
- \_\_\_\_\_, 1968. Marine benthic diversity: A comparative study. *Am. Naturalist*, 102: 243-282.
- Scherba, Jr., S. and V. F. Gallucci, 1976. The application of systematic sampling to a study of infauna variation in a soft substrate environment. *Fishery Bulletin*, 74: 937-948.
- Tenore, K. R., 1972. Macrobenthos of the Pamlico River Estuary, North Carolina. *Ecol. Monogr.*, 42: 51-69.
- Watling, Les, 1975. Analysis of structural variations in a shallow estuarine deposit-feeding community. *J. Exp. Mar. Biol. Ecol.*, 19: 275-313.
- Wilhm, J. L., 1968. Use of biomass units in Shannon's formula. *Ecology*, 49: 153-156.
- Young, D. K. and D. C. Rhoads, 1971. Animal-sediment relations in Cape Code Bay, Mass. I. A transect study. *Mar. Biol.*, 11: 242-254.
- \_\_\_\_\_, M. A. Buzas, and M. W. Young, 1976. Species densities of macrobenthos associated with seagrass: A field experimental study of predation. *J. Mar. Res.*, 34: 577-592

## SITE 1 LYNNHAVEN SAND

SPECIES	SAMPLING PERIOD						$\bar{x}$
	1	2	3	4	5	6	
Capitella	34	19	21	15	12	7	14.3
Chaetozone			4				0.7
Diptera		2					0.3
Eteone	3				1	32	6.0
Gammarus M.	1					1	0.2
Gemma	11	4	9	11	1	1	6.2
Heteromastus	22	29	36	17	16	19	23.2
Laeonereis	260	150	133	60	61	125	131.5
Macoma					1		0.2
Mya	2				1	2	0.8
Myzobdella		3					0.5
Nassarius	4						0.7
Nereis	1		4	6	2	14	4.5
Palremonetes	2						0.3
Peloscolex	36	121	339	236	300	134	194.3
Polydora		1	3				0.7
Streblospio	9	1	14			21	7.5
Tagelus		1		1			0.3
Total Species		12	10	9	6	8	10
Total Individuals		390	331	563	331	381	356

## SITE 2 LYNNHAVEN SAND

SPECIES	SAMPLING PERIOD						$\bar{x}$
	1	2	3	4	5	6	
Capitella	6	58	50	28	12	2	26.0
Chaetozone	71	43	33	46	202	66	76.8
Corophium		1					0.2
Drilonereis	1	3	2	5	1	2	2.3
Eteone	2				2	12	2.7
Gemma	7	11	4	16	2	1	6.8
Glycera						2	0.3
Heteromastus	17	17	15	17	42	37	24.2
Laeonereis	74	68	34	100	37	57	61.7
Loima			1				0.2
Macoma					1		0.2
Microphthalmus						1	0.2
Mya	1		9		1	1	2.0
Myzobdella		3					0.5
Nassarius						1	0.2
Nemertea	4	2	3		2	5	2.7
Nereis	4	8	10	14	9	7	8.7
Peloscolex	2	98	61	93	95	39	64.7
Polydora			15	13		2	5.0
Saceoglossus	2	4	2	1	1		1.7
Scoloplos		2		1			0.5
Streblospio	16	15	153	57	22	59	53.7
Tagelus	4	4	2	2	1	2	2.5
Total Species		14	15	15	13	15	17
Total Individuals		211	337	394	393	430	296

## SITE 3 LYNNHAVEN SAND

SPECIES	SAMPLING PERIOD						$\bar{x}$
	1	2	3	4	5	6	
Capitella	67	45	32	45	22	24	39.2
Chaetozone			5				0.8
Corophium				1			0.2
Cyathura				1			0.2
Eteone						2	0.3
Gemma				4			0.7
Heteromastus	34	40	125	87	173	38	182.8
Laeonereis	36	14	10	18	9	21	18.0
Macoma	1		1	1	3		1.0
Mya	1			7	5		2.2
Nemertea	8	1	4	3	6	1	3.8
Nereis	3	1	6	17	8	4	6.5
Peloscolex	18	47	94	123	176	21	79.8
Polydora	1	1	20	17	1		6.7
Streblospio	8	12	75	88	36	14	38.8
Tagelus			6	3		1	1.7
Total Species		10	8	11	14	10	9
Total Individuals		177	161	378	415	439	126

## SITE 4 LYNNHAVEN MUD

SPECIES	SAMPLING PERIOD						$\bar{x}$
	1	2	3*	4	5	6	
Ancistrosyllis					2	1	0.2
Capitella	21	29	49	32	11	5	24.5
Corophium		1		1			0.3
Cyathura	1	1	1	7	6	1	2.8
Cymadusa					5		0.8
Eteone						4	0.7
Glycinde	1						0.2
Heteromastus	10	5	23	7	18	12	12.5
Laeonereis	42	34	51	52	24	24	37.8
Lysippides			2		1	1	0.7
Macoma					1		0.2
Microphthalmus					5		0.3
Mya		1	1				0.3
Nemertea	6	3	8	4	12	9	7.5
Nereis	1		1			1	0.5
Peloscolex	1	9	71	14	28	22	24.2
Polydora			2				0.3
Streblospio		7	44	18	16	13	16.3
Total Species		8	8	11	8	11	11
Total Individuals		83	90	253	135	124	93

\*Only nine samples.

## SITE 5 LYNNHAVEN MUD

## SAMPLING PERIOD

SPECIES	1	2	3	4	5	6	$\bar{x}$
Capitella	36	38	21	6	6	7	19.0
Corophium				1			0.2
Cyathura	3	4	4	4	6	8	4.8
Eteone						2	0.3
Heteromastus	19	12	9	13	34	26	18.8
Laeonereis	86	116	96	59	32	46	72.5
Nemertea	4	6	10	6	1	9	6.0
Nereis		2		2		1	0.8
Peloscolex	3	96	11	11	76	4	33.5
Polydora			1				0.2
Spiophanes						1	0.2
Streblospio	3	3	55	20	35	9	20.8
Total Species		7	8	8	9	7	10
Total Individuals		154	277	207	122	190	113

## SITE 6 LYNNHAVEN MUD

SPECIES	SAMPLING PERIOD						$\bar{x}$
	1	2	3	4	5	6	
Capitella	8	66	120	4	14		35.0
Chaetognath	1						0.2
Corophium		1	17				3.0
Heteromastus	13	9	19	17	13	4	12.5
Laeonereis	38	175	136	33	16	33	71.8
Lysippides	1	3	19	16	41	23	17.2
Mya			1				0.2
Nemertea		7	2		1		1.7
Peloscolex	27	34	79	72	258	95	90.8
Polydora			3				0.5
Streblospio	1	9	42	3	24	1	13.3
Total Species		7	8	10	6	7	5
Total Individuals		89	304	438	145	367	136

## SITE 1 LYNNHAVEN SAND

SPECIES	SAMPLING PERIOD						$\bar{x}$
	1	2	3	4	5	6	
Capitella	.0015	.0038	.0053			.0035	.0024
Chaetozone			.0001				
Diptera		.0017					
Eteone	.0198				.0016	.0016	
Gammarus M	.0001					.0001	
Gemma	.0087	.0010	.0017	.0001	.0036	.0001	
Heteromastus	.2370	.0999	.1358	.0579	.1491	.1675	.1412
Laeonereis	.3105	.3391	.4623	.1827	.4688	.4960	.3766
Macoma					.0835		
Mya	.7968				.9674	.6846	
Myzobdella		.0001					
Nassarius	.5374						
Nereis	.0208		.0040	.0106	.0413	.0037	.0133
Peloscolex	.0019	.0100	.0218	.0181	.0440	.0109	.0163
Polydora		.0012	.0009				
Streblospio	.0001	.0003	.0010			.0011	.0004
Tagelus		.4565		.6113			
Total Species	12	10	9	6	8	10	
Total Biomass (g)	1.9353	0.9135	0.6329	0.8807	1.7593	1.3691	
Biomass less							
Mollusca	0.6011	0.4570	0.6329	0.2694	0.7084	0.6845	



## SITE 2 LYNNHAVEN SAND

## SAMPLING PERIOD

SPECIES	1	2	3	4	5	6	$\bar{x}$
Capitella	.0042	.0087	.0079	.0039	.0086	.0002	.0056
Chaetozone	.0456	.0270	.0177	.0372	.0436	.0151	
Corophium		.0001					
Drilonereis	.0039	.0299	.0247	.1335	.0054	.0015	
Eteone	.0019				.0026	.0006	
Gemma	.0054	.0016	.0015	.0002	.0018	.0003	
Glycera						.0004	
Heteromastus	.0362	.0444	.0100	.0582	.1128	.0893	.0585
Laeonereis	.1573	.2031	.0594	.2674	.1130	.0919	.1487
Loima			.1343				
Macoma					.2172		
Microphthalmus						.0002	
Mya	.3971		.0214		.1132	.1626	
Myzobdella		.0021					
Nassarius						.0333	
Nemertea		.0009	.0014		.0091	.0058	
Nereis	.0283	.0197	.2297	.1100	.0210	.0101	.0698
Peloscolex	.0025	.0037	.0031	.0052	.0069	.0017	.0039
Polydora			.0042	.0088		.0001	
Saceoglossus	.0282	.0417	.0004	.0136	.0243		
Scoloplos				.0001			
Streblospio	.0046	.0014	.0240	.0120	.0028	.0047	.0083
Tagelus	1.5553	2.2380	1.7200	.7960	.2632	1.6979	
Total Species	14	15	15	13	15	17	
Total Biomass (g)	2.3000	2.6222	2.2597	1.4461	0.9455	2.1159	
Biomass Less Mollusca	0.3476	0.3842	0.5183	0.6501	0.3519	0.2604	

## SITE 3 LYNNHAVEN SAND

SPECIES	SAMPLING PERIOD						$\bar{x}$
	1	2	3	4	5	6	
Capitella	.0150	.0096	.0066	.0080	.0105	.0084	.0062
Chaetozone			.0002				
Corophium				.0001			
Cyathura				.0001			
Eteone						.0001	
Gemma				.0001			
Heteromastus	.0939	.1676	.2513	.3771	.7936	.1379	.3036
Laeonereis	.0951	.0508	.0180	.0618	.0255	.0292	.0467
Macoma	.1314		.1395	.0001	.4263		
Mya	.0020			.1265	12.0325		
Nemertea	.0020	.0003		.0016		.0001	
Nereis	.0176	.0578	.7050	.1539	.0946	.0025	.0658
Peloscolex	.0004	.0225	.0057	.0068	.0089	.0004	.0033
Polydora	.0005	.0001	.0063	.0044	.0001		
Streblospio	.0010	.0019	.0111	.0112	.0273	.0002	.0088
Tagelus			.0294	.7089		.0739	
Total Species	10	8	11	14	10	9	
Total Biomass (g)	0.3569	0.2896	0.5420	1.4606	13.4236	0.2507	
Biomass Less Mollusca	0.2255	0.2896	0.3731	0.6251	0.9648	0.1768	

## SITE 4 LYNNHAVEN MUD

## SAMPLING PERIOD

SPECIES	1	2	3	4	5	6	$\bar{x}$
Ancistrosyllis					.0021	.0011	
Capitella	.0059	.0054	.0104	.0056	.0066	.0006	.0052
Corophium		.0032		.0062			
Cyathura	.0018	.0007	.0139	.0208	.0348	.0008	
Cymadusa					.0038		
Eteone						.0003	
Glycinde	.0015						
Heteromastus	.0023	.0023	.0074	.0025	.0306	.0077	.0088
Laeonereis	.2097	.2097	.3103	.1867	.2121	.0509	.1966
Lysippides			.0001		.0023	.0010	
Macoma					.0155		
Microphthalmus					.0001		
Mya		.0016	.0001				
Nemertea	.0002	.0016	.0038	.0189	.0448	.0063	
Nereis	.0578		.1169			.0947	.0449
Peloscolex	.0003	.0003	.0033	.0002	.0001	.0006	.0008
Polydora			.0002				
Streblospio		.0008	.0029	.0017	.0028	.0003	.0014
Total Species	8	9	11	8	12	11	
Total Biomass (g)	0.0633	0.2226	0.4693	0.2401	0.3535	0.1643	
Biomass Less Mollusca	0.0633	0.2210	0.4693	0.2401	0.3380	0.1643	

## SITE 5 LYNNHAVEN MUD

## SAMPLING PERIOD

SPECIES	1	2	3	4	5	6	$\bar{x}$
Capitella	.0113	.0055	.0045	.0001	.0014	.0015	.0041
Corophium				.0001			
Cyathura	.0195	.0013	.0273	.0013	.0525	.0161	
Eteone						.0008	
Heteromastus	.0031	.0119	.0110	.0206	.0832	.0160	.0243
Laeonereis	.0877	.3947	.4558	.3489	.4074	.0639	.2931
Nemertea	.0016	.0093	.0115	.0244	.0176	.0080	
Nereis		.0180		.0013		.0012	.0034
Peloscolex	.0033	.0074	.0019	.0005	.0071	.0001	.0034
Polydora			.0011				
Spiophanes						.0001	
Streblospio	.0023	.0011	.0065	.0023	.0041	.0030	.0032
Total Species	7	8	8	9	7	10	
Total Biomass (g)	0.1232	0.4492	0.5196	0.3995	0.5733	0.1107	
Biomass Less Mollusca	0.1232	0.4492	0.5196	0.3995	0.5733	0.1107	

## SITE 6 LYNNHAVEN MUD

SPECIES	SAMPLING PERIOD						$\bar{x}$
	1	2	3	4	5	6	
Capitella	.0008	.0134	.0314	.0001	.0048		.0085
Chaetognath	.0001						
Corophium		.0001	.0100				
Heteromastus	.0019	.0020	.0116	.0040	.0037	.0013	.0042
Laeonereis	.0538	.2047	.2754	.1651	.0927	.0206	.1354
Lysippides	.0004	.0010	.0043	.0036	.0030	.0023	
Mya			.0004				
Nemertea		.0054	.0126		.0050		.0038
Peloscolex	.0018	.0015	.0033	.0019	.0204	.0013	.0050
Polydora			.0004				
Streblospio	.0001	.0009	.0052	.0001	.0019	.0002	.0014

Total Species	7	8	10	6	7	5
Total Biomass (g)	0.0588	0.2292	0.3446	0.1748	0.1315	0.0257
Biomass Less Mollusca	0.0588	0.2292	0.3442	0.1748	0.1315	0.0257

## A. SHANNON-WEAVER INDEX FOR SPECIES DIVERSITY (H')

SITE		SAMPLING PERIOD					
		AUG	OCT	DEC	FEB	APR	JUNE
Sand	1	1.7882	1.8516	1.7327	1.3080	1.0009	2.2244
	2	2.5328	2.8922	2.8061	2.9129	2.3154	2.9335
	3	2.4205	2.2538	2.5192	2.7181	2.0180	2.5548
	4	1.9480	2.2874	2.6888	2.3948	3.4081	2.8035
Mud	5	1.8010	1.9751	2.1392	2.3349	2.2180	2.4177
	6	1.4582	1.8093	2.4893	1.9597	1.5383	1.6045

## B. PIELOU'S INDEX FOR EVENNESS

SITE		SAMPLING PERIOD					
		AUG	OCT	DEC	FEB	APR	JUNE
Sand	1	0.4988	0.5544	0.5466	0.5060	0.3376	0.6696
	2	0.6342	0.7483	0.8112	0.7871	0.5926	0.7177
	3	0.7286	0.7513	0.8182	0.7139	0.6025	0.8060
	4	0.6493	0.7625	0.7772	0.7183	0.9129	0.8104
Mud	5	0.6415	0.6584	0.7124	0.7366	0.7845	0.7278
	6	0.5194	0.6031	0.8290	0.7581	0.5479	0.6910

## C. MARGALEF'S SPECIES RICHNESS INDEX

SITE		SAMPLING PERIOD					
		AUG	OCT	DEC	FEB	APR	JUNE
Sand	1	1.8438	1.5512	1.2632	0.8618	1.1769	1.5317
	2	2.4291	2.4055	2.3426	2.0478	2.3088	2.8118
	3	1.7383	1.3776	1.6849	2.1565	1.4792	1.6542
	4	1.5841	1.5556	1.8072	1.4271	2.0746	2.2062
Mud	5	1.1912	1.2447	1.3127	1.6655	1.1435	1.9038
	6	1.3367	1.2244	1.4779	1.0091	1.0160	0.8142

TABLE 4. Species Diversity Analysis - Shannon-Weaver Index for Species Diversity, Pielou's Index for Evenness, Margalef's Species Richness Index for Each Site.

# D. Constancy and Fidelity Values Determined by Nodal Analysis

		Species Group					
		1		2		3	
		C	F	C	F	C	F
Site Groups	A	1.00	1.36	0.94	0.97	0.08	0.40
	B	0.47	0.66	1.00	1.02	0.33	1.60

C: Constancy Values

F: Fidelity Values

Site Groups: A (site 1, 2, 3); B (site 4, 5, 6).

Species Groups: 1 - refers to density subset cluster group "d".  
 2 - refers to density subset cluster group "e".  
 3 - refers to density cluster groups "b" and "c".