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Benthic Macroinvertebrate Communities as Indicators of Pollution in the Elizabeth River, Hampton Roads, Virginia

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BENTHIC MACROINVERTEBRATE COMMUNITIES AS INDICATORS OF POLLUTION IN THE ELIZABETH RIVER, HAMPTON ROADS, VIRGINIA

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by

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of

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ABSTRACT

The macrobenthos of the Elizabeth River, Hampton Roads, Virginia, was sampled to define community structure and to determine possible alteration of this community because of pollution. The samples were dominated by pollution tolerant organisms with wide geographic ranges. These organisms are rarely dominant in other communities, except under stress conditions.

Non-selective deposit feeders were found in low numbers because of the lack of oxygen and high concentration of hydrogen sulfide found in deposits below 1 cm. Suspension feeders and selective deposit feeders were favored because of the good supply of well aerated detrital material on the sediment surface and trapped in abundant oyster shells.

The mean H' diversity value (2.96 bits/indiv.) was as high as that in some unpolluted areas, because pollution tolerant species maintained high equitability values. Species richness was reduced.

The benthos was most affected by pollution in May. Diversity and species richness values were reduced and the ratio of pollution tolerant to non-pollution tolerant organisms increased.

BENTHIC MACROINVERTEBRATE COMMUNITIES AS INDICATORS OF POLLUTION IN THE ELIZABETH RIVER, HAMPTON ROADS, VIRGINIA

INTRODUCTION

History of Pollution Studies

The use of invertebrates as indicators of water quality has been reviewed by Wass (1967), Reish (1960), McNulty (1970), Hynes (1960), and Hawkes (1962). Benthic invertebrates are among the best indicators of pollution because of their constant presence, relatively long lives and sedentary habits (Wass, 1967). Benthic invertebrates indicate the water quality at the time of sampling and past conditions during the life spans of the organisms sampled (Gaufin and Tarzwell, 1952).

Most benthic pollution studies written before 1960 were based on the saprobic system or the use of indicator organisms. The saprobic system was developed for freshwater studies in Europe by Kolkwitz and Marsson (1908, 1909). Lists of organisms known to be associated with different pollution conditions were developed. A more complex system of classification of saprobic zones was developed by Richardson (1921) for the Illinois River. Patrick (1949) and Wurtz (1955) developed various indices involving histograms of tolerant and intolerant species for freshwater streams in the United States.

Gaufin and Tarzwell (1952, 1956), studying pollution in freshwater streams in Ohio, were the first workers to emphasize the effect of pollution on community structure. They stressed that the presence of an indicator organism did not indicate pollution, but that the presence of indicator organisms in large numbers to the exclusion of non-pollution forms did indicate pollution.

Wilhm and Dorris (1966) were the first workers to use diversity indices as measures of water quality. Wilhm (1970) published a review of diversity in polluted and unpolluted freshwater streams to develop a basis for comparisons of these measures.

Most marine and estuarine pollution workers have used the saprobic system or the indicator species approach developed by freshwater biologists. Estuarine pollution work was begun by European workers in the Teas estuary (Alexander and Southgate, 1936; Fraser, 1932) and marine work by Blegvad (1932) studying an offshore sewage outfall near Copenhagen, Denmark. Extensive work has been done along the California coast and in California bays (see McNulty, 1970). These workers used the indicator species Capitella capitata in addition to developing saprobic zones of pollution. On the east coast work has been done by McNulty (1961, 1970) in Biscayne Bay and Dean and Haskin (1964) on the Raritan River. Both studies considered the changes in benthic communities after pollution abatement. Neither study used in-depth measures of community structure. Pearson et. al. (1967) used H' diversity in pollution studies of San Francisco Bay.

Marine and estuarine systems are more complex than the unidirectional flow of a freshwater stream. When the saprobic system or indicator species approach developed by freshwater biologists is applied, only the most severe pollution is defined. Wilhm and Dorris (1968) and Wass (1967) reanalyzed Reish and Winters' (1964) data on pollution of Alamitos Bay, California, and found that areas thought to be unpolluted by Reish and Winter were mildly polluted. New techniques for analysis of a more complex marine pollution system must be developed.

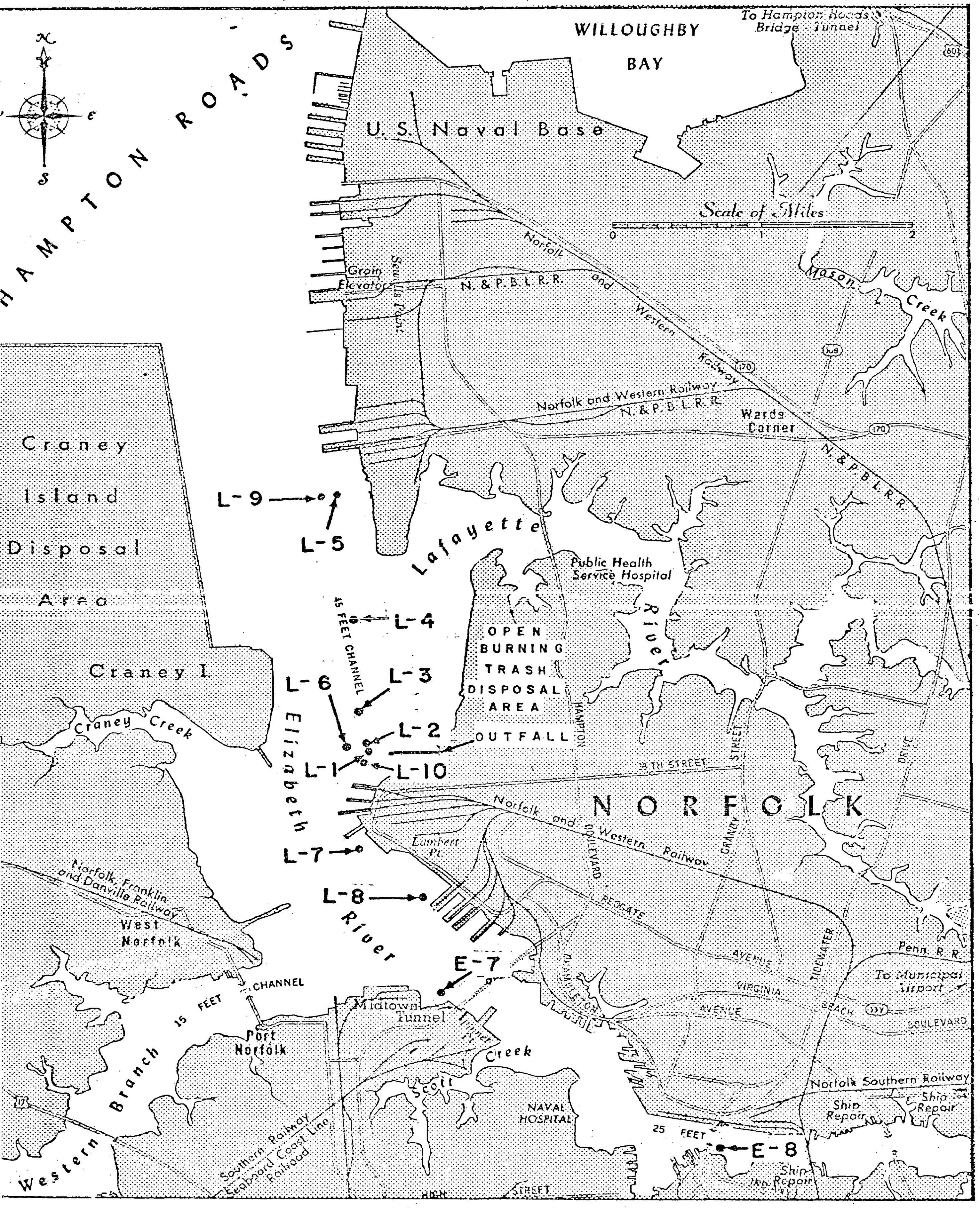
Modern numerical techniques will be used to define the benthic community structure in the Elizabeth River, Hampton Roads, Virginia. Diversity (H') and its components, equitability and species richness, will be calculated. Dominant species will be determined by a Biological Index. Dominance-affinity values will be calculated to determine station and sample homogeneity. Distribution, tolerance to pollution, and feeding types of dominant species will be discussed. The possible alteration of this community structure will be determined by comparisons with a recent study of Hampton Roads (Boesch, 1971) and other benthic studies throughout the world. This approach should better define the sometimes subtle effects of pollution in a complex estuarine system.

Physical and Chemical Conditions

The Elizabeth River drains into the James River, the southernmost tributary of the Chesapeake Bay (Fig. 1). The tidal range is about 0.8 m and current velocities seldom exceed 0.9 m/sec (Calder and Brehmer, 1967). The bottom consists of poorly sorted sediments of clay, silt, and sand, with numerous shells, predominantly of the oyster *Crassostrea virginica*. A 15-meter channel is maintained in mid-stream of the river. Salinity and temperature data from Newport News Point are given in Figure 2 for 1969. Temperature and salinity regimes in the Elizabeth River are similar to those off Newport News Point, with the possible exception of station E-8.

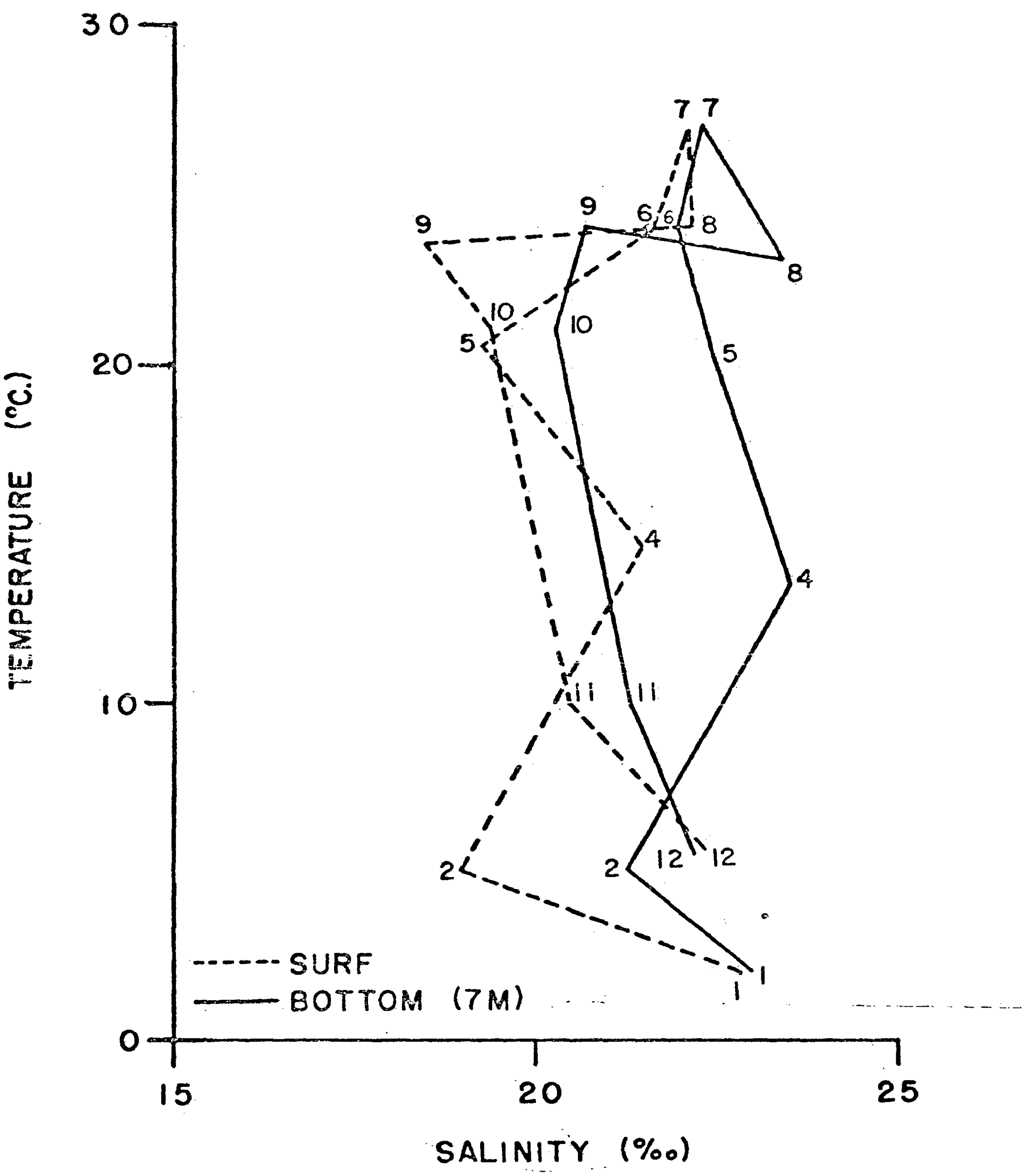
Hampton Roads and the Elizabeth River is the largest naval port facility on the East Coast of America, and a population and industrial center. Several primary sewage treatment outfalls drain into the

Figure 1. The port of Norfolk, including station locations on the Elizabeth River occupied in 1969.



WILLOUGHBY
BAY
To Hampton Roads Bridge - Tunnel
HAMPTON ROADS
U. S. Naval Base
Scale of Miles
0
1
2
Grain Elevator
Sewells Point
N. & P. B. L. R.R.
Norfolk and Western Railway
Mason Creek
Norfolk and Western Railway
N. & P. B. L. R.R.
Wards Corner
170
Craney Island Disposal Area
L-9
L-5
Lafayette River
Public Health Service Hospital
L-4
45 FEET CHANNEL
OPEN BURNING TRASH DISPOSAL AREA
Craney I.
L-6
L-3
L-2
OUTFALL
L-1
L-10
Craney Creek
Elizabeth River
HAMPTON BOULEVARD
GRANBY STREET
8TH STREET
NORFOLK
Norfolk and Western Railway
Lambert Pt.
L-7
L-8
Norfolk, Franklin and Danville Railway
West Norfolk
REDGATE
AVENUE
TIDEWATER
DRIVE
Penn. R. R.
To Municipal Airport
E-7
CHANNEL
15 FEET
VIRGINIA
BEACH
BOULEVARD
AVENUE
Midtown Tunnel
Port Norfolk
Creek
Western Branch
Scott
NAVAL HOSPITAL
Norfolk Southern Railway
Ship Repair
Ship Repair
25 FEET
E-8
Ship Repair
Southern Railway
Seaboard Coast Line Railroad
HIGH
STREET

Figure 2. Salinity-temperature polygon for Newport News Point, 1969.



J5 — NEWPORT NEWS POINT — 1969
SLACK BEFORE FLOOD

Elizabeth River in addition to numerous industrial effluents. The substrate is covered with residue from the open-burning trash disposal area between the Lafayette and Elizabeth rivers and coal dust from coal loading piers at Lamberts Point. Freshwater runoff from surrounding land adds domestic and agricultural waste to the system. Shellfish are condemned for market because of high bacterial levels. The highest concentrations of heavy metals and pesticides found in the lower James River basin occur in the Elizabeth River.

METHODS

Field Operations

Three replicate grabs were obtained from each of several stations in the Elizabeth River during three sampling periods in 1969. Six stations were sampled with a 0.06 m^2 Petersen grab in late January. A 0.07 m^2 Van Veen grab was used to sample 11 stations in May and 12 stations in August. Station locations and descriptions are presented in Figure 1 and Table 1. All samples were sieved through a 1 mm screen and the fraction remaining on the screen was preserved in 10% seawater-buffered formalin.

Sediment samples for particle size analysis and water samples for dissolved oxygen determination were obtained at all 12 stations in August. The sediment samples consisted of the upper 1 cm of substrate from an undisturbed 0.07 m^2 Van Veen grab. A Kemmerer bottle was used to collect the water samples as close to the bottom as possible.

Laboratory Procedure

All animals were sorted from the debris, identified and counted with the aid of a dissecting microscope. Sediment particle size distribution was determined by wet sieving and pipette analysis (Folk, 1961). Sediments were classified according to Shepard's (1954) sand-silt-clay terminology (Table 1). Dissolved oxygen determinations were made using a modified Winkler method (Table 2).

TABLE 1

Description of stations including depth, distance from Lamberts Point outfall, sediment type, and non-living material present.

Station	Depth (meters)	Distance from Lamberts Point outfall (meters)	Sediment type	Non-living material
L-1	3.3	0	clayey sand	*Nassarius obsoletus* shells, seeds, leaves, and coal.
L-2	4.0	100	clayey sand	Oyster reef
L-3	2.5	500	clayey sand	Oyster reef
L-4	4.8	1500	clayey sand	
L-5	4.0	3000	clayey sand	Oyster reef
L-6	6.5	100	clayey sand	*Mya arenaria* shells
L-7	6.5	1250	sand-silt-clay	*Spiochaetopterus oculatus* tubes, coal, and wood
L-8	3.3	2250	sand-silt-clay	*Mya arenaria* shells, *Spiochaetopterus oculatus* tubes, and coal
L-9	8.2	3000	clayey sand	*Mya arenaria* shells and *Spiochaetopterus oculatus* tubes

TABLE 1 (Cont'd.)

Station	Depth (meters)	Distance from Lamberts Point outfall (meters)	Sediment type	Non-living material
L-10	3.3	100	clayey sand	Oyster reef
E-7	3.6	3500	sand-silt-clay	
E-8	5.0	7500	sand-silt-clay	

TABLE 2

Dissolved oxygen (mg/liter) and percent saturation of Elizabeth River samples taken at slack water after ebb flow 0.3 meter from the bottom, August 19, 1969.

Station	Oxygen O_2 mg/liter	Percent Saturation at 23°C and 23 ‰
L-1	5.79	74%
L-2	6.00	77%
L-3	5.83	74%
L-4	6.15	79%
L-5	6.64	85%
L-6	6.15	79%
L-7	4.55	58%
L-8	5.16	66%
L-9	5.61	71%
L-10	5.61	71%

RESULTS

Macrofauna

A total of 22,404 individuals divided among 122 taxa were identified and counted from 87 grabs at 29 stations. A total of 5.5 m^2 of surface was sampled. Of the 122 taxa, 113 were identified to species, three to genera and six to higher taxa. Polychaetes were the most numerous group (17,122 individuals, 46 species) followed by molluscs (3,438 individuals, 25 species) and crustaceans (771 individuals, 36 species). The remaining 15 species (1,073 individuals) were in other phyla. A complete list of the species and individuals found in each sample is presented in Appendix II.

The mean density at stations in the Elizabeth River was 3,803 individuals per m^2 with a range of 142/m^2 at E-7 in August to 19,858/m^2 at L-3 in May (Table 3). Comparing only those six stations occupied at all the sampling periods, May had the highest mean density (7,553 individuals/m^2), followed by January (4,210 individuals/m^2) and August (1,664 individuals/m^2).

Dominant Organisms

A biological index of dominance (B.I.) modified from Fager (1957) was calculated to determine the dominant species present during each sampling period. In this analysis, the most numerous species at each station is given 5 points, the next 4, etc. The scores for each species are summed for all stations during a sampling period and divided by the

TABLE 3

Density of individuals per m^2 for all stations during each sampling period (dashed lines indicate no sample taken).

Station	January	May	Aug.	Total	Mean
L-1	3,575	1,499	547	5,621	1,874
L-2	1,996	17,297	4,522	23,815	7,938
L-3	3,697	19,858	2,132	25,687	8,562
L-4	2,875	2,679	723	6,277	2,092
L-5	11,386	3,360	8,548	23,294	7,765
L-6	----	2,380	333	2,713	1,356
L-7	----	1,989	371	2,306	1,153
L-8	----	2,065	542	2,607	1,303
L-9	----	----	1,494	1,494	1,494
L-10	----	5,497	4,879	10,376	5,188
E-7	1,734	623	142	2,499	833
E-8	----	3,027	495	3,522	1,761

total number of stations during that sampling period. Species are listed in order of decreasing B.I. for each sampling period in Tables 4, 5, 6. Included in those tables are the frequency per sample, frequency per station, number of individuals, mean density, and Fisher's coefficient of dispersal for each species. Fisher's coefficient of dispersal $\frac{s^2}{x}$ (ratio of variance to mean) is a measure of the pattern of distribution of the numbers of individuals of a species among the stations (Greig-Smith, 1964). In a Poisson distribution the variance is equal to the mean. If the ratio of variance to mean is less than one, an even distribution is indicated. If the ratio of variance to mean is greater than one, an aggregated distribution is indicated. Species whose values deviate from a Poisson distribution at the 5% level (Chi-square test) are marked with an asterisk. Lie (1968) criticized the use of Fisher's coefficient of dispersal when it is applied to species with low numbers of individuals per station. The coefficient was only calculated for species with a high B.I. value, i.e., high numbers of individuals per species. Fisher's coefficient of dispersal may not describe the distribution pattern of species over the entire sampling area because the stations were not selected randomly. The values only apply to stations sampled. The coefficient of dispersal was also calculated for the species in the three replicate samples within each station. With few exceptions, the species did not deviate from a Poisson distribution at the 5% probability level within stations.

The combined B.I. values of species at each station for all three sampling periods, together with the frequency per sample, frequency per station, number of individuals, and mean density per 0.1 m^2 are

TABLE 4

Biological-index (B.I.), frequency (f) per sample, frequency (f) per station, numbers of individuals per 0.1 m^2, and coefficient of dispersal ($s^2/\bar{x}$) for dominant species, January 1969.

Species	B.I.	f(station) 6 stations	f(sample) 18 samples	No. of Indiv.	Density 0.1/m^2	$s^2/\bar{x}$
Mulinia lateralis	2.22	6	18	438	40.5	0.999
Nereis succinea	2.03	6	18	405	37.5	1.030
Mya arenaria	1.87	6	16	414	38.3	0.596
Streblospio benedicti	1.86	5	15	607	56.2	0.933
Retusa canaliculata	1.25	6	17	293	27.1	1.114
Spiochaetopterus oculatus	1.25	6	18	307	28.4	0.844
Sabella microphthalma	1.17	6	14	391	29.5	1.497
Heteromastus filiformis	1.00	6	18	230	21.3	0.900
Paraprionospio pinnata	0.86	6	18	96	8.9	0.995
Sabellaria vulgaris	0.64	2	4	476	44.1	2.443*
Unciola irrorata	0.39	2	4	215	19.9	2.436*
Polydora ligni	0.11	3	8	145	13.4	2.150*

TABLE 5

Biological-index (B.I.), frequency (f) per sample, frequency (f) per station, numbers of individuals, density per 0.1 m^2, and coefficient of dispersal ($s^2/\bar{x}$) for dominant species, May 1969.

Species	B.I.	f(station) 11 stations	f(sample) 33 samples	No. of Indiv.	Density 0.1/m^2	$s^2/\bar{x}$
Streblospio benedicti	4.03	11	33	2547	110.3	0.853
Mya arenaria	2.36	11	31	1548	67.0	0.953
Nereis succinea	1.73	11	33	1100	47.6	1.652
Heteromastus filiformis	1.53	11	33	577	25.0	1.076
Polydora ligni	1.41	11	32	887	38.4	1.233
Sabellaria vulgaris	0.85	3	7	2616	113.2	2.251*
Sabella microphthalma	0.85	7	11	1990	86.1	2.202*
Mulinia lateralis	0.48	8	19	151	6.5	1.114
Paraprionospio pinnata	0.39	7	17	98	4.2	1.842
Macoma balthica	0.33	6	17	170	7.4	1.582
Corophium acherusicum	0.30	2	5	44	1.9	3.464*

TABLE 6

Biological-index (B.I.), frequency (f) per sample, frequency (f) per station, numbers of individuals, density per 0.1 m^2, and coefficient of dispersal ($s^2/\bar{x}$) for dominant species, August 1969.

Species	B.I.	f(station) 12 stations	f(sample) 36 samples	No. of Indiv.	Density $0.1/m^2$	$s^2/\bar{x}$
Heteromastus filiformis	2.11	12	30	694	27.5	1.654
Nereis succinea	2.08	12	31	512	20.3	1.378
Spiochaetopterus oculatus	1.82	10	23	349	13.8	1.681
Sabella microphthalma	1.29	9	17	664	26.3	1.512
Scoloplos fragilis	0.94	11	28	176	7.0	0.793
Phoronis architecta	0.83	7	18	80	3.2	1.259
Molgula manhattensis	0.64	8	17	381	15.1	1.479
Paraprionospio pinnata	0.58	9	16	48	1.9	1.638
Polydora ligni	0.61	6	13	474	18.8	1.969*
Nassarius obsoletus	0.50	4	8	43	1.7	2.272*
Pseudeurythoe paucibranchiata	0.39	9	21	118	4.7	1.186
Diadumene leucolena	0.36	5	13	221	8.8	1.652

presented in Table 7. This table was included to compare the Elizabeth River with other areas for which data is integrated for the entire year.

January stations were characterized by high B.I. values and random distribution of the mollusks Mulinia lateralis, Mya arenaria and Retusa canaliculata and the polychaetes Nereis succinea, Streblospio benedicti, Heteromastus filiformis and Paraprionospio pinnata.

The polychaetes Sabellaria vulgaris, Sabella microphthalma and Polydora ligni, and the amphipod Unciola irrorata were found in large numbers, but had low B.I. values because of their aggregated distributions. Sabellaria, Sabella, Polydora and Unciola were usually found together, attached to the abundant oyster shells found at station L-5.

May was characterized by a high B.I. (4.03) and random distribution of Streblospio. Mulinia decreased in dominance (B.I. 2.22 to 0.48). Mya, Nereis, Heteromastus and Paraprionospio had high bio-index values, as in January, and a random distribution. Polydora increased in dominance (B.I. 0.11 to 1.41) and numbers, and was randomly distributed. Sabella and Sabellaria remained aggregated and were found on dead oyster shells, while Unciola was not present. Macoma balthica, although not found in January, had a B.I. value of 0.33 and a coefficient of dispersal of 1.582, which suggested an aggregated distribution. Corophium acherusicum was collected only at the most upriver stations, E-7 and E-8.

August was characterized by an increased aggregation of most species. Streblospio and Mya, dominant species in May, were severely reduced. Spiochaetopterus oculatus (Polychaeta), Phoronis architecta (Phoronida), Molgula manhattensis (Tunicata), Diadumene leucolena

TABLE 7

Biological-index (B.I.), frequency (f) per sample, frequency (f) per station, numbers of individuals, and density per 0.1 m^2 for the dominant species (all sampling periods combined).

Species	B.I.	f(station) 29 stations	f(samples) 86 samples	No. of Indiv.	Density $0.1/m^2$
Nereis succinea	1.94	29	82	2017	34.1
Streblospio benedicti	1.90	22	61	3227	54.6
Heteromastus filiformis	1.66	29	81	1501	25.4
Mya arenaria	1.29	19	50	1966	33.3
Spiochaetopterus oculatus	1.09	20	50	674	11.4
Sabella microphthalma	1.09	22	42	3045	51.5
Polydora ligni	0.81	21	53	1506	25.5
Mulinia lateralis	0.64	21	45	598	10.1
Paraprionospio pinnata	0.57	22	51	242	4.1
Sabellaria vulgaris	0.55	8	21	3375	57.1
Scoloplos fragilis	0.40	25	58	253	4.3
Phoronis architecta	0.40	17	36	142	2.4
Retusa canaliculta	0.34	15	30	316	5.3
Molgula manhattensis	0.26	17	29	425	7.2
Nassarius obsoletus	0.21	8	14	49	0.8
Unciola irrorata	0.18	6	11	409	6.9
Diadumene leucolena	0.16	13	28	385	6.5
Pseudeurythoe paucibranchiata	0.16	28	47	178	3.0
Macoma balthica	0.15	8	18	172	2.9

(Coelenterata) and Nassarius obsoletus (Gastropoda), all rare in January and May, increased in dominance in August. Heteromastus, Nereis, Sabella, Paraprionospio, and Polydora continued to be important members of the community as they were in January and May.

Sample Homogeneity

Sanders' (1960) dominance-affinity index was calculated among the three samples at each station and among each of the three samples and the mean of the three samples at each station. Mean dominance-affinity values for each station are found in Table 8 and 9. The index is obtained by computing the percentage of the total sample represented by each species present in the sample and then summing the smallest percentages for each species between the two samples.

Only four stations, L-3, L-4, E-7, and E-8, all sampled in August, had dominance-affinity values below 70% when the samples were compared to their mean. The mean dominance affinity for all stations was 77% and was highest in May (83%), followed by January (76%) and August (72%).

The mean dominance-affinity value was 61% when this index was calculated among three samples at each station, May had the highest mean value (72%), followed by January (58%) and August (53%). These values will be compared with those from other studies.

Station Homogeneity

Sanders' (1960) dominance-affinity between all possible pairs of stations was calculated for each sampling period. Trellis diagrams were constructed to show station affinities (Fig. 3, 4, 5). Dominance-affinity values above 50% were chosen to indicate a high degree of

TABLE 8

Mean dominance-affinity values among three samples at each station.

Station	Sampling Period		
	January	May	August
L-1	67.02	72.94	58.81
L-2	50.44	76.39	81.22
L-3	52.04	75.68	29.17
L-4	56.18	56.90	40.77
L-5	67.87	76.32	52.79
L-6	-----	59.40	61.94
L-7	-----	71.51	60.12
L-8	-----	82.50	63.33
L-9	-----	-----	71.17
L-10	-----	81.69	72.37
E-7	56.23	62.08	15.48
E-8	-----	73.98	29.81

TABLE 9

Mean dominance-affinity value between each of the three samples and mean of the three lumped samples at each station.

Station	Sampling Period		
	January	May	August
L-1	79.97	83.97	77.02
L-2	73.50	86.70	87.71
L-3	70.57	85.88	57.78
L-4	73.21	70.11	64.42
L-5	81.20	86.35	74.59
L-6	-----	76.62	76.23
L-7	-----	84.16	76.01
L-8	-----	89.93	77.50
L-9	-----	-----	82.78
L-10	-----	88.41	84.75
E-7	74.67	76.33	48.81
E-8	-----	83.65	59.39

Figure 3. Trellis diagram of the dominance-affinity index for all station pairs, January 1969, Elizabeth River.

JANUARY 1969

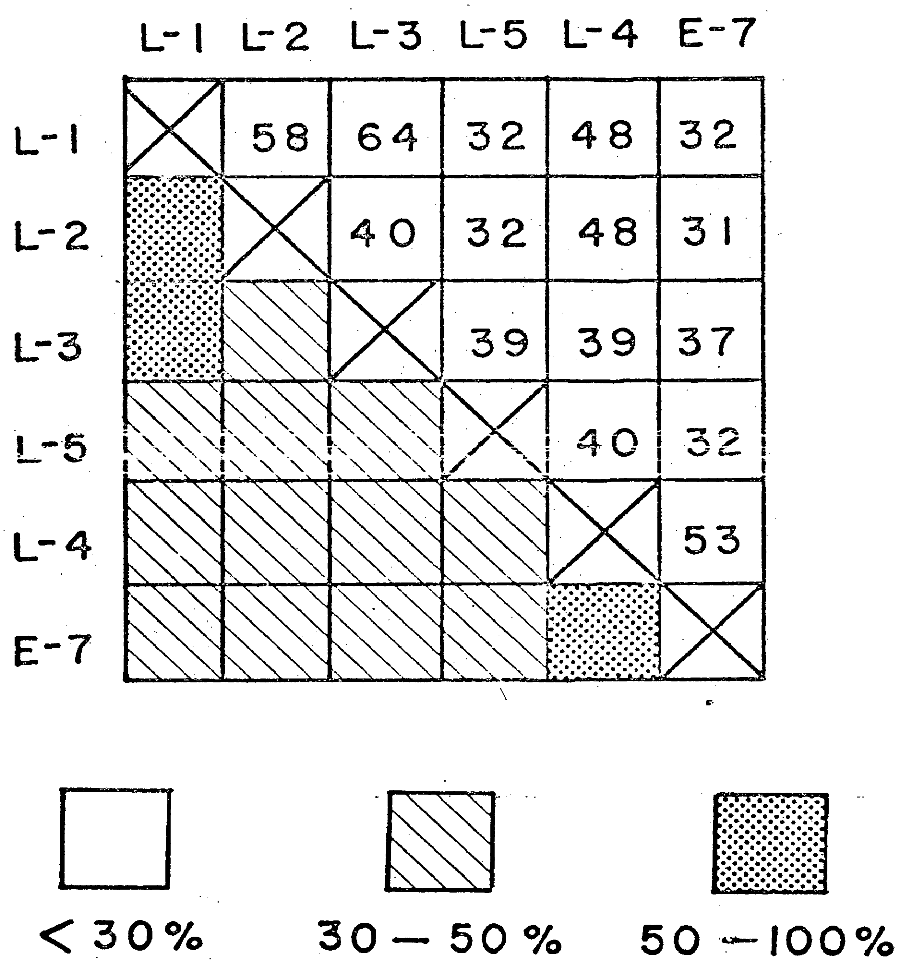


Figure 4. Trellis diagram of the dominance-affinity index for all station pairs, May 1969, Elizabeth River.

MAY 1969

	L-2	L-3	E-8	L-4	L-7	L-8	L-6	L-1	L-5	L-10	E-7
L-2	X	87	22	50	34	38	33	40	30	31	33
L-3		X	19	40	23	26	27	32	21	21	25
E-8			X	48	32	71	37	22	16	17	22
L-4				X	55	65	57	46	43	38	48
L-7					X	58	65	66	54	72	58
L-8						X	53	40	37	37	35
L-6							X	63	44	48	46
L-1								X	50	67	63
L-5									X	57	40
L-10										X	66
E-7											X

<30%   30—50%   50—100%

Figure 5. Trellis diagram of the dominance-affinity index for all station pairs, August 1969, Elizabeth River.

AUGUST 1969

	E-8	L-3	L-10	L-2	L-5	L-7	L-8	L-9	L-4	L-1	L-6	E-7
E-8	X	68	42	42	30	20	16	10	11	24	17	9
L-3		X	48	50	34	24	28	22	21	11	24	20
L-10			X	81	68	35	30	16	23	24	25	14
L-2				X	58	34	29	17	21	22	26	13
L-5					X	33	31	22	26	19	24	15
L-7						X	63	34	38	26	28	26
L-8							X	60	67	38	26	30
L-9								X	60	39	27	37
L-4									X	40	34	41
L-1										X	31	22
L-6											X	20
L-7												X

< 30 %   30 — 50 %   50 — 100 %

affinity, values between 30% and 50% indicate a moderate affinity, and values below 30% indicate a weak affinity (Sanders, 1960).

January had a mean dominance-affinity index of 41.2% between all station pairs. Station pairs L-1, L-2, L-3, L-4, E-7 had a high degree of affinity. In May the mean dominance affinity between station pairs was 43.0%. Nineteen station pairs had a high degree of affinity. These stations were ordered into three groups of high affinity (L-2, L-3; L-4, L-6, L-7, L-8; and L-1, L-5, L-10, E-7). E-8 showed little affinity with any other stations. August had the lowest mean dominance-affinity between station pairs (31.2%). Only eight station pairs had a high degree of affinity. These stations were ordered into two groups of high affinity (L-2, L-3, L-5, L-10, E-8; and L-4, L-7, L-8, L-9). Three stations (L-1, L-6, E-7) showed little affinity with any other stations.

Indicator Species

Wass (1967) proposed an index of pollution which is the ratio of the number of pollution-tolerant organisms to that of pollution-intolerant organisms.

$$W.I. = \frac{\text{number pollution tolerant individuals}}{\text{number of pollution intolerant individuals}}$$

Any value of the index above one indicates pollution. The higher the value of this index the more severe the pollution.

A list of benthic macroinvertebrates found in the study area and considered to be tolerant of pollution was compiled from the literature (Table 10). Assuming the remaining species to be intolerant of pollution, I calculated values for Wass' index for each station (Table 11).

TABLE 10

Marine organisms considered to be tolerant to pollution (determined by the literature and personal observation).

Species	Reference
Polychaeta	
Capitella capitata	Reish (1960), Wass (1967)
Diopatra cuprea	McNulty (1970)
Glycera americana	McNulty (1961)
Heteromastus filiformis	Leppakoskei (1968), Wass (1967)
Nereis succinea	Wass (1967)
Paraprionospio pinnata	Boesch (1971)
Pectinaria gouldi	Burbanck et. al. (1956), McNulty (1961)
Polydora ligni	Wass (1967)
Pista cristata	McNulty (1961)
Spiochaetopterus oculatus	McNulty (1961)
Streblospio benedicti	Wass (1967), Reish & Winter (1954)
Clymenella torquata	Burbanck et. al. (1956)
Scoloplos fragilis	Pettibone (1963)
Sabella microphthalma	Personal observation
Sabellaria vulgaris	Personal observation
Mollusca	
Mulinia lateralis	Boesch (1971)
Mya arenaria	Boesch (1971)
Nassarius vibex	McNulty (1961)
Tagelus divisus	McNulty (1961)
Mercenaria mercenaria	Cooper et. al. (1964)
Crustacea	
Corophium acherusicum	Wass (1967, Reish & Winter (1954)
Corophium tuberculatum	Wass (1967)
Erichthonius brasiliensis	Barnard (1958)
Jassa falcata	Barnard (1958)
Others	
Molgula manhattensis	Van Name (1945)
Balanus improvisus	McNulty (1970)

TABLE 11

Ratio of pollution tolerant to non-pollution tolerant organisms for all stations (Wass' index).

Station	January	May	August
L-1	4.14	7.51	6.67
L-2	6.98	15.75	2.96
L-3	2.30	16.98	2.53
L-4	3.86	14.64	1.24
L-5	3.45	13.71	2.00
L-6	------	3.07	0.52
L-7	------	6.74	0.90
L-8	------	14.50	1.59
L-9	------	-----	3.67
L-10	------	5.60	2.35
E-7	12.08	31.75	2.33
E-8	------	16.14	2.71
Mean	5.46	13.31	2.46

Two stations, L-6 and L-7, in August had values below one. According to Wass' index the remaining station values were altered due to pollution. The highest values of this index were calculated for May (mean 13.3) followed by January (5.46) and August (2.46).

Feeding Types

The feeding and purchase types of the 18 dominant organisms (bio-index) were compiled from the literature (Table 12). Pseudeurythoe paucibranchiata was not included because no record of its feeding type was found. For the purpose of this paper, four feeding types have been defined as follows:

Suspension feeders - organisms feeding most on material suspended in the overlying water mass.

Selective deposit feeders - organisms feeding on the detrital material deposited on rocks, vegetation, and the upper surface of the substrate.

Non-selective deposit feeders - organisms feeding indiscriminately on sediment below the surface.

Omnivore - opportunistic organisms feeding on whatever is available.

The percentage of each feeding type found during each sampling period and for the total sampling period was calculated (Table 13). The 18 dominant species accounted for 20,275 individuals or 90% of the total 22,404 individuals found in the samples. The remaining 2,129 individuals, divided among 105 species, would not drastically change the percentages in this analysis.

Suspension feeders dominated the Elizabeth River stations (53% by individuals). Most of the species are epifaunal organisms associated

TABLE 12

Feeding and purchase types for the 19 dominant species (Bio-Index) found in the study area.

Species	Feeding Type	Purchase Type	References
1. *Nereis succinea*	omnivore	infauna-tube builder	Phelps (1964) Pettibone (1963)
2. *Streblospio benedicti*	selective deposit	infauna-burrower	Sanders *et. al.* (1962) Phelps (1964)
3. *Heteromastus filiformis*	non-selective deposit	infauna-tube builder	Sanders *et. al.* (1962) Phelps (1964)
4. *Mya arenaria*	suspension	infauna-free	Lucy (personal communication) Phelps (1964)
5. *Spiochaetopterus oculatus*	suspension	tube-builder	Boesch (1971)
6. *Sabella microphthalma*	suspension	epifauna-attached tube	Jorgenson (1966) Dales (1957)
7. *Mulinia lateralis*	suspension	epifauna-free	Sanders (1960) Rhoads & Young (1970)
8. *Paraprionospio pinnata*	selective deposit	infauna-burrower	Sanders (1956)
9. *Sabellaria vulgaris*	suspension	epifauna-attached tube	Jorgenson (1966) Dales (1957)
10. *Scoloplos fragilis*	non-selective deposit	infauna-free	Phelps (1964) Pettibone (1963)
11. *Phoronis architecta*	suspension	infauna-tube builder	Nicol (1960)
12. *Retusa canaliculata*	non-selective deposit	infauna-free	Sanders (1958)

TABLE 12 (Cont'd.)

Species	Feeding Type	Purchase Type	References
13. Molgula manhattensis	suspension	epifauna-attached	Jorgenson (1966) Haven & Morales-Alamo (1967)
14. Nassarius obsoletus	selective deposit	infauna-free	Scheltema (1964)
15. Unciola irrorata	selective deposit	infauna-tube builder	Feeley (1967) Sanders (1960)
16. Diadumene leucolena	suspension	epifauna-attached	Calder (1966)
17. Macoma balthica	selective deposit	infauna-free	Yonge (1950) Sanders (1956)
18. Polydora ligni	selective deposit	infauna-tube builder	Sanders et. al. (1962) Phelps (1964)
19. Pseudeurythoe paucibranchiata	----------	----------	

TABLE 13

Percentage composition of feeding types of the 18 dominant species (Bio-Index), by individuals, for each sampling period.

Feeding Type	January	May	August	Total
Suspension	50	58	48	53
Non-selective deposit	13	5	17	10
Selective deposit	26	26	23	27
Omnivore	10	10	12	10

with exposed dead oyster shells, particularly *Sabella microphthalma*, *Sabellaria vulgaris*, *Molgula manhattensis*, and *Diadumene leucolena*. *Macoma balthica*, *Mulinia lateralis*, *Mya arenaria*, *Phoronis architecta*, and *Spiochaetopterus oculatus* are infaunal and associated with mud substrates.

Selective deposit feeders feeding on the abundant detrital material in the upper 1 cm of substrate and on the exposed oyster shells accounted for 27% of the individuals. *Streblospio benedicti*, *Polydora ligni*, *Paraprionospio pinnata*, *Nassarius obsoletus*, and *Unciola irrorata* are all infaunal organisms in this category.

Heteromastus filiformis, *Scoloplos fragilis*, and *Retusa canaliculata* are all non-selective deposit feeders. These infaunal organisms comprised 10% of the individuals.

The infaunal omnivore *Nereis succinea* accounted for 10% of the individuals and was the dominant organism in the Elizabeth River (Bio-index).

Diversity

Diversity indices have often been used to summarize large amounts of data on the distribution of species and individuals from communities. The most meaningful and universally accepted diversity indices are those based on information theory. The most commonly used diversity index was developed from the information function of Shannon and Weaver (1963):

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

Where H' = diversity in bits of information/individual

s = total number of species

p_i = the observed proportion of individuals that belong to the i-th species.

Lloyd and Ghelardi (1964) have showed that diversity (H') is sensitive to two components, the number of species in a sample (species richness) and the distribution of individuals among species (equitability).

Sanders (1968) rarefaction method was used to reduce each station to 200 individuals. This method allows comparison of the number of species present at stations with different numbers of individuals. Each sample generates a regression of the number of species that would be found in decreasing sample sizes if the percentage composition of the component species remains constant.

Equitability (E) was calculated from a formula developed by Lloyd and Ghelardi (1964):

$$E = \frac{s'}{s}$$

where E is a measure of equitability, s is the number of species in the sample and s' is the number of species predicted by MacArthur's broken-stick model, assuming the observed H' diversity. Tables for calculation of s' are given in Lloyd and Ghelardi (1964).

H' diversity, equitability (E), and the number of species present at each station if all stations had 200 individuals (R/200) are presented in Tables 14, 15, and 16. The lines generated by rarefaction are found in Figures 6, 7, and 8. It was necessary to extrapolate several of the R/200 values where the total number of individuals at a station was below 200. One station in May and seven stations in August

TABLE 14

H' diversity values for each station (3 lumped replicates).

Stations	January	May	August
L-1	3.09	2.70	3.08
L-2	2.63	2.97	3.38
L-3	3.56	2.65	3.33
L-4	3.18	2.97	2.97
L-5	3.94	2.17	4.12
L-6	----	2.83	3.22
L-7	----	2.61	3.38
L-8	----	2.18	3.26
L-9	----	----	3.01
L-10	----	2.48	3.66
E-7	3.01	2.06	2.45
E-8	----	1.82	3.03

TABLE 15

Equitability values (E) for each station (3 lumped replicates).

Stations	January	May	August
L-1	0.46	0.56	0.71
L-2	0.45	0.26	0.47
L-3	0.47	0.21	0.47
L-4	0.54	0.38	0.58
L-5	0.37	0.22	0.38
L-6	----	0.43	0.76
L-7	----	0.40	1.00
L-8	----	0.32	0.70
L-9	----	----	0.41
L-10	----	0.24	0.46
E-7	0.50	0.50	0.77
E-8	----	0.19	0.60

TABLE 16

Number of species present in each station when stations are reduced to 200 individuals (3 lumped replicates). Stations marked with an asterisk are extrapolated values.

Stations	January	May	August
L-1	19.4	15.3	20.0*
L-2	17.6	18.5	21.1
L-3	28.9	14.9	25.0
L-4	18.0	19.6	22.0*
L-5	31.9	21.6	34.5
L-6	----	16.2	26.0*
L-7	----	17.2	20.0*
L-8	----	15.6	26.0*
L-9	----	----	25.4
L-10	----	20.1	26.5
E-7	20.2	14.0*	20.0*
E-8	----	16.9	27.0*

Figure 6. Arithmetical plot generated by rarefaction for each station, January 1969. Each sample represents a regression of the number of species that would be found in decreasing sample sizes if the percentage composition of the component species remains constant.

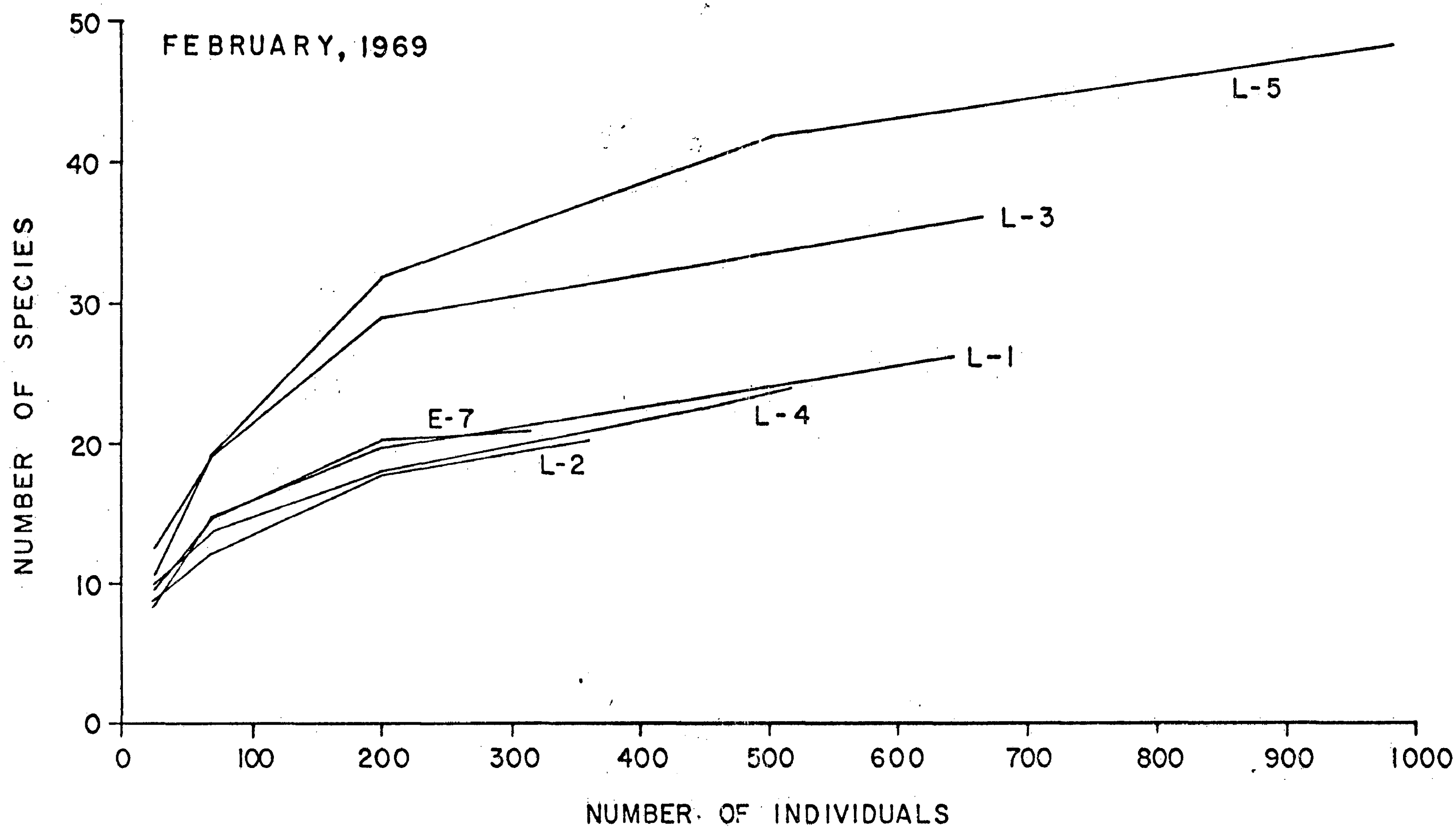

FEBRUARY, 1969
NUMBER OF SPECIES
NUMBER OF INDIVIDUALS
0
10
20
30
40
50
0
100
200
300
400
500
600
700
800
900
1000
L-5
L-3
L-1
L-4
L-2
E-7

Figure 7. Arithmetical plot generated by rarefaction for each station, May 1969. Each line represents a regression of the number of species that would be present if the percentage composition of the component species remains constant.

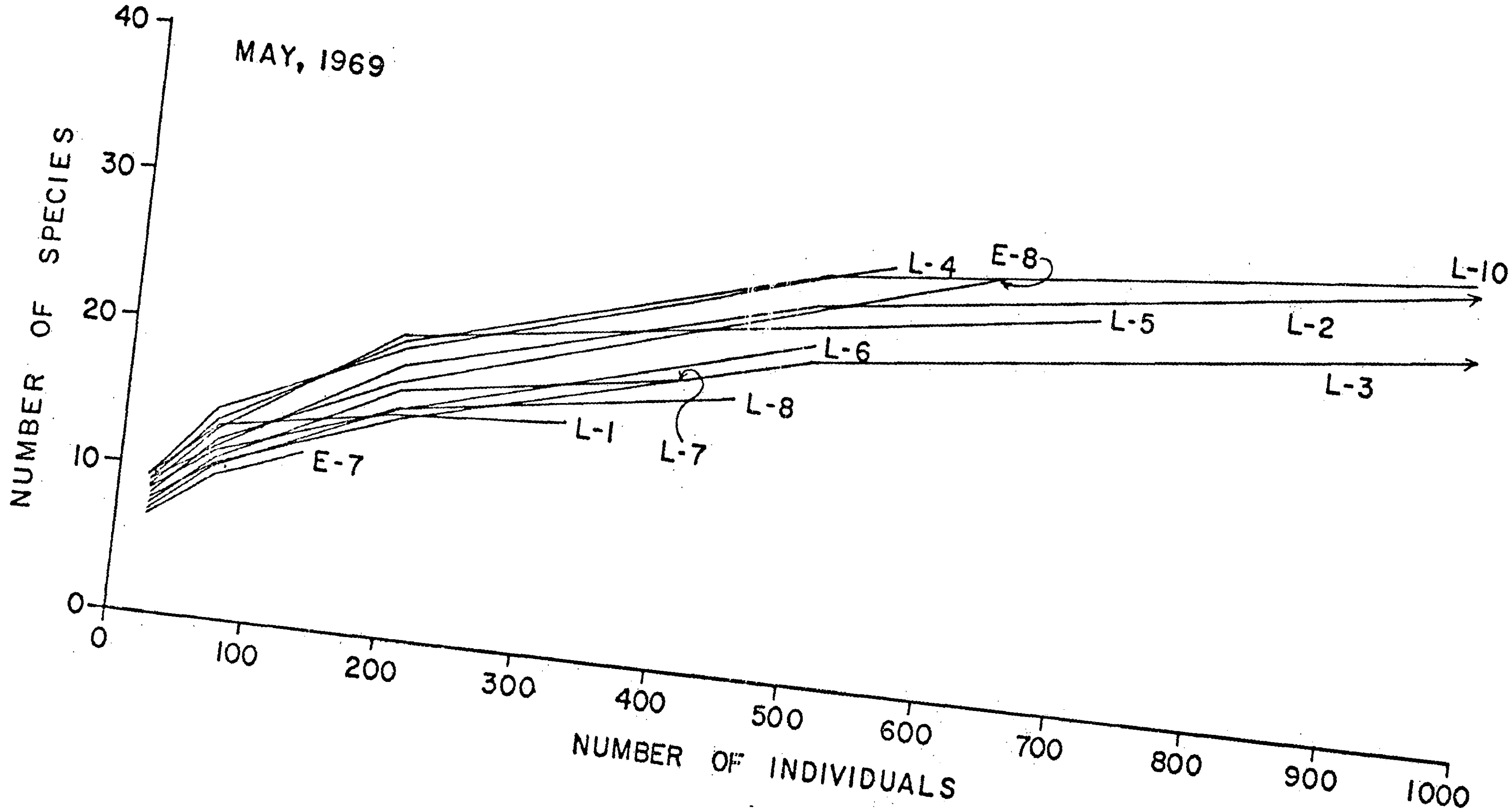
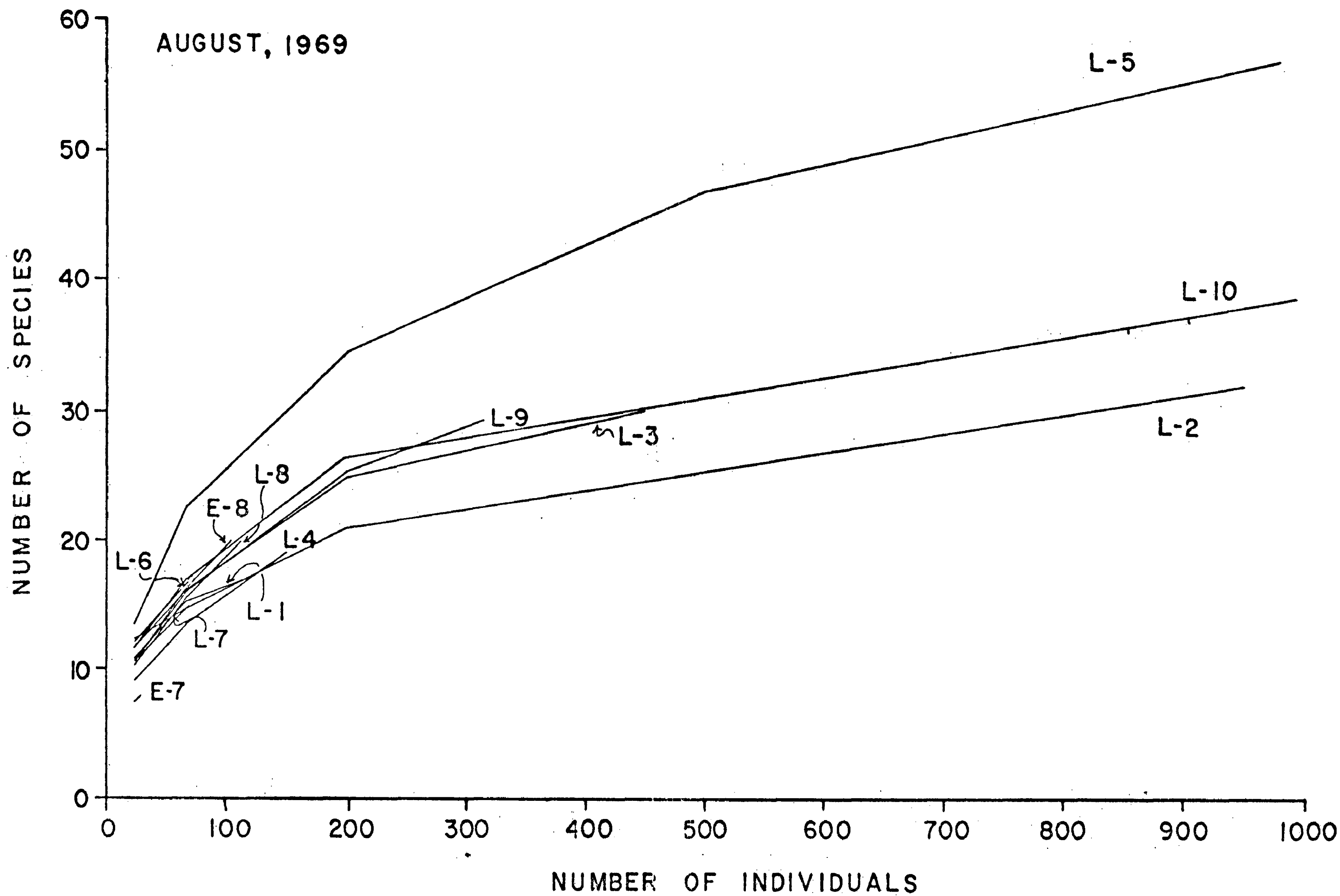

MAY, 1969
NUMBER OF SPECIES
0
10
20
30
40
NUMBER OF INDIVIDUALS
0
100
200
300
400
500
600
700
800
900
1000
L-4
E-8
L-10
L-5
L-2
L-6
L-3
L-8
L-1
L-7
E-7

Figure 8. Arithmetical plot generated by rarefaction for all stations, August 1969. Each line represents a regression of the number of species that would be present if the percentage composition of the component species remains constant.


AUGUST, 1969
NUMBER OF SPECIES
NUMBER OF INDIVIDUALS
0
10
20
30
40
50
60
100
200
300
400
500
600
700
800
900
1000
L-5
L-10
L-2
L-9
L-3
L-8
E-8
L-4
L-6
L-1
L-7
E-7

had less than 200 individuals. The species richness value for the remaining five stations in August was 26.5. This value was only two individuals lower than the species richness value calculated with the extrapolated values.

The mean diversity for the Elizabeth River stations was 2.96 bits/individual with a range of 1.82 at E-8 in May to 4.12 at L-5 in August. May had the lowest mean diversity value (2.49) with higher mean values of 3.23 and 3.24 in January and May.

Equitability (E) had a range of 1.00 at L-7 in August to 0.19 at E-8 in May, with a mean of 0.48. May had the lowest mean equitability value (0.34) with higher mean values of 0.47 and 0.61 in January and August.

Using Sanders' rarefaction method, the mean number of species found at each station containing 200 individuals was 21.4, with a high of 34.5 species at L-5 in August and a low of 14 species at E-7 in May. May had the lowest mean R/200 value of 17.3 with higher mean values of 22.7 and 24.5 in January and August, respectively.

DISCUSSION

Macrofauna

Reish (1959b) emphasized the importance of screen size in determining the density of marine benthic invertebrates. He found four times as many individuals on a .27 mm screen as on a 1.0 mm screen. Numerous small polychaetes and nematodes accounted for this increase. I observed abundant small capitellid and spionid polychaetes and nematodes in my samples and compared density only to other studies which used a 1.0 mm screen size.

Haven (1967) found a mean density of 928 individuals/m^2 for mud stations and 5,548 individuals/m^2 for sand stations, in the lower York River, Virginia.

Wigley and McIntyre (1964) sampled the macrobenthos from a transect across the continental shelf south of Woods Hole, Massachusetts. They found a mean density of 4,740 individuals/m^2 on the inner shelf, 1,496 individuals/m^2 on the outer shelf and 1,214 individuals/m^2 on the slope.

Lowry (1969), in a soft bottom community in Antarctica, found a mean density of 6,957 individuals/m^2. He attributed the high density of benthic organisms in his samples and that of Wigley and McIntyre on the inner continental shelf to high primary productivity.

Boesch (1971) in conjunction with the present study reported mean densities of 2,663 individuals/m^2 for sand stations, 1,382 individuals/m^2 for mud stations, and 1,047 individuals/m^2 for mixed sediment stations.

The mean density of benthic macroinvertebrates at the Elizabeth River stations (3,803 individuals/m^2) was higher than for comparable mud stations sampled by Boesch in Hampton Roads and Haven in the York River. The mean density was lower than those of Lowry's Antarctic stations and of Wigley and McIntyre's stations on the inner continental shelf. Both are areas of high primary productivity.

The mean density for Elizabeth River stations located on oyster reefs (L-2, L-3, L-5, L-10) was 7,561 individuals/m^2, higher than the areas of high productivity sampled by Lowry and by Wigley and McIntyre. The density of the remaining mud stations was 1,502 individuals/m^2, which was only slightly higher than comparable mud stations in Hampton Roads and the York River. The higher density of organisms at stations downstream from Lambert's Point and stations with a clayey sand substrate was probably due to the presence of dead oyster shells at those stations.

The Elizabeth River is supplied by abundant detrital material from sewage outfalls and other runoff from numerous industrial, domestic, and agricultural sources. The exposed oyster shells served as a sediment trap for infaunal species *Streblospio benedicti*, *Nereis succinea*, *Heteromastus filiformis*, and *Paraprionospio pinnata* and a substrate for attached species *Sabella microphthalma*, *Sabellaria vulgaris*, and *Polydora ligni*. The oyster shells, coupled with high dissolved oxygen levels, made the abundant detrital material available to support high densities of organisms.

Dominant Organisms

Dominant organisms (Bio-Index) from the Elizabeth River stations were compared to the dominant organisms of three studies in the Chesapeake Bay and its tributary rivers and to a study in Buzzards Bay, Massachusetts (Table 17).

Wass (personal communication) collected benthic organisms 300 meters from the VIMS pier, Gloucester Point, Virginia, for a six year period. Wass et. al. (1967) and Stone (1963) sampled the benthos in the lower Chesapeake Bay off the Rappahannock River. Boesch (1971) collected samples from mud stations in Hampton Roads. Sanders (1960) sampled a mud-silt station in Buzzards Bay, monthly, for a period of a year.

Mulinia lateralis, a suspension feeding bivalve with a sporadic distribution over the entire Chesapeake Bay, was the only organism dominant in the Elizabeth River and in Wass' studies in the lower Chesapeake Bay and the York River. Sanders' Buzzards Bay station had no dominant organisms in common with the Elizabeth River. Four dominant organisms were found in common between the mud stations in Hampton Roads and the Elizabeth River stations. Mulinia has been discussed. Nereis succinea had the highest bio-index in the Elizabeth River, but was 10th in the mud stations in Hampton Roads. Paraprionospio pinnata ranked first in Hampton Roads mud stations and ranked 10th in the Elizabeth River. Polydora ligni ranked 8th in both studies.

The dominant fauna of the Elizabeth differed greatly from that of mud stations in Hampton Roads and almost no similarities existed

TABLE 17

Dominant organisms (Bio-Index) found in three studies in Virginia and one study at Buzzards Bay, Massachusetts.

Lower Chesapeake Bay
Wass _et_. _al_. (1967)

1. _Nephtys incisa_
2. _Retusa canaliculata_
3. _Ensis directus_
4. _Mulinia lateralis_
5. _Molgula manhattensis_
6. _Pectinaria gouldi_
7. _Ampelisca vadorum_
8. _Macoma tenta_
9. _Lyonsia hyalina_
10. _Cirriformia filigera_

Off VIMS Pier, Gloucester Point, Va.
6 year study, Wass (unpublished data)

1. _Nephtys incisa_
2. _Retusa canaliculata_
3. _Ogyrides limicola_
4. _Mulinia lateralis_
5. _Edwardsi elegans_
6. _Pectinaria gouldi_
7. _Ampelisca_ sp.
8. _Amphiodia atra_
9. _Phoronis architecta_

Hampton Roads (mud stations
Boesch (1970)

1. _Paraprionospio pinnata_
2. _Spiochaetopterus oculatus_
3. _Phoronis architecta_
4. _Retusa canaliculata_
5. _Mulinia lateralis_
6. _Pseudeuythoe paucibranchiata_
7. _Unciola irrorata_
8. _Polydora ligni_
9. _Nereis succinea_

Buzzards Bay, Station R (mud-silt),
Sanders (1960)

1. _Nucula proxima_
2. _Nephtys incisa_
3. _Ninoe nigripes_
4. _Cyclichna oryza_
5. _Callocardia morrhuana_
6. _Hutchinsoniella mocrocantha_
7. _Lumbrinereis tenuis_
8. _Turbonilla a_
9. _Spio filicornis_
10. _Retusa canaliculata_

between the Elizabeth River fauna and that from areas outside Hampton Roads.

The ten dominant species found at stations in the Elizabeth River are found in estuarine environments throughout the temperate East Coast of North America (Table 18). Nereis succinea, Mya arenaria and Heteromastus filiformis are cosmopolitan, and Streblospio benedicti and Polydora ligni occur on both coasts of North America. The remainder range widely along our East Coast. The 10 dominant species found at stations in the Elizabeth River, although widely distributed, have rarely been dominant members of benthic studies except under stress situations. All are considered indicators of pollution (Table 8).

Sample and Station Homogeneity

Sanders (1960) calculated a mean dominance-affinity of 69.3% between samples taken in Buzzards Bay at one station over a period of a year. Sanders chose this area as one being homogeneous and stable on the basis of an earlier study. The mean dominance-affinity ratio between samples taken at the same station in the Elizabeth River was 61.5%, indicating homogeneity within stations. Mean dominance-affinity among stations was 38.5%, indicating heterogeneous distribution of stations within the total area. The dominance-affinity between each sample and the mean of a station was 77%. This high value justifies use of the station means in later analyses.

Sanders' dominance-affinity method is not only an index of faunal homogeneity, but when the dominance-affinity values are arranged in a trellis diagram (Figs. 3-5), they delineate groups of stations with

TABLE 18

World distribution of the 10 dominant species (Bio-Index) in the Elizabeth River.

Species	Range	
Nereis succinea	Cosmopolitan	Hartman (1951)
Streblospio benedicti	Both U.S. coasts	Hartman (1951)
Mya arenaria	Circumboreal	Turgeon (1968)
Spiochaetopteus oculatus	New England to Gulf of Mexico	Hartman (1951)
Heteromastus filiformis	Cosmopolitan	Pettibone (1963)
Sabella microphthalma	New England to North Carolina	Hartman (1945)
Polydora ligni	Both U.S. coasts	Hartman (1951)
Mulinia lateralis	Maine to West Indies	Turgeon (1968)
Paraprionospio pinnata	Virginia to Gulf of Mexico	Hartman (1951) Wass (1965
Sabellaria vulgaris	New England to Gulf of Mexico	Hartman (1951)

similar faunas. These groups of stations were related to variations in substrate and the dispersal patterns of dominant organisms. The presence or absence of dead oyster shells was the controlling factor.

The similar dominance-affinity values between stations in January reflected the random distribution of species throughout most of the stations. Station L-5, because of its location on an oyster reef, had a lower dominance-affinity value with the other stations. *Sabella microphthalma, Sabellaria vulgaris* and *Unciola irrorata* dominated this station and had aggregated distributions for the entire sampling area.

In May stations L-2 and L-3, located on oyster reefs, were dominated by *Sabella* and *Sabellaria*. Both species had aggregated distributions. The remaining stations had little or no oyster reef material and were dominated by *Streblospio benedicti* and *Mya arenaria*. Both species had a random distribution. Stations L-4, L-6, L-7, and L-8 were dominated by both *Streblospio* and *Mya,* stations L-1, L-5, L-10, E-7 by *Streblospio* alone and station E-8 by *Mya* alone

In August the lower dominance-affinity values between stations was reflected by the increased aggregation of most dominant species. Stations L-2, L-3, L-5, and L-10, located on oyster reefs, were dominated by the attached organisms *Sabella, Molgula manhattensis, Diadumene leucolena* and *Polydora ligni* and the free-living *Nereis succinea* and *Heteromastus filiformis*. Station E-8 was closely related, with high densities of *Molgula, Sabella* and *Nereis*. Stations L-4, L-7, L-8, and L-9 lacked oyster reefs and were dominated by *Spiochaetopterus oculatus, Phoronis architecta* and *Heteromastus filiformis*. Stations L-1, L-6, and E-7 had low dominance-affinity values with the other stations. Station L-1 was dominated by *Spiochaetopteus* and *Nereis*, E-7 by Paraprionospio pinnata, and L-6 by Nassarius obsoletus.

Indicator Species

The saprobic or indicator species analysis of pollution showed no alteration of the benthic community in the Elizabeth River. The mean value of Wass' index of pollution was 7.2 which was higher than the mean index value I calculated from Boesch's (1971) data (1.8) from mud stations in Hampton Roads. Comparison of these different pollution analyses indicate that the Elizabeth River benthos were mildly affected by pollution but not severely enough to eliminate most of the species present.

The highest values for Wass' index were calculated for May. These high values were accompanied by an increase in density of individuals, especially the pollution tolerant species Streblospio benedicti, Mya arenaria, Nereis succinea, Sabellaria vulgaris, and Sabella microphthalma. The diversity and species richness in May were also reduced, both indicating an increased effect of pollution.

Care must be taken in the use of this index. The ecological tolerances of all the organisms designated as pollution tolerant have not been studied. Factors other than water and substrate quality could influence their distribution and abundance. However, this index, used in conjunction with other community parameters, is a useful tool for pollution analysis.

Feeding Types

The majority of suspension feeders (53%), selective deposit feeders (37%) and omnivores (15%) found at the stations in the Elizabeth River feed on suspended or recently deposited detrital material. Of the remaining 10%, non-selective deposit feeders, Retusa canaliculata was only found in the upper 1 cm, indicating it was functioning as a selective-deposit feeder. Heteromastus filiformis and Scoloplos fragilis, both reported to inhabit muds with high levels of H_2S levels, are the only dominant organisms able to utilize the abundant organic matter found below the upper 1 cm.

Non-selective deposit feeders can be restricted from some areas, because of the lack of food or the high phi size of compacted sediments. Neither factor was limiting to these burrowing organisms in the nutrient-rich, poorly sorted sediments of the Elizabeth River. Hydrogen sulfide was found in the black mud below 1 cm at many stations, which indicated a limited supply of oxygen. The lack of oxygen eliminated the food supply of these non-selective deposit feeders by limiting their penetration into the substrate.

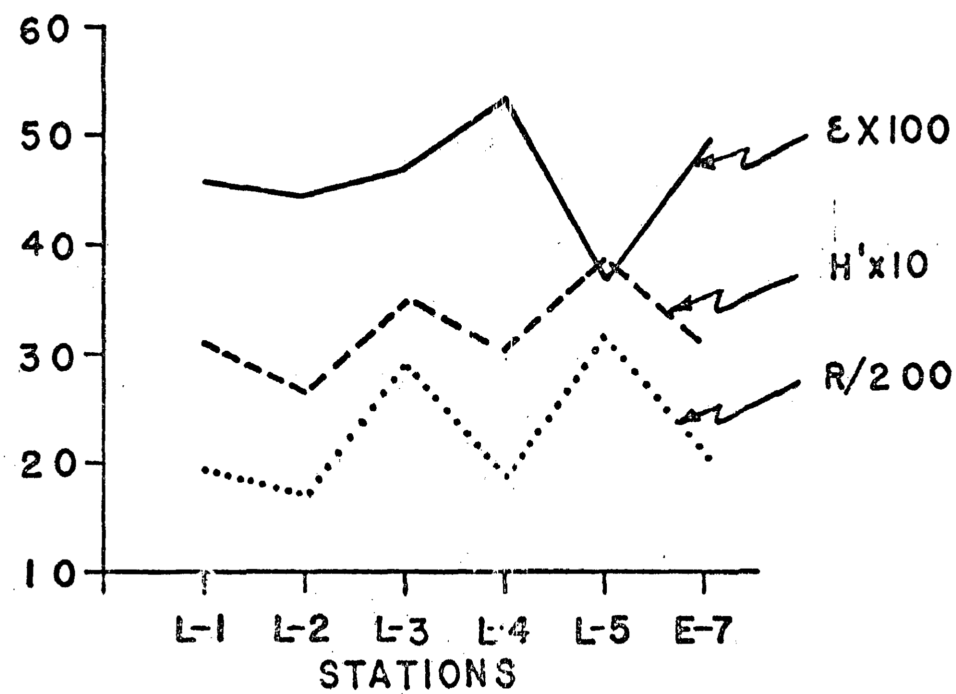
Oxygen was not limiting in the suspended and recently deposited detrital material because of constant currents and tidal mixing. This abundant detrital material was available to support large numbers of suspension and selective deposit feeders.

Relationship of Diversity Components

Species richness (R/200 values) and equitability (E) relationships to H' diversity were defined graphically and by correlation values (R) obtained by the analysis of covariance. The lines joining values on Figures 9, 10, and 11 are not meant to show values between points, but to facilitate interpretation.

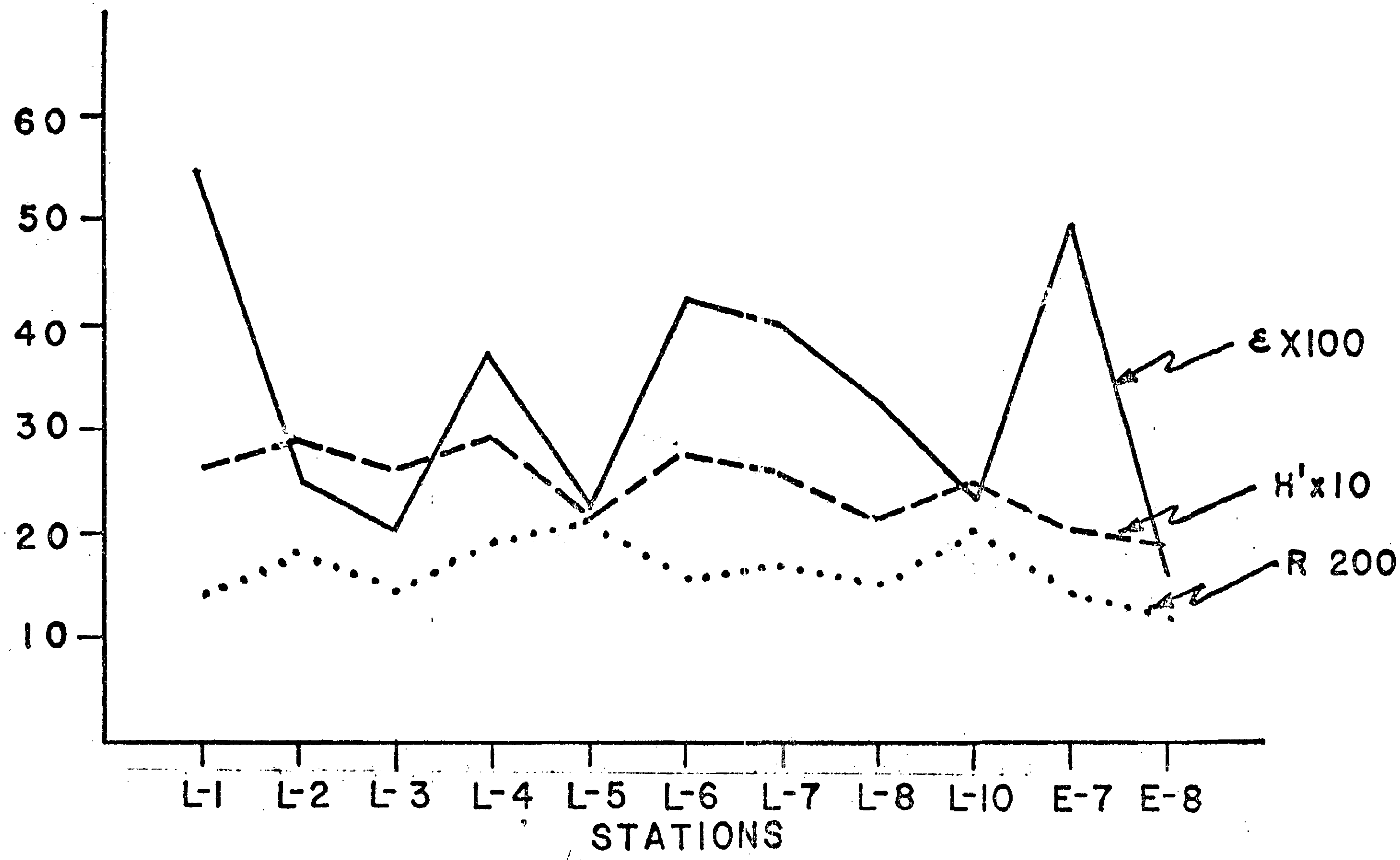
Species richness (R/200) is highly correlated with H' diversity ($r = 0.7760$) indicating the dependence of diversity in the species-

Figure 9. Relationship of equitability (E), diversity (H'), and species richness (R/200) for the Elizabeth River, January 1969.



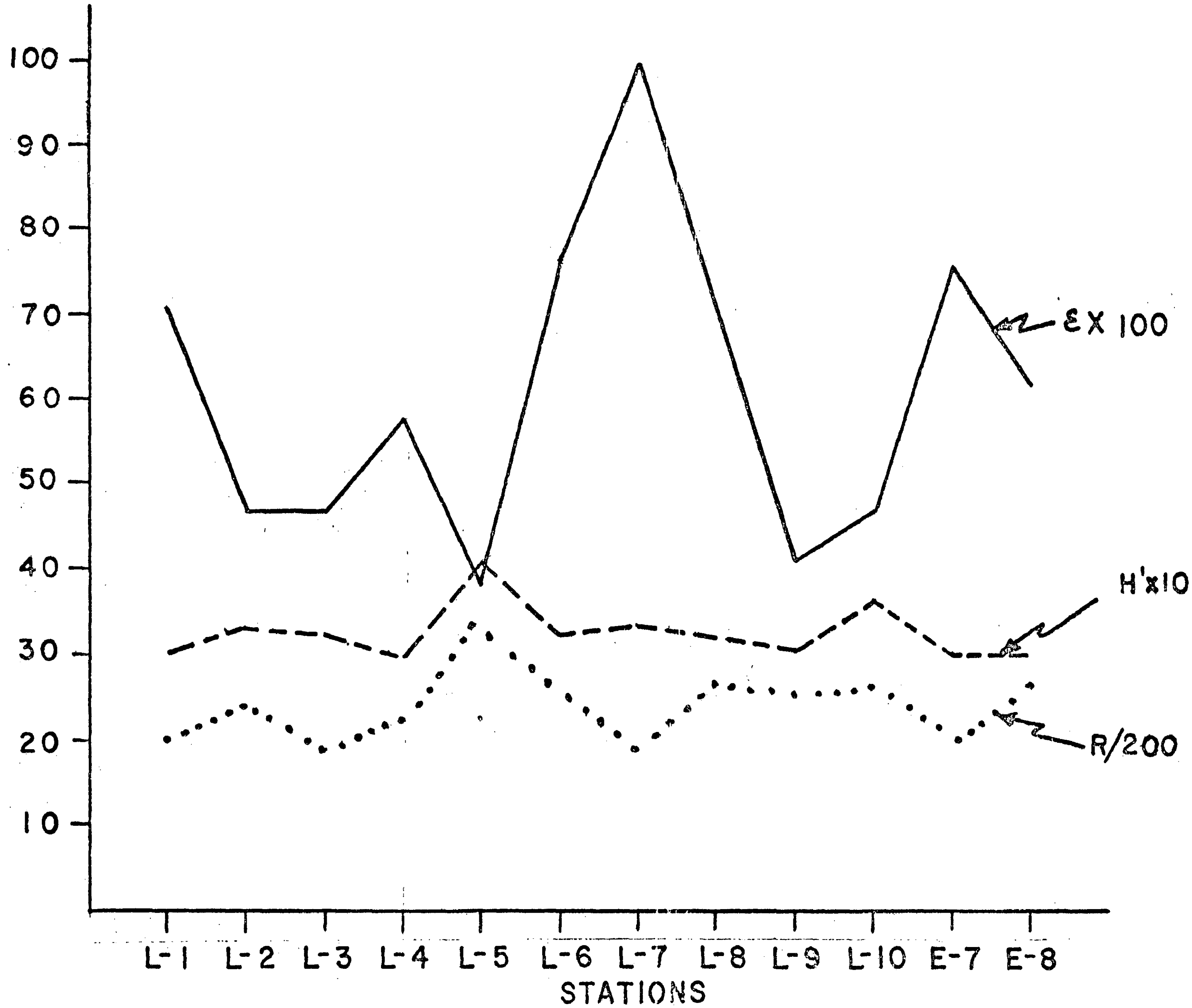
60
50
40
30
20
10
εX100
H'x10
R/200
L-1
L-2
L-3
L-4
L-5
E-7
STATIONS

Figure 10. Relationship of equitability (E), diversity (H'), and species richness (R/200) for the Elizabeth River, May 1969.



60
50
40
30
20
10
ε X100
H'x10
R 200
L-1
L-2
L-3
L-4
L-5
L-6
L-7
L-8
L-10
E-7
E-8
STATIONS

Figure 11. Relationship of equitability (E), diversity (H'), and species richness (R/200) for the Elizabeth River, August 1969.



100
90
80
70
60
50
40
30
20
10
ε X 100
H'x10
R/200
L-1 L-2 L-3 L-4 L-5 L-6 L-7 L-8 L-9 L-10 E-7 E-8
STATIONS

richness component. The lower correlation between equitability and H' diversity (r = 0.3036) indicates less dependence of H' diversity on equitability.

Species Diversity Compared to Other Areas

Diversity (H') values calculated for stations in the Elizabeth River were compared to H' values from other studies (Fig. 12).

Wilhm (1970), in a review paper on freshwater streams, calculated H' values for 21 polluted and 23 healthy streams. The range of diversity values did not overlap, yielding a clear distinction between healthy and polluted streams.

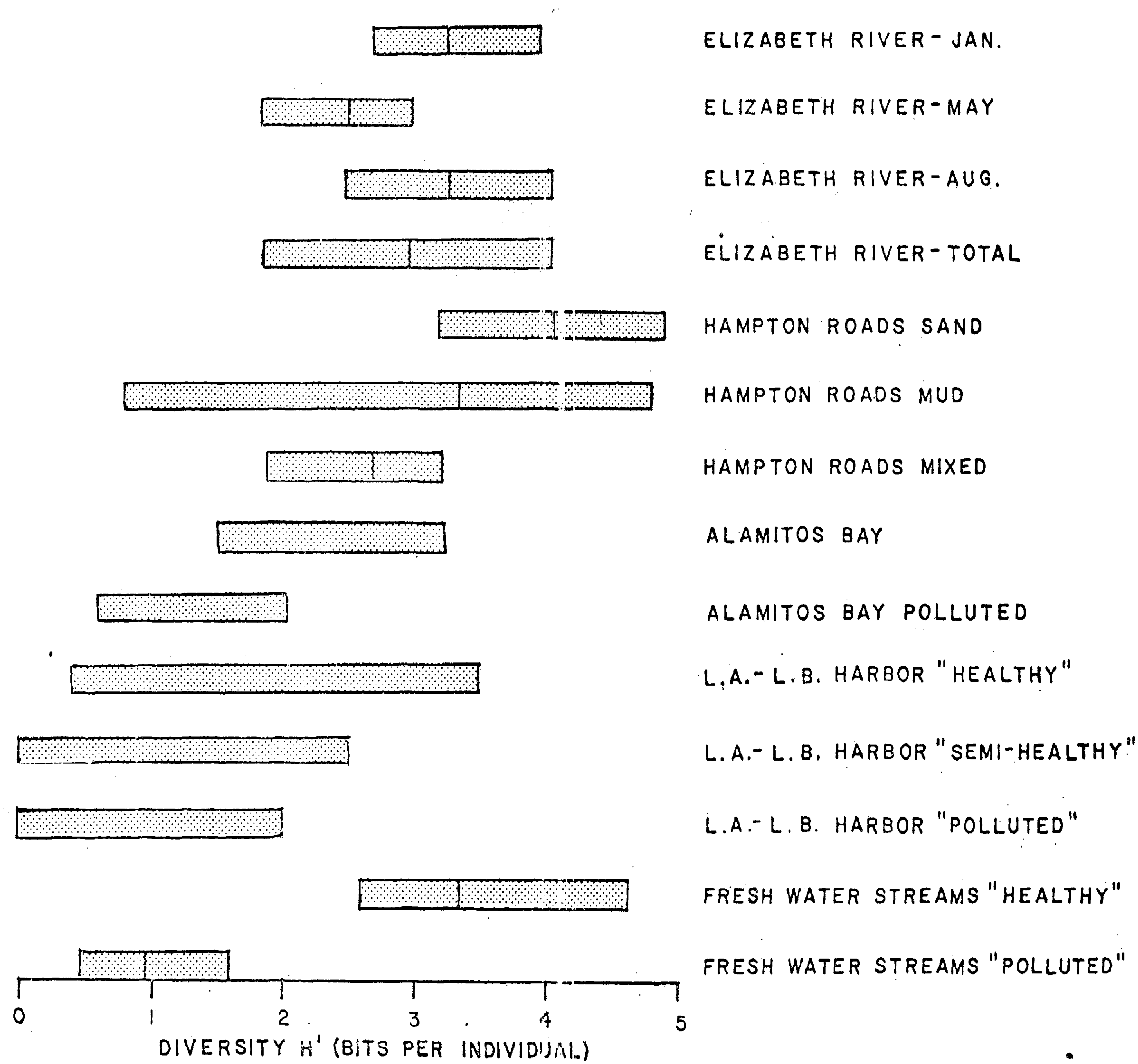
Pearson *et. al.* (1967) found H' of macrobenthos to be a good indicator of pollution in San Francisco Bay, California. He found a range of H' of 1.7 to 4.5 (mean 3.3) near the Golden Gate Bridge in unpolluted water. The H' values fell below 1.0 on both ends of San Francisco Bay where pollution was severe.

Boesch (1971) calculated H' values from data on healthy, semi-healthy and polluted areas in Los Angeles and Long Beach harbors, California (Reish, 1959). The H' values were low in all areas. Boesch suggested that Reish, confronted with areas of gross pollution, underestimated areas of mild pollution.

Wilhm and Dorris (1968) re-examined Reish and Winter's (1954) data on Alamitos Bay, and calculated H' values for the nine stations considered mildly polluted by Wass (1967). Wilhm and Dorris, concluded as Wass; that, contrary to Reish and Winter's findings, those nine stations were mildly polluted.

Boesch (1971) calculated H' diversity values for mud, sand and "mixed sediment" stations in Hampton Roads. The lower H' diversity

Figure 12. Ranges of H' diversity for the Elizabeth River and other studies - Elizabeth River (present study), Hampton Roads (Boesch, 1971), Alamitos Bay (Reish and Winter, 1954), Los Angeles, Long Beach Harbor (Reish, 1959), Fresh water streams (Wilhm, 1970).


ELIZABETH RIVER - JAN.
ELIZABETH RIVER - MAY
ELIZABETH RIVER - AUG.
ELIZABETH RIVER - TOTAL
HAMPTON ROADS SAND
HAMPTON ROADS MUD
HAMPTON ROADS MIXED
ALAMITOS BAY
ALAMITOS BAY POLLUTED
L.A.- L.B. HARBOR "HEALTHY"
L.A.- L.B. HARBOR "SEMI-HEALTHY"
L.A.- L.B. HARBOR "POLLUTED"
FRESH WATER STREAMS "HEALTHY"
FRESH WATER STREAMS "POLLUTED"
0
1
2
3
4
5
DIVERSITY H' (BITS PER INDIVIDUAL)

values of mixed-sediment stations were related to low values of species richness.

The mean diversity (H') for the Elizabeth River stations was 2.95, much higher than the diversity of freshwater polluted streams and Los Angeles and Long Beach harbors, and slightly higher than Alamitos Bay. The Elizabeth River H' diversity is much lower than Hampton Roads sand and slightly lower than healthy freshwater streams and Hampton Roads mud. Sanders (1969) reported a higher diversity for sand stations than mud stations. He attributed the higher diversity to an increase in available niches in sand. It was therefore concluded from comparisons with other areas that the diversity at stations in the Elizabeth River is slightly lower than in unpolluted areas.

Several factors may explain the high diversity values found in the mildly polluted Elizabeth River and estuarine areas in general. Patterns of dispersal of pollutants are more complex in an estuary than in freshwater streams which have unidirectional flows. Tides, tidal currents, and winds tend to distribute pollutants throughout the systems, but this constant mixing also tends to maintain high levels of oxygen. The effects of pollution are more noticeable in areas of little water movement where oxygen becomes limiting. Oxygen can be limiting when large amounts of organic matter are added to streams, even though there is constant water movement. The stream recovers downstream from the pollution source as the organic material is utilized and oxygen is replenished.

Organisms inhabiting estuaries are hardy species and must be capable of withstanding large environmental fluctuations to survive. This is certainly true of the 10 dominant organisms found at the

Elizabeth River stations. Enough of these estuarine species are capable of withstanding mild pollution to retain a fairly equitable distribution of individuals among species, and maintain high diversity values. The reduction of diversity in May was related mostly to a reduction in species richness and not in equitability.

Mild pollution in the Elizabeth River eliminates some species (reduction in species richness) but is compensated for by high values of equitability, which maintains high diversity. A similar interplay of species richness and equitability was noted by Marsh (1970) in his study of an estuarine *Zostera* community.

SUMMARY

1. Macrobenthos in the Elizabeth River, Hampton Roads, Virginia, were sampled to define community structure and to determine the effects of pollution on community structure. Twelve stations were sampled by grabs during three sampling periods in 1969.

2. Eighty-seven grabs yielded 22,404 individuals divided among 122 identifiable taxa. Of these, 76.4% were polychaetes, 15.3% mollusks, 3.4% crustaceans, and 4.9% other taxa.

3. The samples had a mean density of 3,803 individuals/m^2. Density was higher at stations located on dead oyster reefs, because of the increased availability of oxygenated detrital material and the presence of a substrate for attachment.

4. The samples were dominated by *Nereis succinea*, *Streblospio benedicti*, *Heteromastus filiformis*, *Mya arenaria*, *Spiochaetopterus oculatus*, *Sabella microphthalma*, *Polydora ligni*, *Mulinia lateralis*, *Paraprionospio pinnata*, and *Sabellaria vulgaris*. These organisms are all pollution tolerant, have wide geographic distributions, and are not usually dominant in other communities in Chesapeake Bay or in other estuarine and coastal areas.

5. Samples taken from the same station were homogeneous (69.3% in common) but there was heterogeneity between stations (38.5% in common). Most species had a random distribution within stations and a contagious distribution among stations, indicating that most species were found in aggregates larger than the stations.

6. The ratio of pollution tolerant organisms to intolerant ones was 7.08. May had the highest ratio (13.31) followed by January (4.89) and August (2.46).

7. The mean H' diversity for the Elizabeth River was 2.96 bits/individual. May had the lowest mean diversity (2.45) followed by January (3.23) and August (3.24). Because of the many pollution tolerant species encountered in this study, diversity was as high as in some unpolluted temperate areas.

8. Non-selective deposit feeders were reduced because of the lack of O_2 and high concentrations of H_2S found in bottom deposits below 1 cm. Suspension feeders and selective deposit feeders were favored because of the good supply of well aerated detritus in suspension and deposited on the substrate.

9. H' diversity was more dependent on the species richness component than on the equitability component.

APPENDIX I. Species collected in the Elizabeth River, February 1969 - August 1969.

CNIDARIA

Ceriantheopsis americanus (Verrill)
Diadumene leucolena (Verrill)
Edwardsia elegans Verrill
Zoantharia (unid.)

PHORONIDA

Phoronis architecta Andrews

RHYNCHOCOELA

Amphiporus bioculatus (McIntosh)
Amphiporus ochraceus Verrill
Carinomella lactea Coe
Cerebratulus lacteus (Leidy)
Cerebratulus luridus Verrill
Micrura rubra Verrill
Tubulanus pellucidus (Coe)
Tetrastemma sp.
Nemerteans (unid.)

POLYCHAETA

Arabella irricolor (Montagu)
Aricidea wassi Pettibone
Asabellides oculata (Webster)
Capitella capitata (Fabricius)
Clymenella torquata (Leidy)
Diopatra cuprea (Bosc)
Drilonereis filum (Claparede)
Drilonereis longa Webster
Eteone heteropoda Hartman
Eteone lactea Claparede
Eumida sanguinea (Oersted)
Glycera americana Leidy
Glycera dibranchiata Ehlers
Glycinde solitaria (Wubster)
Gyptis vittata (Webster and Benedict)
Harmothoe imbricata (Linne)
Heteromastus filiformis (Claparede)
Hydroides hexagona (Bosc)
Lepidonotus sublevis Verrill
Loima medusa (Savigny)

Lumbrineris tenuis (Verrill)
Marphysa sanguinea (Montagu)
Nephtys magellanica (Augener)
Nereis succinea (Frey and Leuckart)
Notocirrus spiniferus (Moore)
Notomastus latericius Sars
Paleanotus heteroseta Hartman
Paraprionospio pinnata (Ehlers)
Pectinaria gouldi (Verrill)
Pilargiidae (unid.)
Pista palmata (Verrill)
Phyllodoce arenae Webster
Podarke obscura Verrill
Polycirrus eximius (Leidy)
Polydora ligni Webster
Pseudeurythoe paucibranchiata Fauvel
Sabella microphthalma Verrill
Sabellaria vulgaris Verrill
Scolecolepides viridis (Verrill)
Scoloplos fragilis Verrill
Spio setosa (Verrill)
Spiochaetopterus oculatus Webster
Stauronereis rudolphi (delle Chiaje)
Streblospio benedicti Webster
Tharyx setigera Hartman
Polychaete a
Polychaete b

BIVALVIA
Anadara transversa (Say)
Anomia simplex Orbigny
Crassostrea virginica (Gmelin)
Ensis directus Conrad
Gemma gemma (Totten)
Lyonsia hyalina Conrad
Macoma balthica (Linnoeus)
Mercenaria mercenaria (Linnaeus)
Mulinia lateralis (Say)
Mya arenaria (Linnaeus)
Tagelus plebeius (Solander)
Bivalve a

GASTROPODA
Acteon punctostriatus Adams
Crepidula convexa Say
Epitonium rupicolum (Kurtz)

Eupleura caudata (Say)
Mangelia plicosa (Adams)
Mitrella lunata (Say)
Nassarius obsoletus (Say)
Nassarius vibex (Say)
Odostomia impressa Say
Pyramidella fusca Adams
Retusa canaliculata (Say)
Turbonilla interrupta Trotten
Urosalpinx cinerea

CIRRIPEDIA

Balanus improvisus Darwin

MYSIDACEA

Neomysis americana (Smith)

CUMACEA

Cyclaspis varians Calman
Leucon americanus Zimmer
Oxyurostylis smithi Calman
Sphaeroma quadridentatum Say

ISOPODA

Cyathura burbancki Frankenberg
Cyathura polita (Stimpson)
Edotea triloba (Say)

AMPHIPODA

Ampelisca vadorum Mills
Batea catharinensis Muller
Caprella geometrica Say
Cerapus tubularis Say
Corophium acherusicum Costa
Corophium lacustre Vanhoffen
Corophium tuberculatum Shoemaker
Elasmopus laevis (Smith)
Erichthonium brasiliensis Dana
Gammarus mucronatus Say
Jassa falcata (Montagu)
Melita appendiculata (Say)
Melita nitida Smith
Paracaprella tenuis Mayer
Stenothoe minuta (Holmes)
Unciola irrorata Say
Amphipod (unid.)

DECAPODA

Alpheus heterochaelis Say
Callinectes sapidus Rathbun
Crangon septemspinosa (Say)
Euceramus praelongus Stimpson
Eurypanopeus depressus (Smith)
Neopanope texana (Smith)
Ogyrides limicola Williams
Pinnixa sayana Stimpson
Pinnixa (unid.)
Upogebia affinis (Say)

APPENDIX II

SPECIES AND NUMBER OF INDIVIDUALS FOUND IN EACH SAMPLE IN THE ELIZABETH RIVER 1969

Station L-1 (1, 2, 3) January 1969

Sample	1	2	3	Total
Species				
Streblospio benedicti	44	37	129	210
Mulinia lateralis	41	59	29	129
Retusa canaliculata	21	37	17	75
Nereis succinea	18	16	24	58
Mya arenaria	17	8	31	56
Spiochaetopterus oculatus	4	5	14	23
Edotea triloba	6	4	7	17
Capitella capitata	2	5	5	12
Pectinaria gouldi	4	2	5	11
Eteone heteropoda	2	3	4	9
Pseudeurythoe paucibranchiata	1		7	8
Heteromastus filiformis	1	1	5	7
Sabella microphthalma	3		2	5
Paraprionospio pinnata	1	2	2	5
Scoloplos fragilis	3	1		4
Glycinde solitaria			3	3
Odostomia impressa		1	1	2
Gemma gemma			1	1
Mangelia plicosa	1			1
Acteon punctostriatus		1		1
Epitonium rupicolum			1	1
Gammarus mucronatus	1			1
Diopatra cuprea	1			1
Glycera americana			1	1
Glycera dibranchiata			1	1
Cerebratulus lacteus			1	1
Number individuals	171	182	290	643
Number species	18	15	21	26

Station L-2 (1, 2, 3) January 1969

Sample	1	2	3	Total
Species				
Mulinia lateralis	75	3	95	173
Nereis succinea	16	3	29	48
Streblospio benedicti	1	14	28	43
Retusa canaliculata	12	2	11	25
Spiochaetopterus oculatus	1	3	10	14
Paraprionospio pinnata	3	4	6	13
Heteromastus filiformis	3	7	3	13
Scoloplos fragilis	3	2	4	9
Pectinaria gouldi	1		3	4
Mya arenaria		1	2	3
Edotea triloba	1		2	3
Glycera dibranchiata			2	2
Pseudeurythoe paucibranchiata		1	1	2
Callinectes sapidus			1	1
Leucon americanus			1	1
Polydora ligni			1	1
Glycera americana			1	1
Sabella microphthalma	1			1
Eteone heteropoda		1		1
Edwardsia elegans	1			1
Number individuals	118	41	200	359
Number species	12	11	17	20

Station L-3 (1, 2, 3) January 1969

Sample	1	2	3	Total
Species				
Streblospio benedicti	13	5	150	168
Retusa canaliculata	62	23	63	148
Spiochaetopterus oculatus	36	17	22	75
Mya arenaria	14	24	24	62
Sabella microphthalma	5	27	3	35
Heteromastus filiformis	4	6	13	23
Nereis succinea	2	15	5	22
Mulinia lateralis	4	3	8	15
Pseudeurythoe paucibranchiata		5	8	13
Scoloplos fragilis	2	3	7	12
Paraprionospio pinnata	5	3	3	11
Glycinde solitaria	4		7	11
Acteon punctostriatus	3	2	2	7
Pectinaria gouldi	1	2	4	7
Polydora ligni		3	2	5
Capitella capitata	1	1	3	5
Polychaetea a		4	1	5
Nassarius vibex		4		4
Tubulanus pellucidus	1		3	4
Pyramidella fusca	1		2	3
Odostomia impressa		1	2	3
Edotea triloba	1	2		3
Lepidonotus sublevis		1	2	3
Diadumene leucolena		1	2	3
Molgula manhattensis		3		3
Epitonium rupicolum	1		1	2
Cyclaspis varians			2	2
Eteone heteropoda			2	2
Cerebratulus lacteus	1		1	2
Mangelia plicosa	1			1
Callinectes sapidus			1	1
Glycera americana	1			1
Tharyx setigera	1			1
Sabellaria vulgaris	1			1
Glycera dibranchiata		1		1
Phoronis architecta	1			1
Number individuals	166	156	343	665
Number species	24	23	27	36

Station L-4 (1, 2, 3) January 1969

Sample	1	2	3	Total
Species				
Mya arenaria	35	40	44	119
Mulinia lateralis	18	49	41	108
Sabella microphthalma	91	5	3	99
Heteromastus filiformis	9	19	23	51
Nereis succinea	10	18	2	30
Spiochaetopterus oculatus	2	11	15	28
Retusa canaliculata	1	4	9	14
Pectinaria gouldi	1	9	3	13
Nassarius vibex	2	2	7	11
Paraprionospio pinnata	2	2	7	11
Polydora ligni		7	2	9
Streblospio benedicti	2	4	2	8
Crepidula convexa	1	1		2
Scoloplos fragilis	1		1	2
Lepidonotus sublevis	1	1		2
Tharyx setigera			2	2
Eteone heteropoda	1			1
Psuedeurythoe paucibranchiata			1	1
Glycera americana			1	1
Phoronis architecta			1	1
Molgula manhattensis	1			1
Corophium acherusicum	1			1
Neopanope texana	1			1
Cerebratulus lacteus	1			1
Number individuals	181	172	164	517
Number species	19	14	17	24

Station L-5 (1, 2, 3) January 1969

Sample	1	2	3	Total
Species				
Sabellaria vulgaris	139	42	294	475
Sabella microphthalma	69	76	104	249
Unciola irrorata	92	67	55	214
Nereis succinea	51	42	114	207
Streblospio benedicti	9	38	131	178
Polydora ligni	43	24	63	130
Spiochaetopterus oculatus	27	70	31	128
Heteromastus filiformis	17	25	59	101
Mya arenaria	15	33	20	68
Retusa canaliculata	7	15	5	27
Mangelia plicosa	12	2	8	22
Glycinde solitaria	1	13	7	21
Ampelisca vadorum	11	3	3	17
Edotea triloba	5	3	7	15
Lepidonotus sublevis	4	1	8	13
Eumida sanguinea	3	8	2	13
Podarke obscura	2	2	9	13
Capitella capitata	1	1	10	13
Nassarius vibex	5	5	1	11
Tharyx setigera	3	3	4	10
Anadara transversa	3	3	3	9
Odostomia impressa	1	3	5	9
Mitrella lunata	1	2	5	8
Neopanope texana	5		3	8
Paraprionospio pinnata	2	4	2	8
Pectinaria gouldi		7	1	8
Pseudeurythoe paucibranchiata	1	1	5	7
Mulinia lateralis	2	2	2	6
Eteone heteropoda		3	3	6
Pyramidella fusca	1	1	3	5
Epitonium rupicolum	1	1	3	5
Lyonsia hyalina		1	2	3
Callinectes sapidus	1	1	1	3
Gammarus mucronatus	3			3
Phoronis architecta		2	1	3
Scoloplos fragilis			3	3
Diadumene leucolena	1		1	2
Micrura rubra		2		2
Glycera dibranchiata	2			2
Marphysa sanguinea	1	1		2

Station L-5 (1, 2, 3) January 1969

Sample	1	2	3	Total
Species				
Eteone lactea		1	1	2
Mercenaria mercenaria			1	1
Turbonilla interrupta	1			1
Crepidula convexa		1		1
Acteon punctostriatus			1	1
Upogebia affinis		1		1
Cyathura burbancki			1	1
Sphaeroma quadridentatum			1	1
Cyclaspis varians			1	1
Corophium lacustre	1			1
Corophium tuberculatum		1		1
Corophium acherusicum			1	1
Melita nitida			1	1
Cucumaria pulcherrima			1	1
Cerebratulus luridus	1			1
Edwardsia elegans		1		1
Molgula manhattensis		1		1
Glycera americana		1		1
Clymenella torquata			1	1
Stauronereis rudolphi			1	1
Number individuals	545	514	989	2048
Number species	37	42	47	60

Station E-7 (1, 2, 3) January 1969

Sample	1	2	3	Total
Species				
Mya arenaria		71	35	106
Paraprionospio pinnata	11	18	19	48
Nereis succinea	17	12	11	40
Spiochaetopterus oculatus	11	8	20	39
Heteromastus filiformis	10	11	14	35
Mulinia lateralis	1	4	2	7
Molgula manhattensis		5	1	6
Pseudeurythoe paucibranchiata	1		3	4
Retusa canaliculata		3	1	4
Edotea triloba		1	3	4
Glycera americana	1	1	1	3
Nephtys magellanica	1		2	3
Phoronis architecta	2			2
Pectinaria gouldi		1	1	2
Sabella microphthalma		1	1	2
Callinectes sapidus			2	2
Nassarius vibex			2	2
Nassarius obsoletus	1			1
Unciola irrorata	1			1
Balanus improvisus		1		1
Cerebratulus lacteus			1	1
Nemertean (unid.)			1	1
Number individuals	57	137	120	314
Number species	11	13	18	22

Station L-1 (1, 2, 3) May 1969

Sample	1	2	3	Total
Species				
Streblospio benedicti	66	28	52	146
Nereis succinea	15	15	19	49
Mulinia lateralis	13	7	10	30
Polydora ligni	2	8	10	20
Mya arenaria	3	7	3	13
Macoma balthica			13	13
Heteromastus filiformis	2	6	4	12
Ensis directus	1	2	3	6
Scoloplos fragilis	1	4	1	6
Edotea triloba	4		1	5
Paraprionospio pinnata	1	2	2	5
Tharyx setigera		1	2	3
Tubulanus pellucidus	2		1	3
Glycera americana		1	1	2
Sabella microphthalma			1	1
Eteone heteropoda	1			1
Number individuals	111	81	123	315
Number species	12	11	15	16

Station L-2 (1, 2, 3) May 1969

Sample	1	2	3	Total
Species				
Sabellaria vulgaris	267	324	531	1122
Sabella microphthalma	281	285	203	769
Streblospio benedicti	156	282	87	525
Nereis succinea	127	155	121	403
Mya arenaria	35	88	89	212
Heteromastus filiformis	66	106	32	204
Polydora ligni	68	53	33	154
Diadumene leucolena	23	15	10	48
Macoma balthica	16	10	3	29
Odostomia impressa	6	6	13	25
Eteone heteropoda	6	8		14
Scoloplos fragilis	3	6	4	13
Molgula manhattensis		8	5	13
Gammarus mucronatus		10		10
Tharyx setigera	4	6		10
Lepidonotus sublevis	3	4	3	10
Edotea triloba	3	2	3	8
Pectinaria gouldi	3	4	1	8
Nassarius vibex		4	2	6
Neopanope texana	2	3		5
Pseudeurythoe paucibranchiata	1	1	3	5
Podarke obscura	3	1	1	5
Tubulanus pellucidus	5			5
Phyllodoce mucosa	4			4
Phoronis architecta	3			3
Epitonium rupicolum	1		1	2
Crepidula convexa	2			2
Nassarius obsoletus		1	1	2
Elasmopus pocillamanus	2			2
Eumida sanguinea	1	1		2
Glycera dibranchiata		1	1	2
Edwardsia elegans			2	2
Mulinia lateralis			1	1
Crassostrea virginica	1			1
Bivalve (a)		1		1
Retusa canaliculata			1	1
Cerapus tubularis	1			1
Unciola irrorata		1		1
Marphysa sanguinea	1			1
Lumbrineris tenuis			1	1

Station L-2 (1, 2, 3) May 1969

Sample	1	2	3	Total
Species				
Micrura rubra			1	1
Melita nitida	1			1
Number individuals	1095	1386	1153	3634
Number species	30	27	26	42

Station L-3 (1, 2, 3) May 1969

Sample	1	2	3	Total
Species				
Sabellaria vulgaris	374	416	703	1493
Sabella microphthalma	435	118	610	1163
Nereis succinea	157	80	223	460
Streblospio benedicti	86	180	139	405
Mya arenaria	99	59	33	191
Polydora ligni	30	53	26	109
Diadumene leucolena	8	1	94	103
Heteromastus filiformis	22	23	48	93
Macoma balthica	6	11	16	33
Molgula manhattensis		2	12	14
Scoloplos fragilis	5	7	1	13
Edotea triloba	2	2	5	9
Lepidonotus sublevis	4	1	4	9
Eteone heteropoda	1	7	1	9
Odostomia impressa		3	5	8
Podarke obscura		3	5	8
Pectinaria gouldi	4	1	2	7
Gammarus mucronatus	1	1	4	6
Neopanope texana	2	2	1	5
Pseudeurythoe paucibranchiata		3	1	4
Mulinia lateralis	1	2		3
Ensis directus		2	1	3
Tharyx setigera		2	1	3
Micrura rubra		1	2	3
Urosalpinx cinerea	2			2
Clymenella torquata	2			2
Glycera dibranchiata	1	1		2
Amphiporus ochraceus			2	2
Bivalve (a)			1	1
Nassarius obsoletus		1		1
Eupleura caudata			1	1
Unciola irrorata		1		1
Drilonereis filum	1			1
Stauronereis rudolphi		1		1
Glycinde solitaria		1		1
Harmothoe imbricata			1	1
Eumida sanguinea			1	1
Edwardsia elegans		1		1

Station L-3 (1, 2, 3) May 1969

Sample	1	2	3	Total
Number individuals	1243	986	1943	4172
Number species	21	30	29	38

Station L-4 (1, 2, 3) May 1969

Sample	1	2	3	Total
Species				
Mya arenaria	5	18	141	164
Streblospio benedicti	21	26	68	115
Heteromastus filiformis	8	12	46	66
Nereis succinea	3	8	47	58
Sabella microphthalma			53	53
Paraprionospio pinnata	11	24	1	36
Mulinia lateralis	3	7	1	11
Polydora ligni	2	5	2	9
Eteone heteropoda	5		2	7
Spiochaetopterus oculatus	2	3	1	6
Pseudeurythoe paucibranchiata			6	6
Scoloplos fragilis	3		2	5
Diadumene leucolena			4	4
Pectinaria gouldi			3	3
Lepidonotus sublevis			3	3
Crangon septemspinosum	2			2
Edotea triloba		1	1	2
Nassarius vibex		1	1	2
Ensis directus		1		1
Mercenaria mercenaria		1		1
Macoma balthica			1	1
Pinnixa sayana		1		1
Neomysis americanus		1		1
Neopanope texana			1	1
Capitella capitata	1			1
Glycera americana			1	1
Cerebratulus lacteus	1			1
Phoronis architecta		1		1
Molgula manhattensis			1	1
Number individuals	67	110	386	563
Number species	13	15	21	29

Station L-5 (1, 2, 3) May 1969

Sample	1	2	3	Total
Species				
Polydora ligni	102	73	128	303
Streblospio benedicti	62	74	57	193
Paraprionospio pinnata	14	28	5	47
Heteromastus filiformis	10	7	17	34
Mulinia lateralis	19	4	4	27
Mya arenaria	6	3	10	19
Pectinaria gouldi	4	1	6	11
Nereis succinea	2	3	6	11
Phoronis architecta	6	5		11
Ensis directus	4	2	2	8
Spiochaetopterus oculatus	1	2	3	6
Eteone heteropoda	3	1	1	5
Scoloplos fragilis	2	2	1	5
Nassarius vibex	1		2	3
Retusa canaliculata		3		3
Odostomia impressa			3	3
Glycera americana	2	1		3
Mangelia plicosa			2	2
Edotea triloba	2			2
Tharyx setigera		2		2
Glycera dibranchiata			2	2
Lyonsia hyalina	1			1
Mitrella lunata			1	1
Crangon septemspinosum			1	1
Pseudeurythoe paucibranchiata	1			1
Sabella microphthalma		1		1
Diadumene leucolena			1	1
Number individuals	242	212	252	706
Number species	18	17	19	27

Station L-6 (1,2,3) May 1969

Sample	1	2	3	Total
Species				
Streblospio benedicti	24	83	59	166
Mya arenaria	12	8	89	109
Macoma balthica	8	49	23	80
Mulinia lateralis	6	39		45
Nereis succinea	2	7	21	30
Ensis directus	11	7	4	22
Polydora ligni	1	1	12	14
Heteromastus filiformis	1	1	6	8
Eteone heteropoda	1	5	2	8
Odostomia impressa	2			2
Asabellides oculata		1	1	2
Capitella capitata	1		1	2
Glycera americana			2	2
Gemma gemma			1	1
Neomysis americanus		1		1
Edotea triloba		1		1
Callinectes sapidus			1	1
Scoloplos fragilis	1			1
Lepidonotus sublevis			1	1
Pseudeurythoe paucibranchiata			1	1
Diadumene leucolena			1	1
Paraprionospio pinnata			1	1
Glycera dibranchiata			1	1
Number individuals	70	203	227	500
Number species	12	12	18	23

Station L-7 (1, 2, 3) May 1969

Sample	1	2	3	Total
Species				
Streblospio benedicti	37	81	66	184
Mya arenaria	16	62	8	86
Polydora ligni	7	35	13	55
Heteromastus filiformis	11	6	8	25
Phoronis architecta	3	5	6	14
Macoma balthica	2	5	2	9
Eteone heteropoda	3	6		9
Nereis succinea	2	3	3	8
Glycera americana	3	4		7
Paraprionospio pinnata	1	3	1	5
Tubulanus pellucidus			3	3
Caprella geometrica		2		2
Crangon septemspinosum		2		2
Tharyx setigera	1	1		2
Pseudeurythoe paucibranchiata	1	1		2
Ensis directus		1		1
Edotea triloba		1		1
Diopatra cuprea	1			1
Callinectus sapidus			1	1
Micrura rubra			1	1
Number individuals	88	218	112	418
Number species	13	16	11	20

Station L-8 (1,2,3) May 1969

Sample	1	2	3	Total
Species				
Mya arenaria	109	52	86	247
Streblospio benedicti	36	27	20	88
Heteromastus filiformis	4	8	16	28
Nereis succinea	10	3	8	21
Polydora ligni	8	5	6	19
Phoronis architecta	3	4	1	8
Macoma balthica	1	3	1	5
Crangon septemspinosum	2		2	4
Paraprionospio pinnata	1	1	1	3
Pseudeurythoe paucibranchiata		1	2	3
Molgula manhattensis			3	3
Eteone heteropoda	2			2
Glycera americana	2			2
Ensis directus		1		1
Edotea triloba	1			1
Tharyx setigera	1			1
Scoloplos fragilis			1	1
Glycera dibranchiata			1	1
Micrura rubra		1		1
Number individuals	180	106	148	434
Number species	13	11	13	19

Station L-10 (1, 2, 3) May 1969

Species \ Sample	1	2	3	Total
Streblospio benedicti	218	139	277	634
Polydora ligni	105	45	47	197
Heteromastus filiformis	23	13	24	60
Tharyx setigera	5	4	49	58
Mya arenaria	23	13	15	51
Mulinia lateralis	5	5	12	22
Phoronis architecta	7	12	2	21
Eteone heteropoda	7	4	9	20
Glycinde solitaria	8	4	3	15
Ensis directus	9	1	3	13
Nereis succinea	4	3	2	9
Drilonereis filum	3	2	3	8
Balanus improvisus	5			5
Neomysis americanus	3	1		4
Edotea triloba		3	1	4
Retusa canaliculata	3			3
Epitonium rupicolum			3	3
Glycera dibranchiata	1	1	1	3
Pseudeurythoe paucibranchiata	1		2	3
Pectinaria gouldi		1	2	3
Spio setosa			3	3
Nassarius obsoletus	1		1	2
Pyramidella fusca	1	1		2
Scoloplos fragilis		1	1	2
Tubulanus pellucidus	2			2
Nassarius vibex		1		1
Sabella microphthalma	1			1
Sabellaria vulgaris	1			1
Diopatra cuprea	1			1
Scolecolepides viridis	1			1
Podarke obscura			1	1
Drilonereis longa			1	1
Cerebratulus lacteus	1			1
Number individuals	439	254	462	1155
Number species	25	19	22	33

Station E-7 (1,2,3) May 1969

Sample	1	2	3	Total
Species				
Streblospio benedicti	12	12	53	77
Heteromastus filiformis	2	8	11	21
Nereis succinea	4	6	2	12
Corophium acherusicum	3	1	2	6
Spiochaetopterus oculatus		3	2	5
Mya arenaria	2			2
Eteone heteropoda	1		1	2
Polydora ligni		1	1	2
Gammarus mucronatus	1			1
Paraprionospio pinnata	1			1
Tharyx setigera	1			1
Glycera americana			1	1
Number individuals	27	31	73	131
Number species	9	6	8	12

Station E-8 (1, 2, 3) May 1969

Samples	1	2	3	Total
Species				
Mya arenaria	120	230	104	454
Nereis succinea	14	17	8	39
Corophium acherusicum	1		37	38
Heteromastus filiformis	6	5	15	26
Streblospio benedicti	3	8	8	19
Gammarus mucronatus			13	13
Mulinia lateralis	2	6	4	12
Polydora ligni	1	3	1	5
Eteone heteropoda		4	1	5
Edotea triloba		3		3
Diadumene leucolena	1		1	2
Ensis directus	2			2
Melita appendiculata		2		2
Alpheus heterochaelis		1	1	2
Sabella microphthalma		2		2
Molgula manhattensis			2	2
Spiochaetopterus oculatus	1			1
Cyathura polita		1		1
Caprella geometrica		1		1
Amphipoda (unid.)		1		1
Nemertean (unid.)		1		1
Podarke obscura		1		1
Elasmopus pocillamanus			1	1
Leucon americanus			1	1
Glycera americana			1	1
Scoloplos fragilis			1	1
Number individuals	151	286	199	636
Number species	10	16	16	26

Station L-1 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Spiochaetopterus oculatus	6	8	18	32
Nereis succinea	9	12	7	28
Capitella capitata	6	6	7	19
Glycera dibranchiata	1	5		6
Nassarius vibrex	1	2	2	5
Sabella microphthalma			4	4
Mulinia lateralis		2	1	3
Diopatra cuprea	1	1	1	3
Streblospio benedicti		2	1	3
Retusa canaliculata			2	2
Edotea triloba			2	2
Paraprionospio pinnata			2	2
Cerebratulus lacteus	2			2
Gemma gemma			1	1
Acteon punctostriatus		1		1
Eteone heteropoda	1			1
Heteromastus filiformis		1		1
Number individuals	27	40	48	115
Number species	8	10	12	17

Station L-2 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Sabella microphthalma	107	45	60	212
Polydora ligni	89	23	53	165
Nereis succinea	62	24	50	136
Heteromastus filiformis	59	24	31	114
Tharyx setigera	49	12	16	77
Diadumene leucolena	21	7	35	63
Molgula manhattensis	28	6	24	58
Scoloplos fragilis	8	2	13	23
Pseudeurythoe paucibranchiata	12	6	2	20
Hydroides hexagonus	15	2		17
Streblospio benedicti	7	2	2	11
Cerebratulus lactens	2	3	3	8
Edotea triloba	1		5	6
Pectinaria gouldi	4		2	6
Tagelus plebius	1	2	2	5
Glycera dibranchiata	2	1	1	4
Sabellaria vulgaris	1	2	1	4
Eupleura caudata		1	2	3
Edwardsia elegans		1	2	3
Nassarius vibex	2			2
Podarke obscura	2			2
Mercenaria mercenaria	1			1
Mulinia lateralis		1		1
Bivalve (unid.)			1	1
Crepidula convexa	1			1
Nassarius obsoletus		1		1
Mitrella lunata			1	1
Melita nitida			1	1
Elasmopus pocillimanus	1			1
Eteone heteropoda	1			1
Phyllodoce mucosa			1	1
Stenothoe minuta			1	1
Number individuals	476	165	309	950
Number species	23	19	23	32

Station L-3 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Molgula manhattensis		114	44	158
Sabella microphthalma		75	8	83
Heteromastus filiformis	9	12	9	30
Hydroides hexagonus			30	30
Diadumene leucolena		8	18	26
Scoloplos fragilis	4	11	7	22
Nereis succinea		9	10	19
Nassarius obsoletus	5	4	7	16
Pectinaria gouldi	2	9	4	15
Polydora ligni		5	3	8
Pseudeurythoe paucibranchiata	1	4		5
Nassarius vibex		1	2	3
Epitonium rupicolum		1	2	3
Edotea triloba		1	2	3
Lepidonotus sublevis		3		3
Edwardsia elegans	1	1	1	3
Tubulanus pellucidus		2	1	3
Retusa canaliculata	2			2
Neopanope texana			2	2
Elasmopus pocillimanus			2	2
Podarke obscura		2		2
Paraprionospio pinnata			2	2
Crepidula convexa	1			1
Eupleura caudata			1	1
Cyathura burbancki			1	1
Paracaprella tenuis			1	1
Spiochaetopterus oculatus		1		1
Glycera americana			1	1
Streblospio benedicti			1	1
Phoronis architecta			1	1
Number individuals	25	263	160	448
Number species	8	18	24	30

Station L-4 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Spiochaetopterus oculatus	41	7	4	52
Pseudeurythoe paucibranchiata	17	8	2	27
Scoloplos fragilis	1	8	16	25
Heteromastus filiformis	2	11	2	15
Nereis succinea	1	2	4	7
Phoronis architecta	3	2	2	7
Paraprionospio pinnata	2	1	1	4
Glycinde solitaria	1		1	2
Pectinaria gouldi		1	1	2
Sabella microphthalma			2	2
Nassarius vibex			1	1
Ogyrides limicola	1			1
Ampelisca vadorum	1			1
Unicola irrorata		1		1
Nephtys magellanica	1			1
Phyllodoce arenae	1			1
Nemertean (unid.)			1	1
Carinomella lactea			1	1
Glycera americana		1		1
Number individuals	72	42	38	152
Number species	12	10	13	19

Station L-5 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Heteromastus filiformis	78	115	118	311
Sabellaria vulgaris	50	141	35	226
Polydora ligni	55	135	3	193
Unciola irrorata	99	64	28	191
Sabella microphthalma	14	152	20	186
Nereis succinea	39	51	25	115
Tharyx setigera	20	64	7	91
Molgula manhattensis	5	35	11	51
Streblospio benedicti	16	22	4	42
Spiochaetopterus oculatus	14	15	10	39
Scoloplos fragilis	20	5	11	36
Diadumene leucolena	6	17	10	33
Edotea triloba	2	16	14	32
Pseudeurythoe paucibranchiata		7	20	27
Eteone heteropoda	10	9	2	21
Phoronis architecta	3	13	2	18
Pectinaria gouldi	4	11	1	16
Glycinde solitaria	3	6	5	14
Phyllococe arenae	1	8	3	12
Micrura rubra		3	8	11
Mitrella lunata	5	2	3	10
Glycera dibranchiata	3	1	5	9
Mangelia plicosa	2	4	2	8
Ampelisca vadorum	3	2	2	7
Eumida sanguinea	1	6		7
Paleanotus heteroseta	1	6		7
Hydroides hexagonus		6		6
Anadara transversa	2	1	2	5
Epitonium rupicolum	2	3		5
Corophium acherusicum	1	2	2	5
Marphysa sanguinea	3	1	1	5
Nassarius vibex		2	2	4
Podarke obscura		2	2	4
Mya arenaria	1		2	3
Retusa canaliculata		1	2	3
Glycera americana		3		3
Lyonsia hyalina	1	1		2
Mercenaria mercenaria		2		2
Crepidula convexa	1	1		2
Paracaprella tenuis		2		2

Station L-5 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Pista palmata	1	1	1	2
Lepidonotus sublevis	1	1		2
Stauronereis rudolphi		2		2
Cucumaria pulcherrima	1	1		2
Amphiporus bioculatus	1	1		2
Nemertean (unid.)		2		2
Tagelus plebius	1			1
Mulinia lateralis			1	1
Neopanope texana		1		1
Melita nitida		1		1
Stenothoe minuta		1		1
Paraprionospio pinnata	1			1
Capitella capitata	1			1
Polycirrus eximius	1			1
Notomastus latericius	1			1
Pilargidae sp.	1			1
Eteone lactea		1		1
Arabella iricolor		1		1
Drilonereis longa			1	1
Aricidea wassi			1	1
Tetrastemma sp.	1			1
Edwardsia elegans		1		1
Ceriantheopsis americanus		1		1
Cerebratulus lacteus			1	1
Amphiporus ochraceus			1	1
Polychaeta (unid.)		1		1
Number individuals	476	953	367	1796
Number species	42	53	35	66

Station L-6 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Nassarius obsoletus	10	9	6	25
Scoloplos fragilis	2	1	7	10
Nereis succinea	3	2	2	7
Heteromastus filiformis	2	2	2	6
Paraprionospio pinnata	1	1	1	3
Capitella capitata	2	1		3
Nassarius vibex		2		2
Retusa canaliculata		2		2
Eupleura caudata		2		2
Glycera dibranchiata	1	1		2
Tubulanus pellucidus	1		1	2
Gemma gemma		1		1
Mulinia lateralis			1	1
Edotea triloba	1			1
Streblospio benedicti	1			1
Spiochaetopterus oculatus	1			1
Pseudeurythoe paucibranchiata			1	1
Number individuals	25	24	21	70
Number species	11	11	8	17

Station L-7 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Phoronis architecta	3	10	5	18
Phyllodoce mucosa	1	4	6	11
Heteromastus filiformis	5	3	2	10
Nereis succinea	2	3	4	9
Spiochaetopterus oculatus		4	4	8
Retusa canaliculata	1	1	1	3
Pseudeurythoe paucibranchiata	1	1	1	3
Pectinaria gouldi	1		2	3
Glycera americana	1		2	3
Molgula manhattensis			3	3
Edotea triloba		1	1	2
Scoloplos fragilis	1	1		2
Erichthonius brasiliensis		1		1
Batea catharinensis			1	1
Cucumaria pulcherrima			1	1
Number individuals	16	29	33	78
Number species	9	10	13	15

Station L-8 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Spiochaetopterus oculatus	17	10	12	39
Phoronis architecta	9	6	5	20
Heteromastus filiformis	3	8	3	14
Scoloplos fragilis	4	1	1	6
Phyllodoce mucosa	3	1	1	5
Pseudeurythoe paucibranchiata	3	2		5
Nereis succinea	4		1	5
Molgula manhattensis		4	1	5
Macoma balthica			2	2
Podarke obscura		2		2
Pectinaria gouldi		2		2
Mulinia lateralis		1		1
Epitonium rupicolum		1		1
Nassarius vibex			1	1
Edotea triloba			1	1
Pinnixa sayana			1	1
Glycera dibranchiata	1			1
Sabella microphthalma	1			1
Glycera americana	1			1
Paraprionospio pinnata			1	1
Number individuals	46	38	30	114
Number species	10	11	12	20

Station L-9 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Spiochaetopterus oculatus	73	51	48	172
Paraprionospio pinnata	5	8	9	22
Scoloplos fragilis	6	8	6	20
Heteromastus filiformis	3	3	13	19
Phoronis architecta	5	6		11
Nassarius vibex	1	1	8	10
Nereis succinea	4		5	9
Micrura rubra	4	1	2	7
Pectinaria gouldi	2	2	2	6
Phyllodoce arenae	1	1	3	5
Retusa canaliculata	1	3		4
Pseudeurythoe paucibranchiata	2		1	3
Loimia medusa	1		2	3
Molgula manhattensis			3	3
Ampelisca vadorum		1	1	2
Edotea triloba			2	2
Tharyx setigera	2			2
Glycera americana	1	1		2
Glycinde solitaria	1	1		2
Lyonsia hyalina	1			1
Eupleura caudata	1			1
Oxyurostylis smithi		1		1
Polydora ligni	1			1
Podarke obscura		1		1
Diopatra cuprea		1		1
Sabella microphthalma			1	1
Sabellaria vulgaris			1	1
Cucumaria pulcherrima			1	1
Anthoza (unid.)			1	1
Number individuals	115	90	109	314
Number species	19	16	18	29

Station L-10 (1, 2, 3) August 1969

Sample Species	1	2	3	Total
Heteromastus filiformis	42	64	65	171
Sabella microphthalma	7	78	80	165
Nereis succinea	18	66	79	163
Polydora ligni	13	45	46	104
Diadumene leucolena	8	37	47	92
Tharyx setigera	16	31	22	69
Molgula manhattensis	1	26	31	58
Sabellaria vulgaris	1	24	27	52
Pseudeurythoe paucibranchiata	9	5	13	27
Scoloplos fragilis	5	12	6	23
Streblospio benedicti	4	7	4	15
Cerebratulus lacteus	4	4	2	10
Pectinaria gouldi		7	2	9
Podarke obscura	1	4	3	8
Nassarius vibex		3	2	5
Neopanope texana		3	2	5
Corophium acherusicum		2	3	5
Edotea triloba		1	3	4
Eteone heteropoda		3	1	4
Eumida sanguinea		1	3	4
Glycinde solitaria		1	2	3
Lepidonotus sublevis		1	2	3
Hydroides hexagonus			3	3
Edwardsia elegans	1	1	1	3
Euceramus praelongus		1	1	2
Melita nitida		2		2
Phoronis architecta		1	1	2
Tubulanus pellucidus		2		2
Stauronereis rudolphi	1	1		2
Anomia simplex		1		1
Mercenaria mercenaria			1	1
Mya arenaria			1	1
Nassarius obsoletus		1		1
Mitrella lunata			1	1
Mangelia plicosa			1	1
Unciola irrorata		1		1
Glycera americana	1			1
Arabella iricolor		1		1
Lumbrineris tenuis			1	1

Station L-10 (1, 2, 3) August 1969

Sample	1	2	3	Total
Number individuals	132	437	456	1025
Number species	16	31	31	39

Station E-7 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Paraprionospio pinnata	1		11	12
Scoloplos fragilis			8	8
Spiochaetopterus oculatus		1	2	3
Heteromastus filiformis			2	2
Pectinaria gouldi			1	1
Nereis succinea			1	1
Mulinia lateralis			1	1
Nassarius vibrex			1	1
Nemertean (unid.)			1	1
Number individuals	1	1	28	30
Number species	1	1	9	9

Station E-8 (1, 2, 3) August 1969

Sample	1	2	3	Total
Species				
Molgula manhattensis	17	28		45
Nereis succinea	8	3	2	13
Sabella microphthalma	6	4		10
Diadumene leucolena	3	4		7
Hydroides hexagonus		6		6
Alpheus heterochaelis	2	1		3
Gyptis vittatus	2	1		3
Polydora ligni		3		3
Elasmopus pocillimanus	1	1		2
Spiochaetopterus oculatus	1		1	2
Eurypanopeus depressus	1			1
Tubulanus pellucidus	1			1
Mulinia lateralis	1			1
Lepidonotus sublevis	1			1
Eteone heteropoda	1			1
Paraprionospio pinnata		1		1
Edotea triloba			1	1
Cerebratulus lacteus			1	1
Scoloplos fragilis			1	1
Heteromastus filiformis			1	1
Number individuals	45	52	7	104
Number species	13	10	6	20

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