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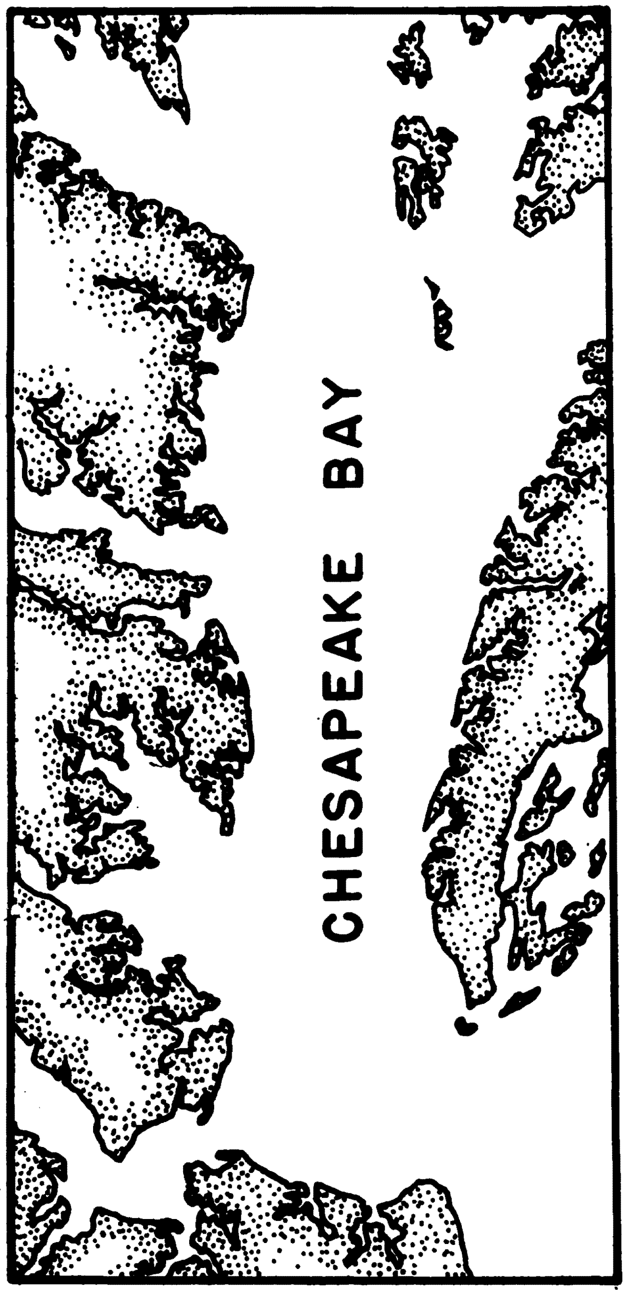
A study of the effects of dredging and dredge spoil disposal on the marine environment: project report.

Virginia Institute of Marine Science

FINAL REPORT

TO

U.S. ARMY CORPS OF ENGINEERS



A STUDY OF THE EFFECTS OF DREDGING AND DREDGE SPOIL DISPOSAL ON THE MARINE ENVIRONMENT

SPECIAL SCIENTIFIC REPORT IN APPLIED MARINE SCIENCE AND OCEAN ENGINEERING, NO. 8. VIRGINIA INSTITUTE OF MARINE SCIENCE

1967

PROJECT REPORT

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and

The Virginia Institute of Marine Science

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of the
Virginia Institute of Marine Science
Gloucester Point, Virginia

INTRODUCTION

Chesapeake Bay is the largest estuary on the East Coast of the United States. The historical value of this body of water both for commerce and marine resources is well documented. Today, as in the past, it is necessary to consider Chesapeake Bay as a multiple-use area--serving the seaports of Hampton Roads, Washington, and Baltimore via surface traffic and serving the same area equally well as a source of seafood products.

Geologically, Chesapeake Bay represents a drowned Pliocene and Pleistocene river valley. Present terrestrial and submerged terraces are thought to have been produced by fluctuations in sea level during the Wisconsin glacial period. In most areas of the bay the Pleistocene and pre-Pleistocene valley characteristics have been buried by Recent sediments. The present rate of sedimentation has been estimated to exceed six million cubic yards per year. The results of sedimentation are manifested in the degradation of oyster grounds and the necessity for maintenance dredging of the shipping channels.

Biologically, Chesapeake Bay is an important producer of seafood products. The commercial value of the harvest from the bay and tributary rivers in 1959 was estimated to be 38.5 million dollars. Commercially important species include oysters, clams, blue crabs, striped bass, shad, croaker, spot, flounder, and menhaden.

Oysters, clams, blue crabs and striped bass complete their life cycle within the waters of the estuary. The members of the shad family utilize the bay as a spawning and nursery area with the young returning to oceanic waters to complete the life cycle. Most other fin-fish species are found in the bay during the summer months but the mature individuals return to oceanic waters in the fall. These species spawn offshore but the young migrate into the low-salinity waters of the estuary to develop.

The waters of Chesapeake Bay are also heavily utilized by sport fishermen and boating enthusiasts. The Rappahannock Shoal area is famous for its summer cobia and fall striped bass fishing.

The bay is, therefore, truly a multiple-use area being utilized for commerce, industry, seafood production, and recreation. This study was undertaken to evaluate the effects of the improvement of the area for commerce by deepening and widening a channel upon the marine organisms directly or indirectly involved with the commercially and recreationally important seafood products.

METHODS

The Rappahannock Shoal and spoil disposal area investigated encompasses an area of approximately 180 square miles. The initial sampling program (1961) consisted of the establishment of a series of transects across the survey area. One hundred sampling stations were located along the established transects.

Inasmuch as the texture of the bottom sediments varied distinctly from place to place within the mid-bay region, the initial objective was to delineate the sediment distribution. Ninety-eight core samples were taken from the area with a modified Phleger coring device and analyzed in detail for textural characteristics. Representative stations were chosen and core samples were taken from these for complete chemical analyses.

The benthic fauna population is dependent upon many environmental factors. Grab samples were taken at each station with a standard

Petersen dredge in order to evaluate the benthic population over the entire area.

Sampling programs were modified during 1962, 1963, and 1964 to gather more information on the specific areas of interest, namely the Rappahannock Shoal Channel area and the spoil disposal area. A more detailed description of the techniques employed is included in each section.

VIRGINIA INSTITUTE OF MARINE SCIENCE

Participating Scientific Personnel

Morris L. Brehmer, Ph.D.--Senior Marine Scientist

Maynard M. Nichols, Ph.D.--In Charge, Geological Studies

Marvin L. Wass, Ph.D.--In Charge, Biological Studies

P. Wyman Harrison, Ph.D.--Geological Studies

Neil Hulings, Ph.D.--Geological Studies

Wesley Batten, M.S.--Geological Studies

David K. Young, M.S.--Geochemical Studies

John C. McCain, M.S.--Biological Studies

James B. Feeley, B.A.--Biological Studies

James A. Kerwin, M.S.--Biological Studies

Donald E. Keith, M.S.--Biological Studies

Richard B. Stone, M.S.--Biological Studies

Richard J. Hochban, Vessel Captain, R/V PATHFINDER

George Snow, Vessel Captain, R/V LANGLEY

HYDROGRAPHIC AND GEOLOGIC STUDIES

HYDROGRAPHIC AND GEOLOGIC STUDIES

This section of the report covers the water and sediment characteristics, including the distribution of chemical and physical properties. The information is of value in identifying spoil, tracing its redistribution, and in establishing the kind of substrate in which bottom-dwelling animals live. Prior to this study, little was known about the character of sediments on the floor of Chesapeake Bay except for several reconnaissance investigations. In the early 1950's Ryan (1953), of the Chesapeake Bay Institute, carried out a bay-wide survey of sediment distributions, and another worker, Powers (1954), reported on the diagenesis of clay in the bay. More recently Biggs (1967) investigated chemical properties of sediments in the central bay off Solomons, Maryland.

HYDROGRAPHY

Chemical and physical characteristics of the water are of importance in controlling the survival and repopulation of organisms. In the study area, water properties vary both tidally and daily as well as seasonally. The temperature ranges from an average of 3.5°C in winter to 26.5°C in summer. Mean water salinity varies from 13 ppt in spring to 20 ppt in fall (Stroup and Lynn, 1963). Furthermore, salinity is about 3 ppt higher on the east side of the bay than on the west side. This feature may be related to the greater fresh water inflow from rivers, as the Potomac and Rappahannock, along the western shore. Inasmuch as this trend is characteristic of many estuaries, the feature is probably due to the effect of the earth's rotation in which more dense water is deflected to the right (viewed upstream). Salinity also increases by 3 to 6 ppt with depth, and vertical distributions exhibit moderate

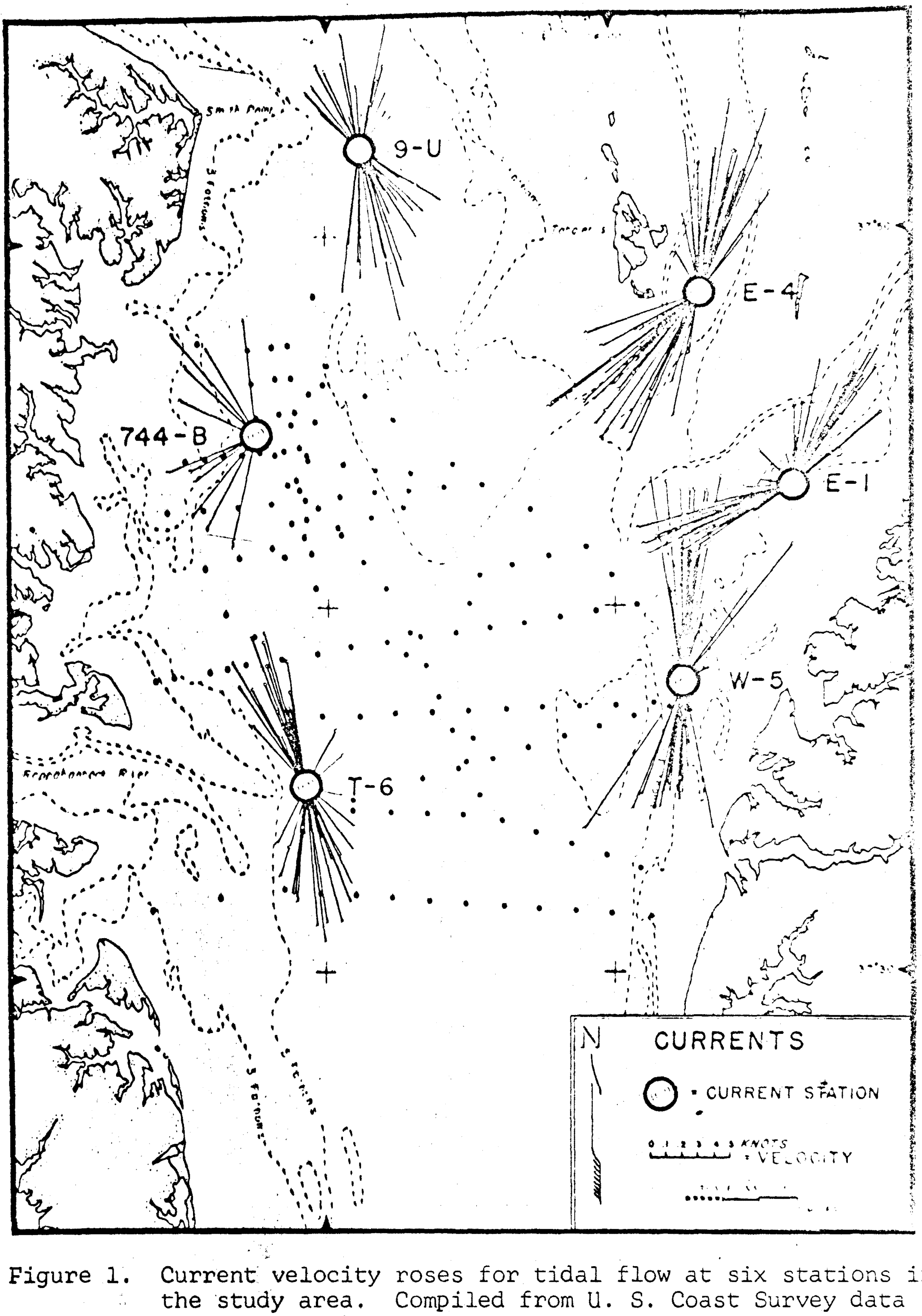
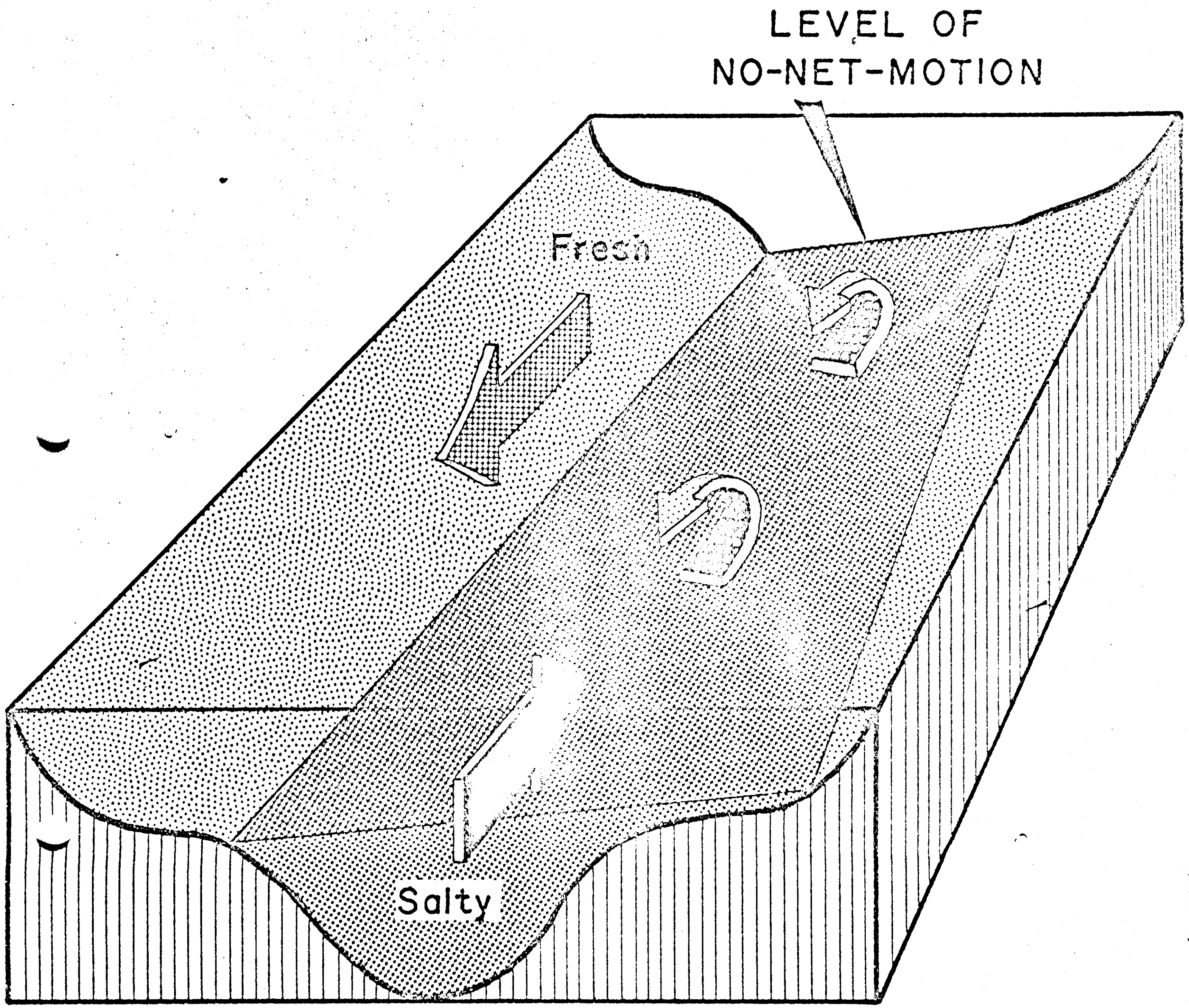


Figure 1. Current velocity roses for tidal flow at six stations in the study area. Compiled from U. S. Coast Survey data (Haight, 1930).

stratification at mid-depth. The average salinity distribution is the result of a balance between the advective flow, from the lower to upper estuarine layer, and the turbulent mixing by tidal action (Pritchard, 1952).

The tide is an important ecological factor because it is partly responsible for fluctuations of salinity, temperature, and other parameters. In the study area the mean tidal range is relatively small--only 1.4 feet; time-height curves are either slightly mixed or of the semi-diurnal type (Hicks, 1964). Current velocities, as occasioned by the tide, vary from nearly zero at slack water to a maximum of 1.2 knots. A summary of preliminary current velocity measurements made by the U. S. Coast and Geodetic Survey (Haight, 1930) is shown in Figure 1. These data consist of short period pole measurements; long period observations with Roberts Meters, such as have been accomplished in adjacent areas north and south, have not been carried out in this area. The Figure shows that velocities are slightly higher on the eastern side of the bay. At stations E-1 and E-4 (Figure 1) flow directions suggest the influence of bottom configuration, inasmuch as they are directed parallel to the bottom contours of the channel.

Although extensive current observations have not been made in the area, it may be inferred, from the salinity structure as well as analysis of long-term current data in nearby estuaries, that a typical net two-way estuarine flow persists in the study area. The chief features of this mechanism are diagrammatically shown in Figure 2. When the tidal flow is averaged over many tidal cycles, there is a net non-tidal circulation in which the upper layer of relatively fresh water moves seaward, whereas the lower layer of more salty water moves headward. The boundary between the upper and lower layer, called the level of no-net motion, is



TYPE B - HORIZONTAL BOUNDARY

Figure 2. Schematic diagram of ideal estuarine circulation. View upstream; arrows represent direction of net flow; curled arrows upward mixing.

gently inclined upward toward the right side of the estuary. This trend reflects the effect of the earth's rotation (Pritchard, 1954). Since the salinity in any selected segment of the upper layer remains at the same level over an annual period, there must be a movement of salty water from the lower layer into the upper layer to maintain the salinity distribution. This upward movement, represented by curled arrows in Figure 2, is generally most active in the upper estuary. Tidal currents supply the energy for the vertical, as well as horizontal, mixing (Pritchard, 1954).

According to this scheme, spoil that settles to the bottom in deeper parts of middle Chesapeake Bay, in the average, will be transported upstream rather than downstream. If tidal flow as well as net flow are sufficiently strong, the spoil will eventually accumulate near the head of the bay; but where flow and turbulence are diminished, as in certain deeper parts of the bay, the spoil would be expected to partly settle out in these areas.

The concentrations of suspended material, or "turbidity" of bay water, vary with river inflow and with wind-induced wave mixing or tidal agitation of bottom materials. Concentrations in the study area may be expected to range from 1 to 5 mg/l (Stroup and Wood, 1966; Bond and Meade, 1966). The concentrations are part of a bay-wide increase with distance from the mouth to the head. The upstream increase reflects the river source at the head of the bay in addition to progressive dilution by water of low sediment concentration moving up the bay from the mouth in the lower layer. Maximum turbidity occurs in spring, a time when river inflow, production of organic matter, and winds are all high. Minimum turbidity occurs in fall (Burt, 1955).

Water in mid-Chesapeake Bay is nearly saturated with dissolved oxygen most of the year except in summer. During this season, water beneath the halocline (below about 40 feet) may become completely devoid of oxygen, leading to death or migration of organisms and black-colored anaerobic sediments. This condition is related to prevailing high summer temperatures, the absence of strong winds and the intensity of stratification which may develop after hurricanes deposit heavy rains over the area. Details of the phenomenon and its consequences are given by McHugh (1967) and Biggs (1967).

SEDIMENT SAMPLING

Over 128 stations were established across middle Chesapeake Bay in the area of the dredged channel and disposal ground, between latitudes 37°30'N and 37°50'N. The plan of sampling is presented in Figure 3. Samples were collected during a series of more than five cruises during the period June 1961 and April 1963. A number of stations were reoccupied at different times to examine changes that may have occurred, as well as to resample the sediment for different analyses.

The bottom samples were taken with either a modified gravity-type corer of 1.5-2 inch diameter and 30-125 pounds, or with a Petersen grab, having a 1/15 square meter area. Gravity cores up to 34 inches in length were obtained and cores were susceptible to compaction of 25 to 50 per cent below a depth of about 6 inches, the compaction varying with sediment type and the diameter of the coring tube.

In the field, fresh cores were split and sections along the core length were sampled for grain size analyses and geochemical determinations. In addition, minor sediment structures were observed, color was determined using Munsell color charts, and pH and Eh were measured with a Model G Beckman pH meter.

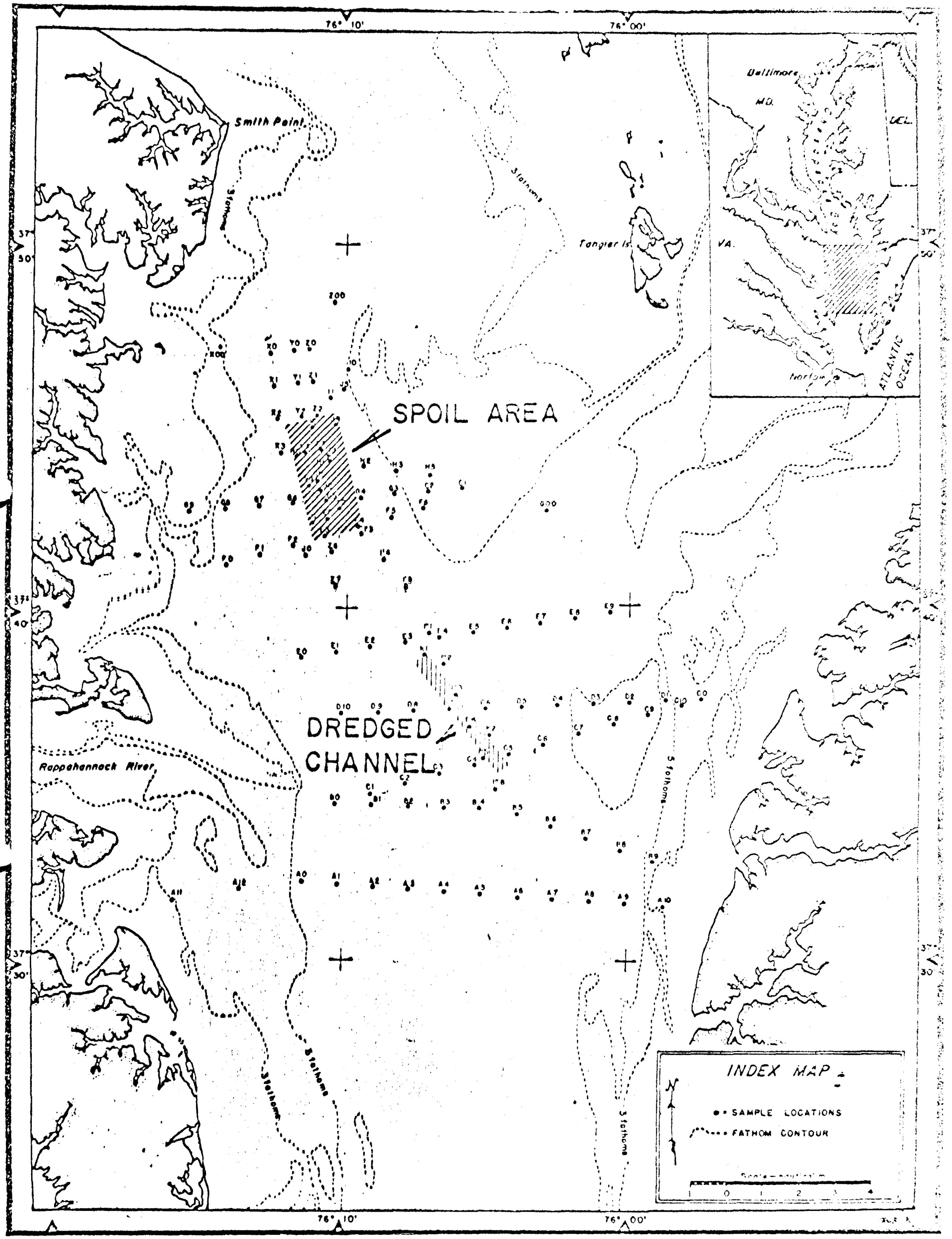


Figure 3. Index map to study area and station locations.

GRAIN SIZE ANALYSES

Grain size distributions were made on the top 5 inches of split core sediment. Samples were initially washed of salts, dried and the total weight determined. Samples were then dispersed in a 10 per cent solution of Calgon and mixed for 5-10 minutes. The coarse fraction (sediment with a size greater than 62 μ) was sieved into five fractions, whereas the fine fraction (less than 62 μ) was further analyzed by the pipette method essentially as described by Krumbein and Pettijohn (1938).

Designations of "sediment types" are based on comparative ratios between sand, silt and clay (Shepard, 1954), where sand is composed of particles $>$ 0.062 mm (4 Ø) in intermediate diameter, silt is 0.062 to 0.004 mm (4 to 8 Ø), and clay particles are less than 0.004 mm (8 Ø). The relative percentages of these three textural grades and the corresponding sediment type were determined for each sample by plotting the ratios on a triangular diagram like that of Figure 4A.

The two statistical measures of the size distributions reported are mean size and sorting. Mean size (M_z) was determined from cumulative curves of size and the formula

$$M_z = \frac{\phi_5 + 2\,\phi_{16} + 4\,\phi_{50} + 2\,\phi_{84} + \phi_{95}}{10}.$$

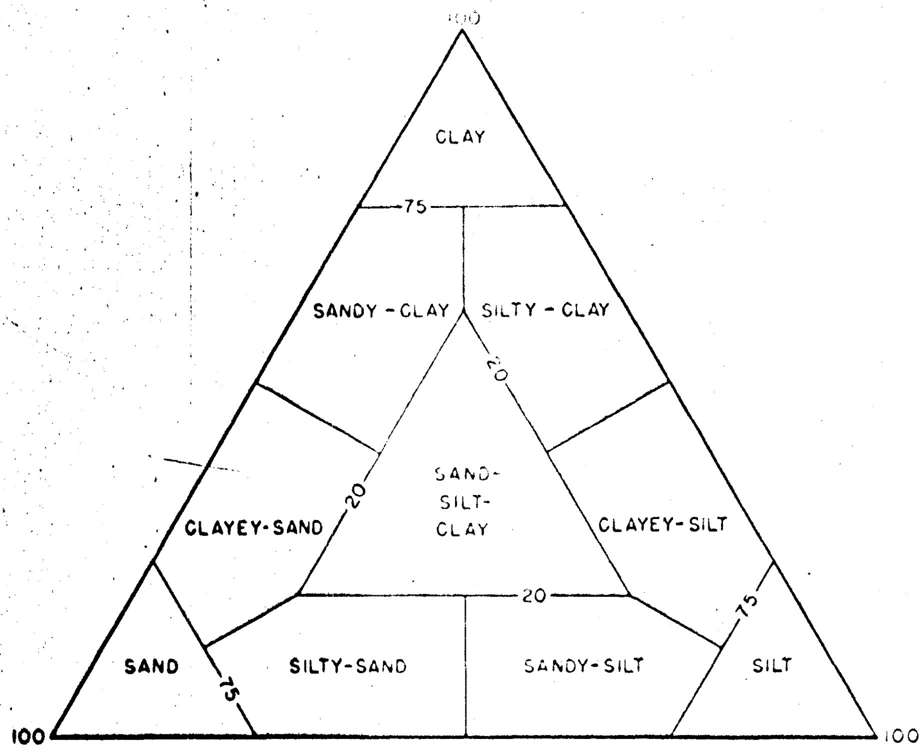
Phi (Ø) is a $\log_2$ transformation (Krumbein, 1936) from millimeters (arithmetic interval) to phi units (geometric interval or logarithmic scale). Krumbein's transformation is derived from the relationship

$$D = 2^{-\phi}$$

$$\log_{10} D = -0.30103\ \phi$$

where D is the diameter in millimeters and Ø is the equivalent logarithmic value of the phi scale.

A



B

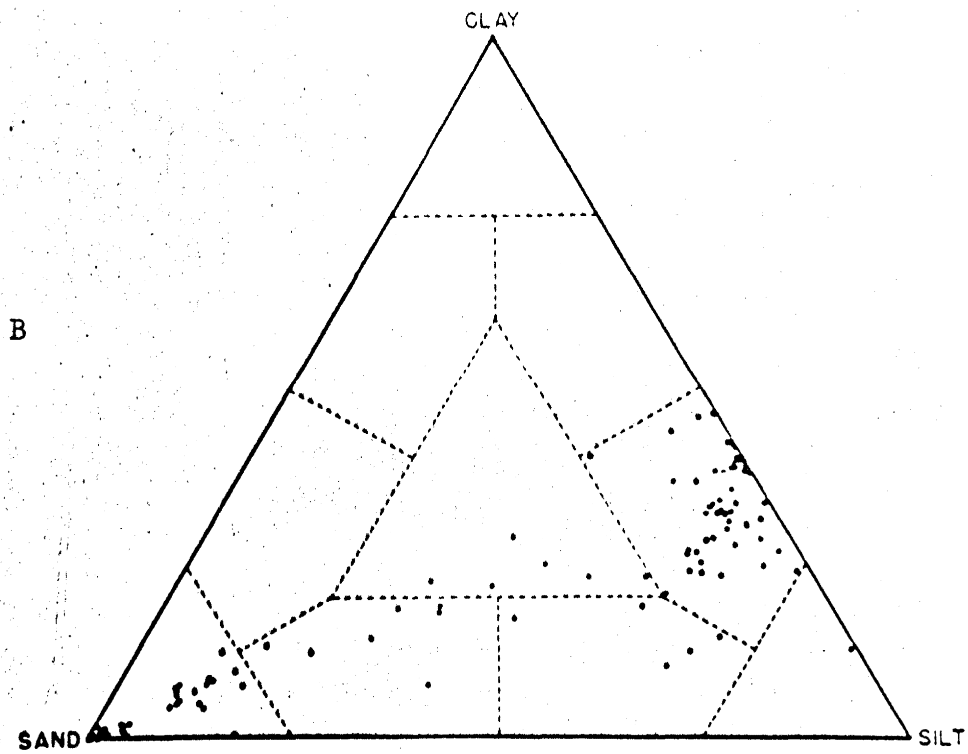


Figure 4A. Sand-silt-clay triangle with class notations; after Shepard, 1954. (Upper)

Figure 4B. Plot of corresponding sand-silt-clay ratios for samples in the study area. (Lower)

Sorting was determined according to Folk and Ward's (1967) relationship termed "inclusive graphic standard deviation":

$$I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6}.$$

The following verbal scale was proposed by Folk and Ward for the computed values, and these terms are used in column 10 of Table 2:

I:	<0.35	"very well sorted"
	0.35 - 0.50	"well sorted"
	0.50 - 1.00	"moderately sorted"
	1.00 - 2.00	"poorly sorted"
	2.00 - 4.00	"very poorly sorted"
	>4.00	"extremely poorly sorted"

In addition to using textural nomenclature, the modal class or predominant fraction of each sample was determined and its horizontal distribution charted. Although the mode varies somewhat with textural distribution, it is a useful expression to substantiate the transitional nature of bottom sediments. A limitation of this form of classification is indicated by the fact that bimodal or polymodal sediments are not truly represented. However, this limitation is offset by the statistical measures of the frequency distribution.

GRAIN SIZE DISTRIBUTION

The results of grain size, analyzed by pipette and sieve, have been utilized to classify the sediments on the basis of the relative proportions of sand, silt and clay according to the classification of Shepard (1954), and to chart the distribution of modal classes.

When the grain size analyses are plotted on a triangle diagram (Figure 4B), two main textural groups are evident. The first group consists mainly of sand with or without minor amounts of silt and clay. The second group consists chiefly of clayey silt with small proportions

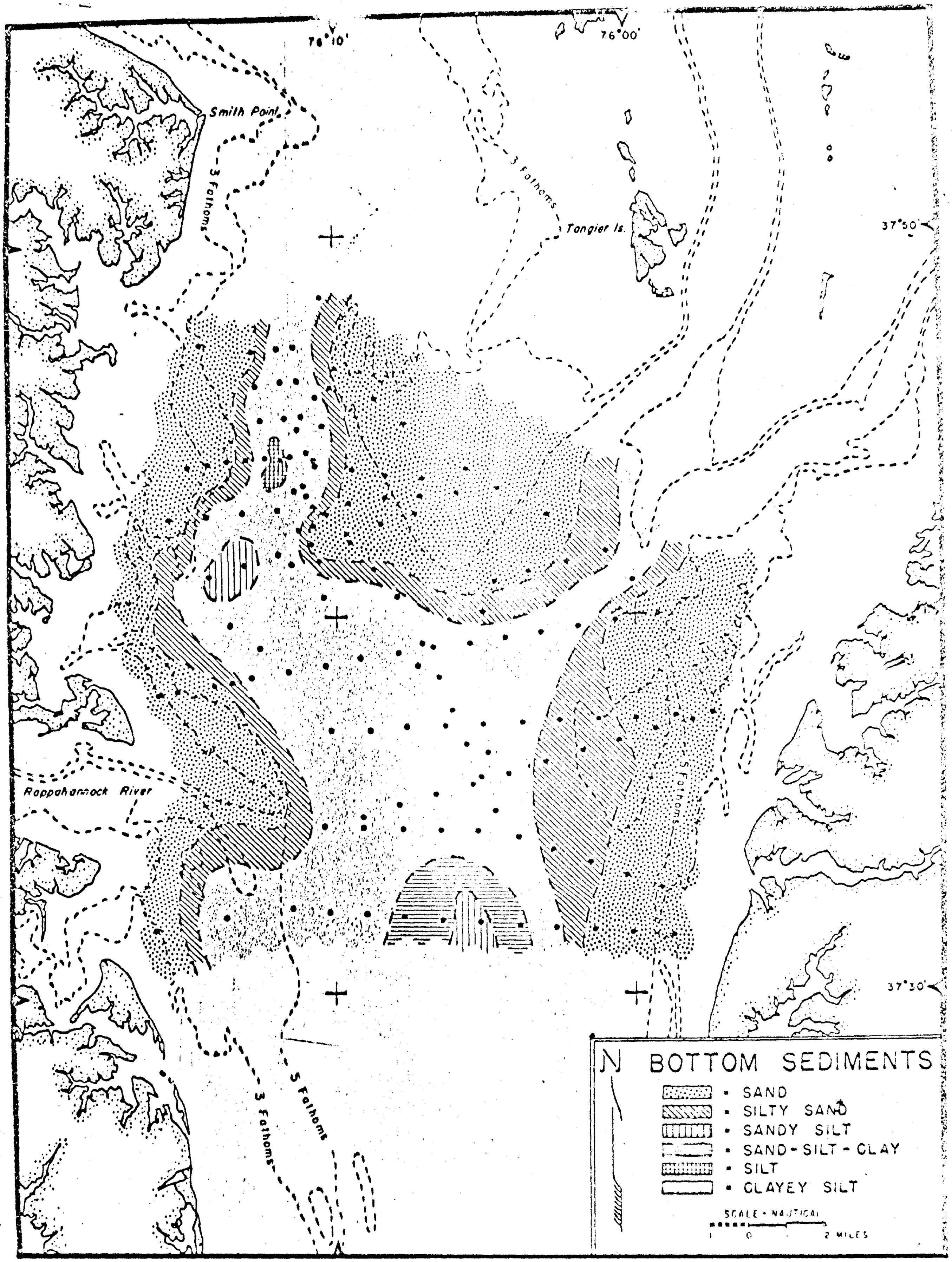


Figure 5. Distribution of sediment types in the study area, based on Shepard, 1954.

of sand. Scattered between these two main groups are samples consisting of silty sand and, locally, sandy silt or sand-silt-clay. Figure 5 shows the areal distribution of grain size for the same sampled plotted in the triangle diagrams. Table 1 lists values of the size analyses. The two main groups fall into a pattern which approximately corresponds to the bathymetry of the bay floor. Sand covers most of the shoals, less than about 5 fathoms (30 feet), whereas clayey silt covers a wide area of the relatively flat bay floor at depths greater than 5 fathoms (30 feet). Silty sand lies in a narrow zone between the sand and clayey silt at intermediate depths. The Rappahannock Shoal channel is cut into clayey silt and the spoil was dumped in an area also consisting of clayey silt.

The distribution of modal class or predominant fraction is presented in Figure 6. In general, the finest material (silt) covers deeper parts of the bay floor, whereas the coarsest material (fine or medium-grained sand) occurs on the shoals. Locally, coarse sand is present on the shoals off the Rappahannock River mouth and fine sand is present on the bay floor in the south central part of the area.

The sand on the shoals is most probably derived by erosion of the shore banks or the nearshore bottom. Although detailed surveys of shore erosion have not been undertaken, comparison of shoreline positions on U. S. Coast Survey boat sheets indicates a substantial shore recession at individual locations. For example, at Windmill Point the shoreline has retreated more than one-half mile during a 100-year period. In a study of erosion and sedimentation near the mouth of the Choptank River, situated north of the present study area, Jordan (1961) reports that broad erosional terraces have formed generally at about the 6-foot depth. Further, in some places, erosion was apparently effective down to 14

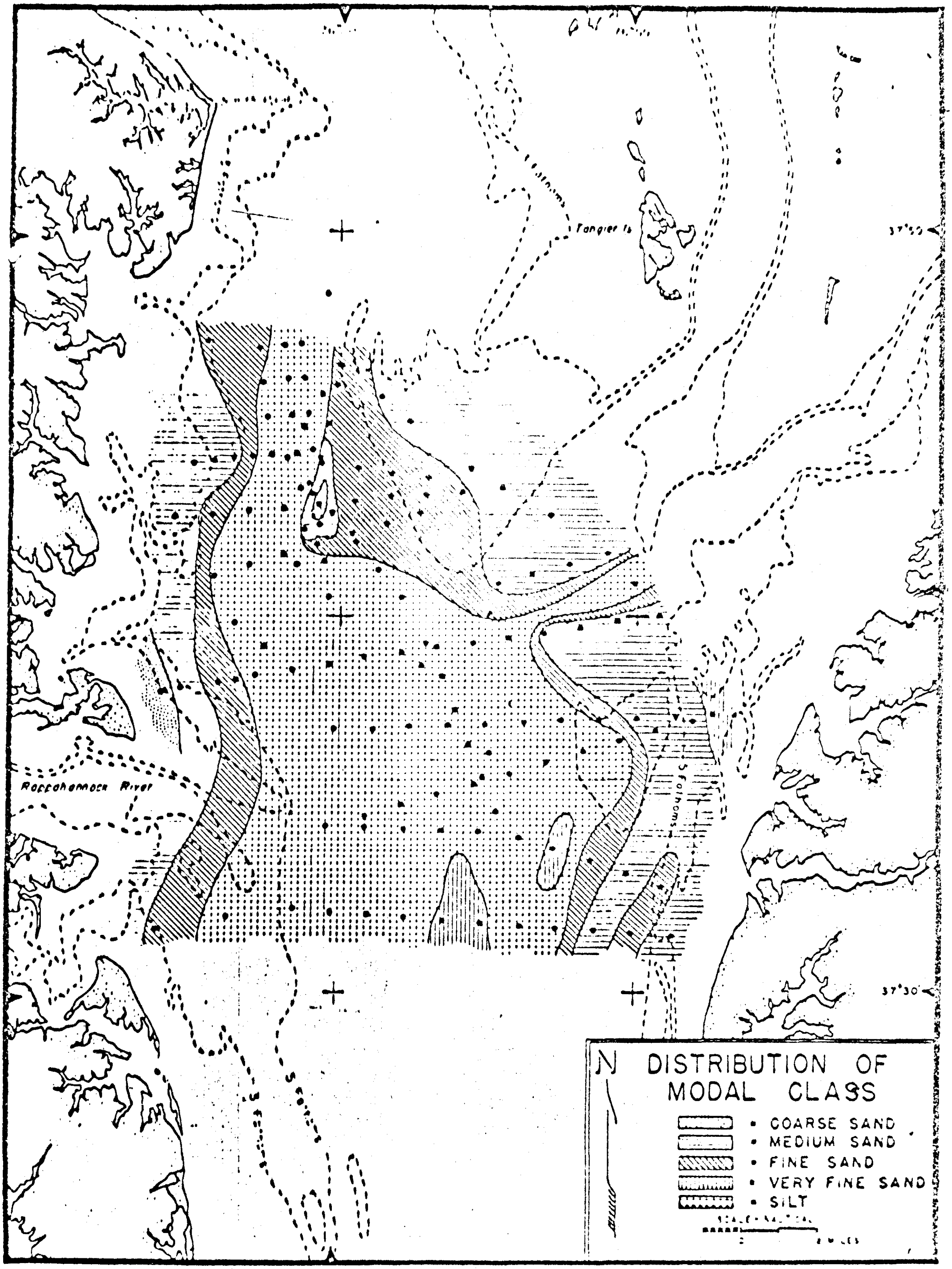


Figure 6. Distribution of modal class in the study area.

feet. In the eastern part of the study area at about the 30-foot depth (C8-C10), iron-stained sand on the bay floor suggests that older deposits are exposed by tide or wave action. Sand on the shoals may also represent lag deposits produced by winnowing of wave action. This process removes fine-grained sediment (clay and silt) from the shoals and carries it elsewhere. Similarly, wave agitation acting with tidal currents deters settling and deposition of fine-grained material on the shoals. The zone of silty sand adjacent to the shoals may be a product of infrequent mixing of material winnowed from the shoals with sand which is indigenous to the shoals.

The source of the fine-grained clayey silt on the bay floor is uncertain. It may be derived from either upstream or downstream areas, and it may also represent an admixture of two sources. Inasmuch as the greater part of the bay floor below about the 30-foot depth is swept by net upstream-borne currents, a seaward source is favored. On the other hand, Nelson (1959), in a study of clay sediment in the Rappahannock River, indicated that most sediment in the estuary is of river origin and is ultimately swept into the sea.

During the course of this study, grain size was determined on different sets of samples from the same stations for the purpose of examining grain size variations in relation to different sediment properties. In particular, the grain size of 55 samples was analyzed by hydrometer to evaluate "mass" properties. These analyses indicated that the sediments were generally coarser (more sandy) than those determined initially by pipette. The differences are expectable inasmuch as different methods of analysis and preparation were used. A reanalysis of selected fresh samples by hydrometer gave results similar to those of the initial pipette analysis reported above. Taken as a whole, the pipette analyses give the best coverage of size distribution and are in agreement with those of Ryan (1953) and Froehling and Robertson, Inc., consulting engineers.

SEDIMENT CHEMISTRY

Sample Preparation

Frozen cores were sectioned and about 10 g of sample was removed at 3.9- and 7.8-inch (10-20 cm) intervals along the length. Sandy cores were sampled only at the surface and at the bottom. The samples were then divided into two portions and either dried without treatment or dried after being washed with distilled water. The two portions were ground, redried and stored in desiccators. A flow chart of the analytical procedures used for analyses is diagramed in Figure 7.

The procedure for the rapid analysis of silicate rock developed at the U. S. Geological Survey by Shapiro and Brannock (1956) provided a basis for determination of sodium, potassium, iron, magnesium, and calcium which was more rapid, simple, and direct that the classical methods of quantitative separations.

The complete digestion of the sediment samples was performed with modifications from a variety of basic methods (Shapiro and Brannock, 1956; Fitch and Rosenfeld, undated; Jackson, 1958; and Carey and Jackson, 1953).

It was desirable to minimize those variations due to differences in the amount of interstitial or pore water contained by each sediment type. Therefore, only washed samples were used.

Approximately 1 g of washed sediment was weighed in a 30 ml platinum crucible. Following a moistening of the sediment with distilled water, 15 ml conc. HF, 2 ml conc. HNO_3, and 10 ml conc. H_2SO_4 were added. The crucible was placed in a sand bath having a temperature of 200° to 225°C,

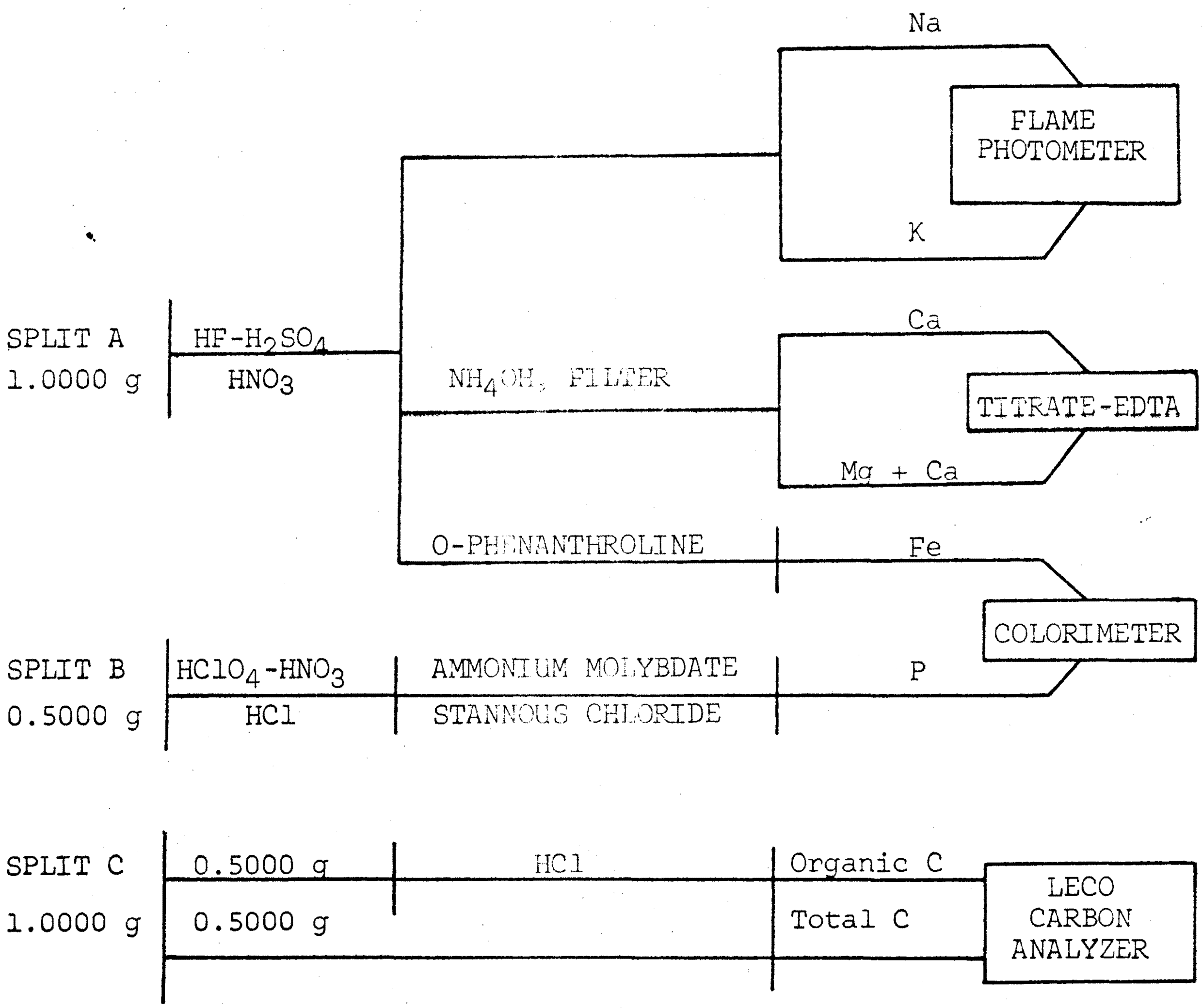


Figure 7. Flow diagram of analytical procedures.

and the contents were digested for 8 to 10 hours. The temperature was then raised to 325° to 350°C, and the solution was evaporated to a low volume.

The contents were transferred to a 250 ml Vycor beaker containing 100 ml distilled water and 2 ml HCl. This solution was diluted to 250 ml after having been boiled for several minutes to digest the remaining solids. Aliquots from this final solution were taken for the determinations of sodium, potassium, calcium, magnesium, and iron.

Sodium and potassium were determined by flame spectroscopy on a Beckman DU spectrophotometer using an oxy-acetylene mixture as fuel. Calcium and magnesium were analyzed by the Versene or EDTA (disodium dihydrogen ethylenediamine tetra acetic acid) titration procedure of Schqarzenbach and Biedermann (1948). Iron was determined colorimetrically after reduction by hydroxylamine hydrochloride and the formation of a stable orange-red complex with O-phenan-throline. Total phosphorus was analyzed colorimetrically, after oxidation with perchloric acid, using the ceruleomolybdic method of Deniges (1920). Total carbon was measured gasometrically with a Leco Carbon Analyzer. Procedural details are given by Young (1962).

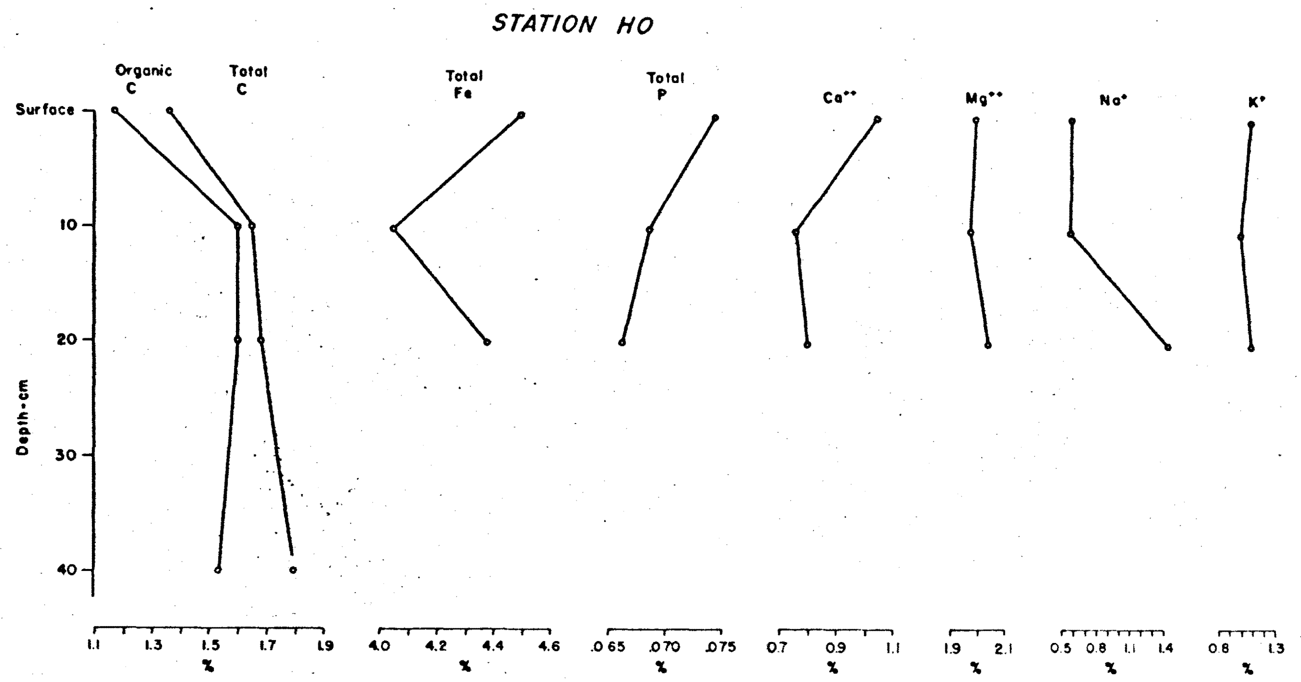
Results

The results of chemical analyses are listed in Table 2 and the depth variations for selected cores are diagramed in Figures 8, 9 and 10. All results are expressed in percentage of the sediment sample weight.

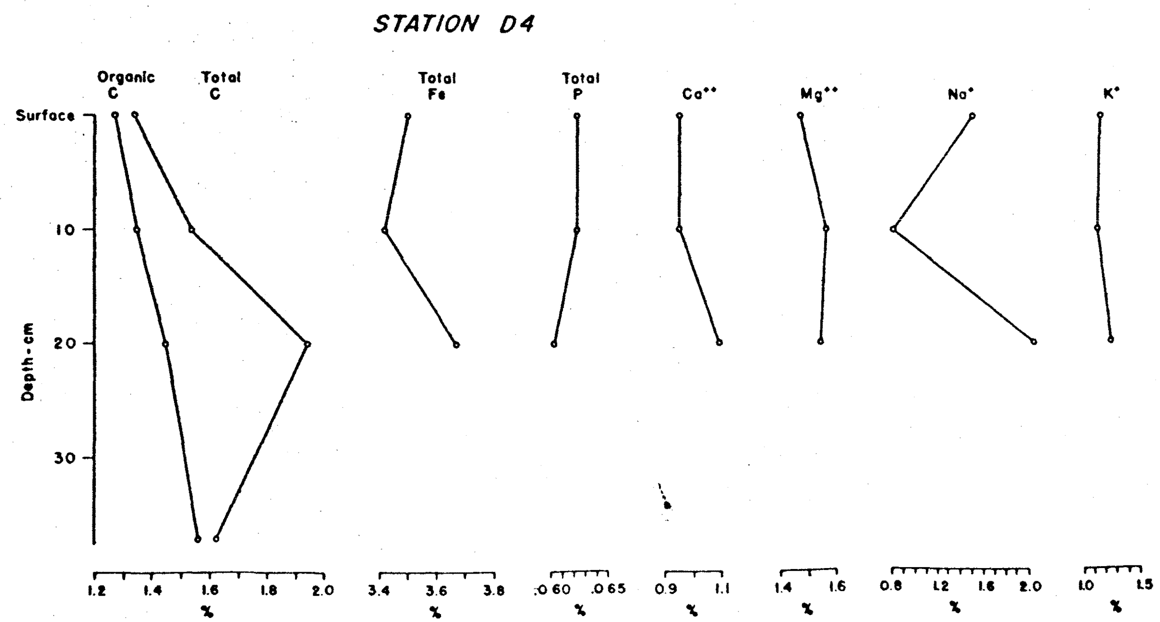
Carbon

Among the eighteen cores examined for carbon content, all but three had the highest organic carbon at a depth of 3.9 and 7.8 inches (10-20 cm). An increase of organic carbon below 7.8 inches (20 cm) was observed

Figure 8. Variations in organic carbon, total carbon, total iron, total phosphorus, calcium, magnesium, sodium, and potassium with depth of sediment at stations HO and D4 of silt and silty sand sediment types.



STATION HO
Organic C
Total C
Total Fe
Total P
Ca++
Mg++
Na+
K+
Surface
10
20
30
40
Depth-cm
1.1 1.3 1.5 1.7 1.9
%
4.0 4.2 4.4 4.6
%
.065 .070 .075
%
0.7 0.9 1.1
%
1.9 2.1
%
0.5 0.8 1.1 1.4
%
0.8 1.3
%



STATION D4
Organic C
Total C
Total Fe
Total P
Ca++
Mg++
Na+
K+
Surface
10
20
30
Depth-cm
1.2 1.4 1.6 1.8 2.0
%
3.4 3.6 3.8
%
.060 .065
%
0.9 1.1
%
1.4 1.6
%
0.8 1.2 1.6 2.0
%
1.0 1.5
%

Figure 9. Variations in organic carbon, total carbon, total iron, total phosphorus, calcium, magnesium, sodium, and potassium with depth of sediment at station Z2 of a clayey silt sediment type.

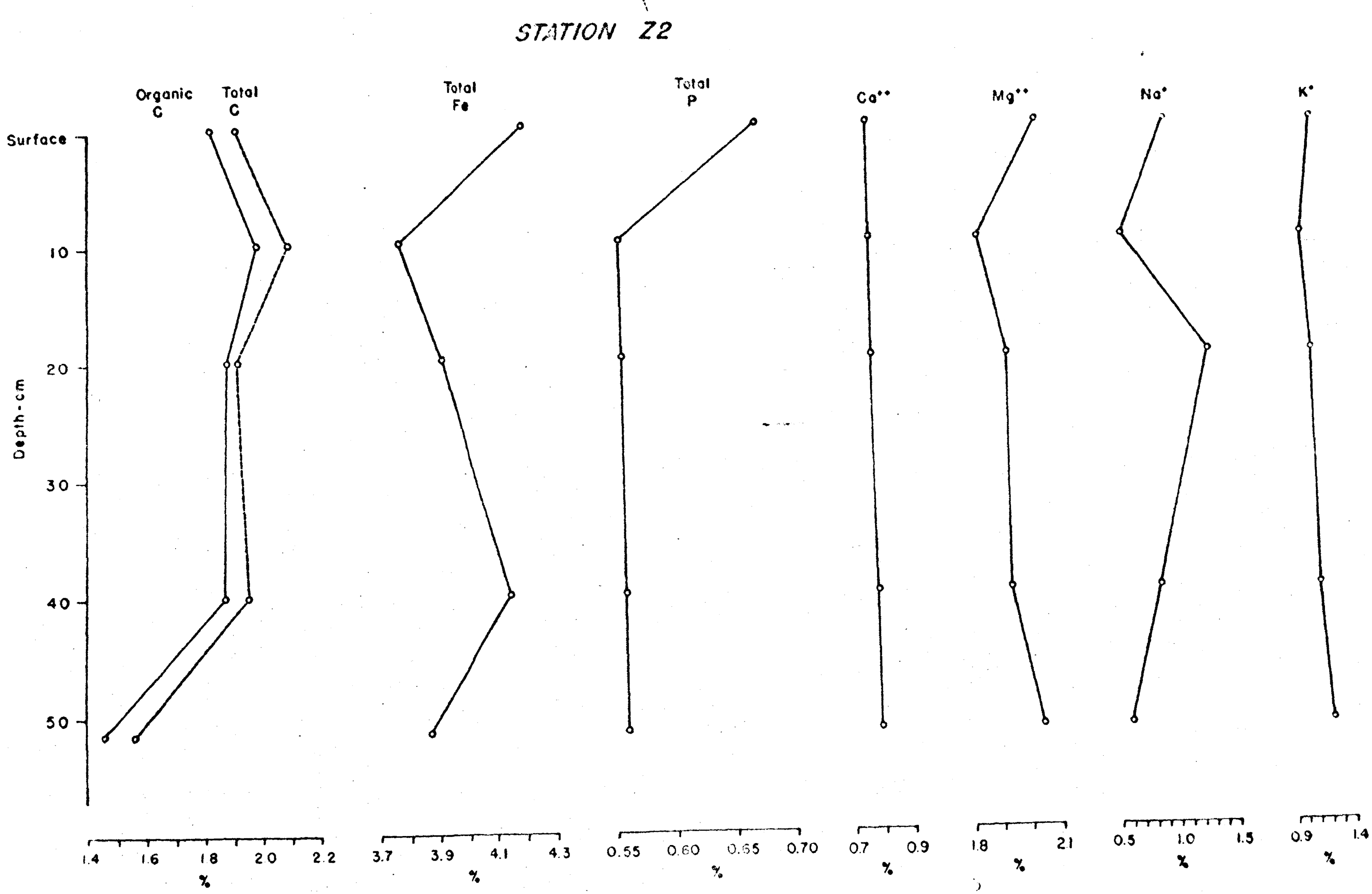
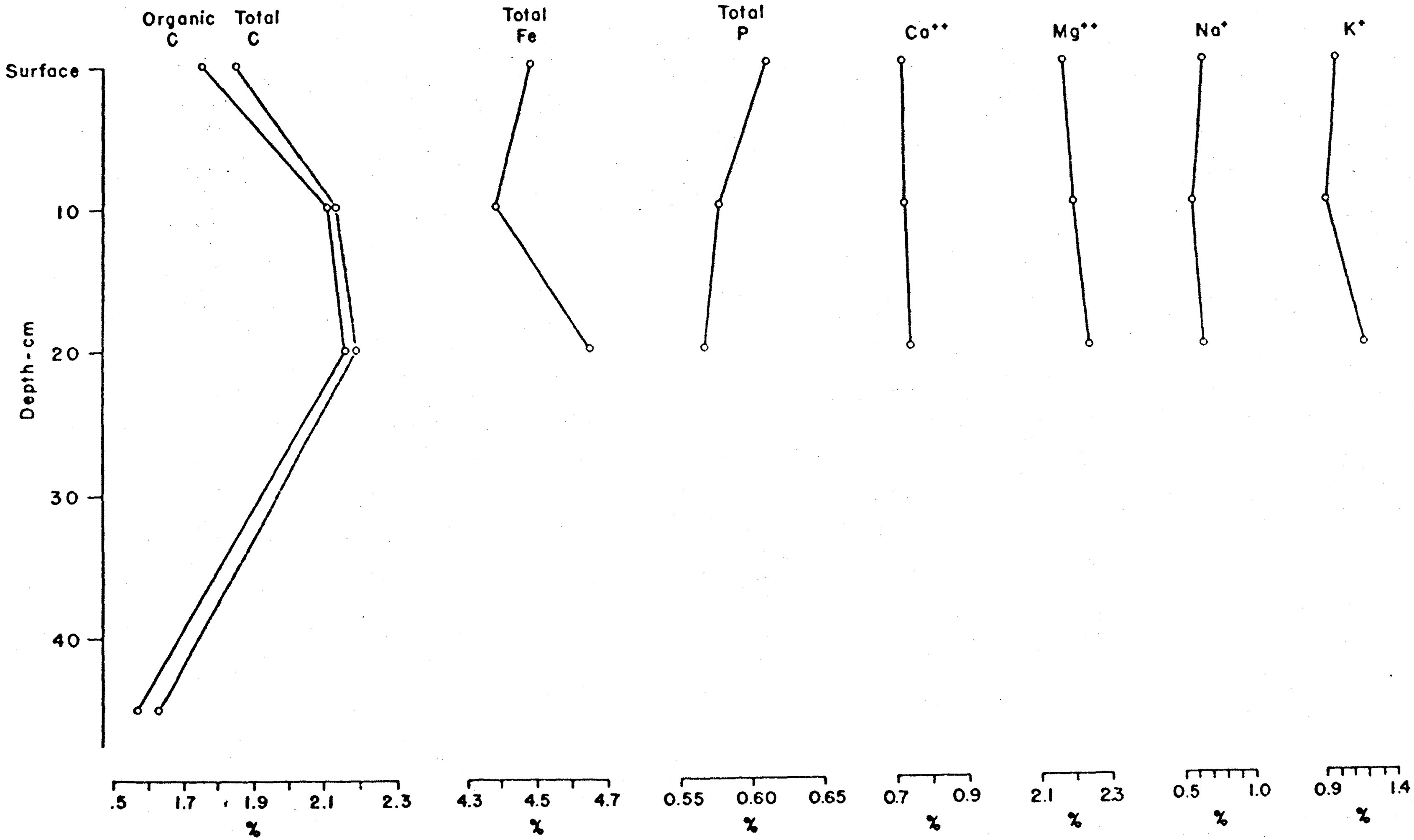

STATION Z2
Organic C
Total C
Total Fe
Total P
Ca++
Mg++
Na+
K+
Surface
10
20
30
40
50
Depth-cm
1.4
1.6
1.8
2.0
2.2
%
3.7
3.9
4.1
4.3
%
0.55
0.60
0.65
0.70
%
0.7
0.9
%
1.8
2.1
%
0.5
1.0
1.5
%
0.9
1.4
%

Figure 10. Variations in organic carbon, total carbon, total iron, total phosphorus, calcium, magnesium, sodium, and potassium with depth of sediment at station Z00 of a clayey silt sediment type.

STATION ZOO



Organic C
Total C
Total Fe
Total P
Ca++
Mg++
Na+
K+
Surface
10
20
30
40
Depth - cm
.5
1.7
1.9
2.1
2.3
%
4.3
4.5
4.7
%
0.55
0.60
0.65
%
0.7
0.9
%
2.1
2.3
%
0.5
1.0
%
0.9
1.4
%

in only one core. The highly variable inorganic carbon content of all sediments was probably due to shell concentrations.

The highest organic carbon values were found in the cores (Z00, Z2, F0, and G6) from the deep water area near the spoil disposal site. Organic carbon content was lowest in the cores of sand (X0, E7, and G8). The range of inorganic carbon content in the surface sediments was from 0.02% in a sand sample (X0) to 0.39% in a clayey silt sample (A0). Organic carbon content in the surface sediments varied from 0.15% in a sand sample (E7) to 2.01% in a clayey silt sample (G6).

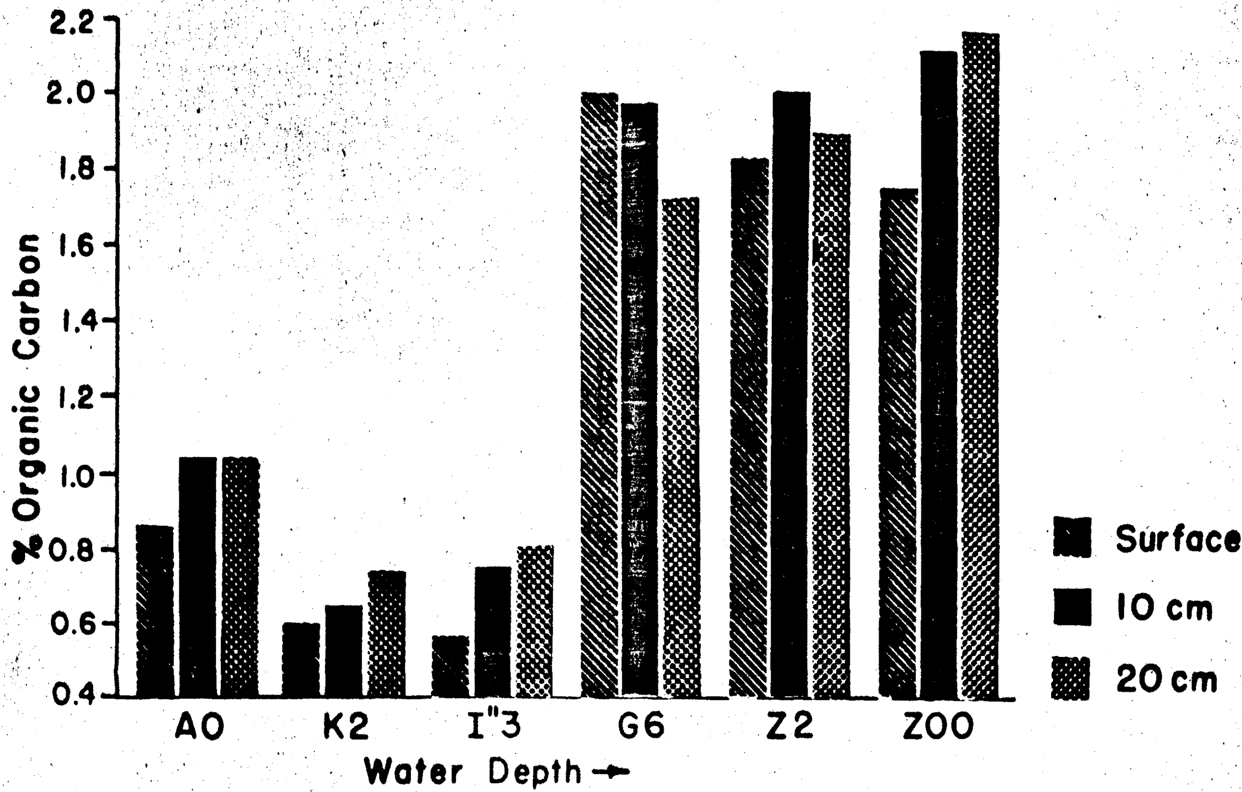
In general, fine-grained sediment had large amounts of carbon and coarse-grained sediment had smaller amounts. Similarly, lowest values occurred in sand on the shoals and highest values in clayey sediment in deep water; values of intermediate size and intermediate water depth varied widely. Therefore, a relation of carbon with size and water depth is evident only at extreme size and depths. The contrasting carbon values at different depths may be attributed to a relatively high rate of oxidation on the shoals owing to large sediment size and better circulation, chiefly wave action, which deters deposition of fine-grained sediment, including organic detritus. During the summer an increasing oxygen depletion has been observed in the inflowing ocean water as it proceeds up the bay (Carpenter and Cargo, 1957). The movement of oceanic water up the deeper channels of Chesapeake Bay has been explained by Pritchard (1952). Oxygen measurements of the bottom waters in the survey area taken during July 1949 and 1950 (Hires, et al., 1963) did not show anaerobic conditions to exist, but a low oxygen measurement of 1.90 ml/l was obtained during July 1950. Similar measurements taken of the bottom water in the middle bay area showed extremely low oxygen conditions consistently during the same period. Therefore, the differences of organic carbon content in the sediments of Chesapeake Bay may reflect the degree of oxygenation of the overlying waters.

A high deposition of organic matter and a rapid accumulation rate of fine-grained inorganic material could account for the high amounts of organic carbon below the surface in the majority of the survey sediments. The reducing conditions (as indicated by Eh) within several centimeters of the surface in the deeper water sediments would stop aerobic oxidation of the organic carbon. Therefore, once buried, there would be a greater likelihood of the preservation of organic carbon in these sediments.

Iron

Eleven cores were examined for changes in total iron content with depth. Only two cores (HO and Z2) showed a higher total iron content at the surface than at greater depths. The distribution of iron with depth in the cores was similar to the distribution of organic carbon in many instances. A relationship between total iron and organic carbon was suggested by a comparison of similar sediment types (Figure 11). Total iron content in the surface sediments varied from 1.118% in a sand sample (E7) to 4.500% in clayey silt and silt samples (ZOO and HO).

The correlation found in this study between iron and organic carbon content with depth of sediment and with areal distribution reflects a similar finding by Rochford (1951) in Australian estuaries. Bass Becking and Moore (1959) also have shown direct relationships between iron and organic matter content in sediments and have theorized the existence of an "organo-iron" complex. The iron in the deep clayey sediments probably existed in the reduced or ferrous state, as indicated by the greenish-gray coloration of the cores.



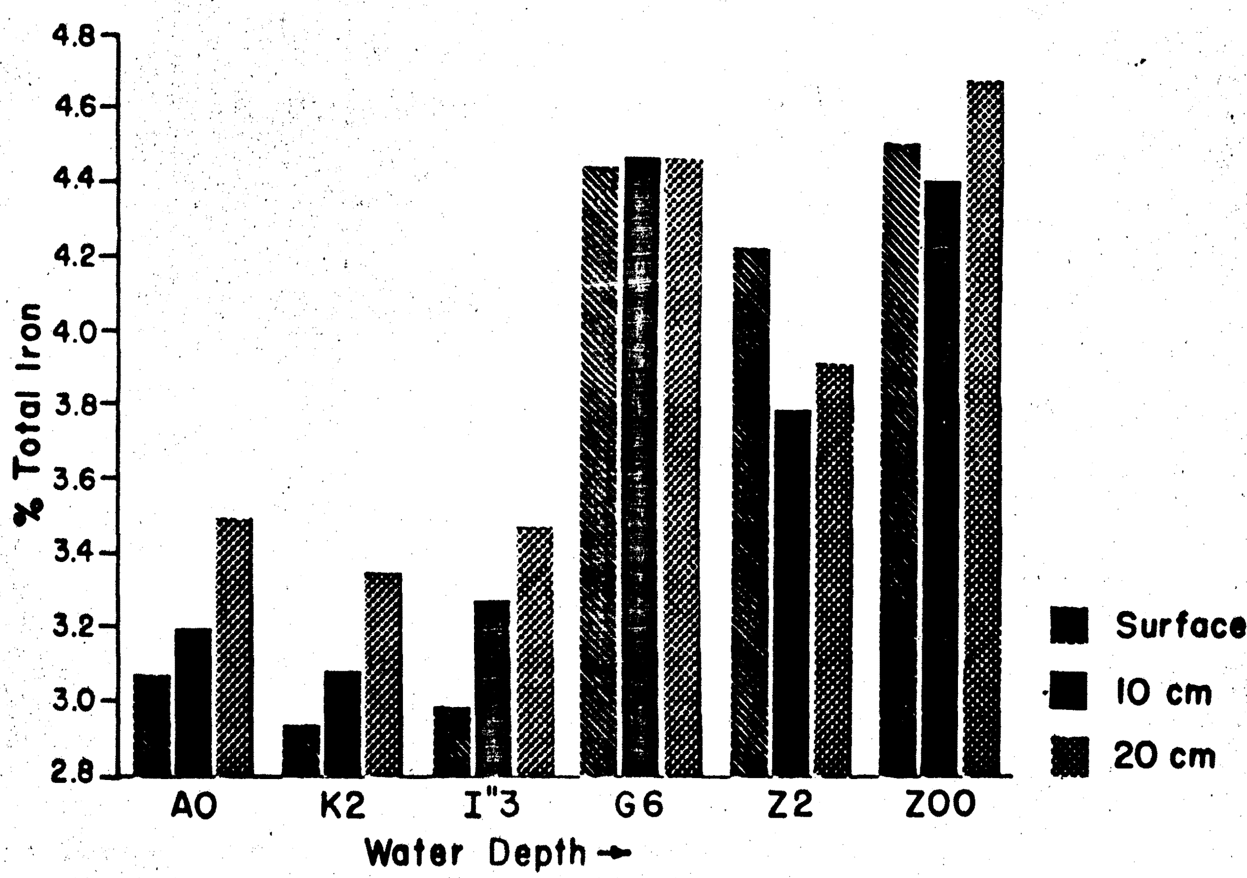


Figure 11. Comparison of total iron and organic carbon with depth of water and depth of core in sample stations AO, K2, I"3, G6, Z2, and ZOO of a clayey silt sediment type.

Phosphorus

Only the core from the dredged area (K2) contained highest phosphorus values at 3.9- and 7.8-inch (10-20 cm) depths. The other ten cores showed phosphorus contents to be higher in the surface sediments. No consistent relationship was found between total phosphorus content and depth of water, sediment type, or median size diameter of sediment. The sand samples (XO, E7, and G8) had the lowest phosphorus contents. The range of phosphorus content in the surface sediments was from 0.012% in a sand sample (E7) to 0.075% in a silt sample (HO).

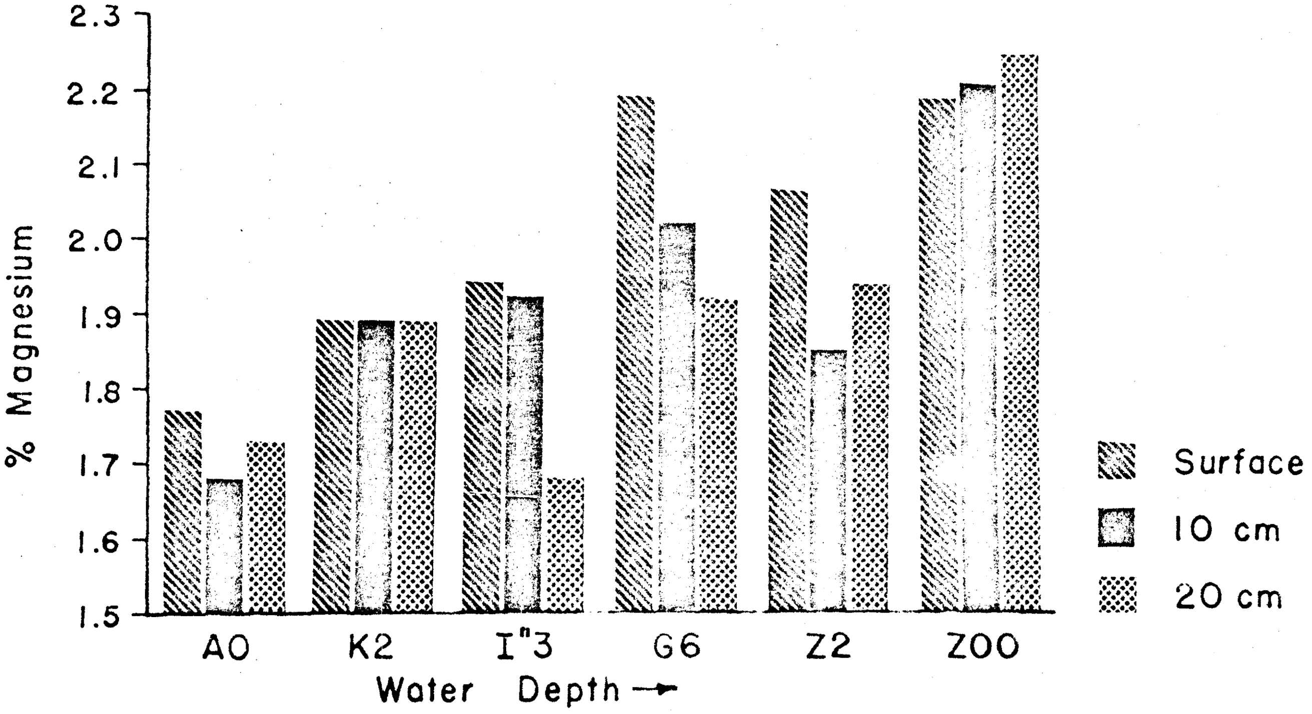
An indication of a typical aerobic hydrosol condition is shown by the high phosphorus content in the surface sediments of the undisturbed stations. The oxygenated water overlying the sediments in this area probably acts as a barrier to the removal of phosphorus ions into solution. The phosphorus may be evidence of either a large contribution by plankton detritus from the overlying water or a concentration by microbial activities in the sediment itself. The condition of phosphorus decreasing with increasing sediment depth, as found in this study, has been found in many marine, estuarine, and lacustrine studies (Moore, 1930; Rochford, 1951; Shepard and Moore, 1955; Mortimer, 1941).

Calcium and Magnesium

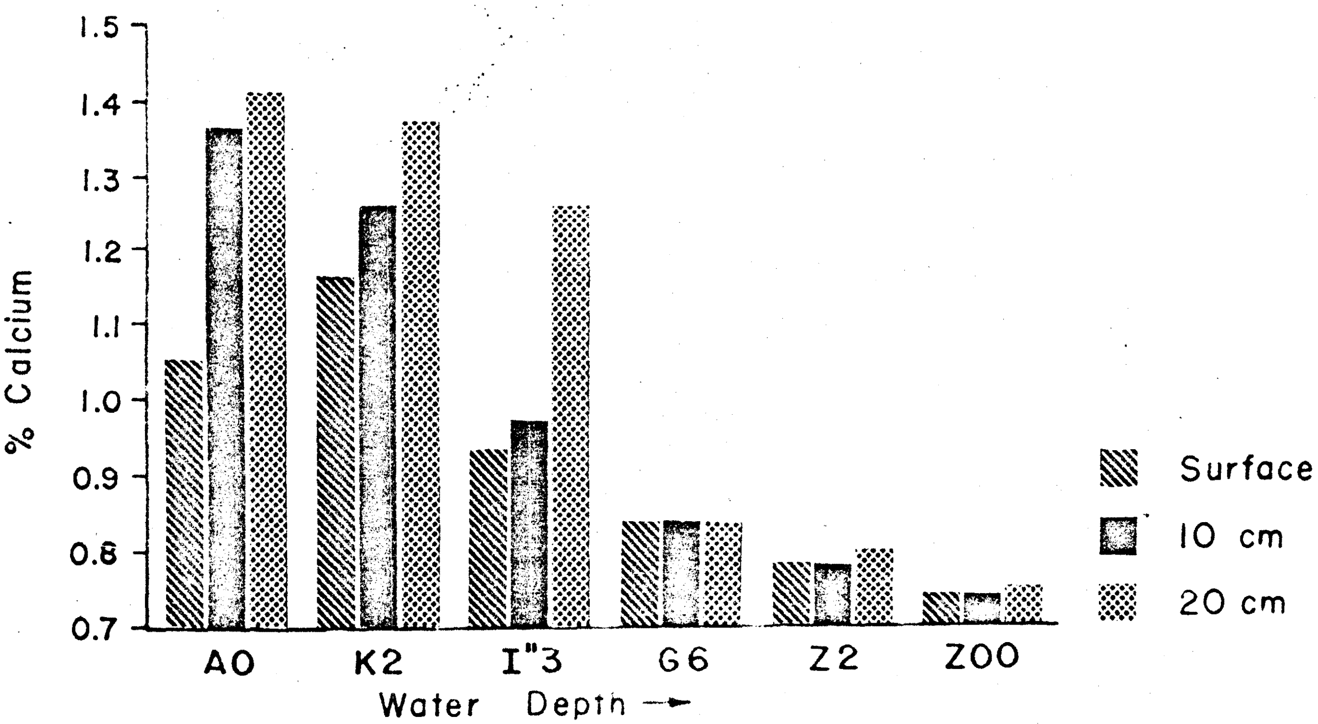
The calcium content decreased at 3.9- and 7.8-inch (10-29 cm) depths in only two (HO and A12) of the eleven cores analyzed. The magnesium content of the sediments did not reflect consistent trends with increasing core depth.

Magnesium was higher than calcium in all cores. An inverse relationship was indicated to exist between calcium and magnesium with increasing water depth (Figure 12). The sand samples (XO, E7, and G8)

Figure 12. Comparison of calcium and magnesium with depth of water and depth of core in sample stations AO, K2, I"3, G6, Z2, and ZOO of a clayey silt sediment type.



% Magnesium
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
AO
K2
I"3
G6
Z2
ZOO
Water Depth →
Surface
10 cm
20 cm



% Calcium
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
AO
K2
I"3
G6
Z2
ZOO
Water Depth →
Surface
10 cm
20 cm

exhibited the lowest calcium and magnesium contents. Calcium content in the surface sediments varied from 0.11% in a sand sample (G8) to 1.25% in a sand-silt-clay sample (A4). The range of magnesium content in the surface sediments was from 0.46% in a sand sample (E7) to 2.19% in a silty clay sample (ZOO).

The cation content of the sediments in the area may reflect the relative amounts of each cation adsorbed onto the mineral particles. In this study, in the comparison of similar sediment types, it is assumed that the differences in cation contents would be primarily due to the adsorbed ions. The greater percentage of magnesium in the survey sediments may be attributed to the higher amount of available magnesium cations rather than available calcium cations in sea water. Carpenter (1957) found a mean calcium-magnesium ratio of four to one in the lower Chesapeake Bay tributaries. This ratio is reversed in sea water, with the proportion of magnesium being approximately three times greater than calcium (Sverdrup et al., 1942). The increase in salinity with depth of water in the bay may explain the decrease of calcium and the increase of magnesium in the sediments with increasing water depth. Salinities of the bottom water in the area of the survey have been shown to be twice that of the surface water.

Sodium and Potassium

No definite trends were indicated in the sodium or potassium content of the sediments with either increasing core depth, water depth, sediment type, or median size diameter of sediment. Neither sodium nor potassium was consistently predominant. Potassium generally showed less variation within or between cores than sodium. Sodium content in the surface sediments varied from 0.220% in a sand sample (E7) to 2.745% in a clayey silt sample (AO). The range of potassium content in the surface sediments was from 0.384% in a sand sample (E7) to 1.175% in a silty clay sample (Z2).

The higher bonding energy of potassium with respect to sodium may explain the nearly equal ratio of sodium and potassium in the survey sediments. The ability of clay to take up potassium has been used as an explanation of the increase of sodium over potassium in the water from rivers to the ocean (Clarke, 1924).

pH and Eh

The hydrogen ion concentration (pH) of surface sediments ranged from 7.0-8.3 pH units, and with depth in individual cores the pH ranged from 6.8 to 8.3. The lowest pH was frequently found in the black portion of cores whereas the grey portion was characterized by increasing pH with increasing depth. In dredged material from the channel floor the pH ranged from 7.5 to 7.9 with depth in core K2 (Figure 13).

The oxidation-reduction potential (Eh) indicated the presence of reducing conditions below the upper one-half or more of brown-olive colored sediment. Grey sediments were generally negative but values varied wiely with depth in cores. Biggs (1967) discusses variations in Eh and pH that result from anaerobic conditions in deep water of mid-Chesapeake Bay.

Summary of Sediment Chemistry

Most of the clayey sediment on the mid-bay floor shows the effect of diagenetic change which follows deposition and subsequent burial. The bulk of most spoil, derived by cutting into natural bottom more than about 1 foot (0.3 m), would be expected to be grey-colored, with an intermediate organic carbon content of 0.5-1.0%, total iron content of

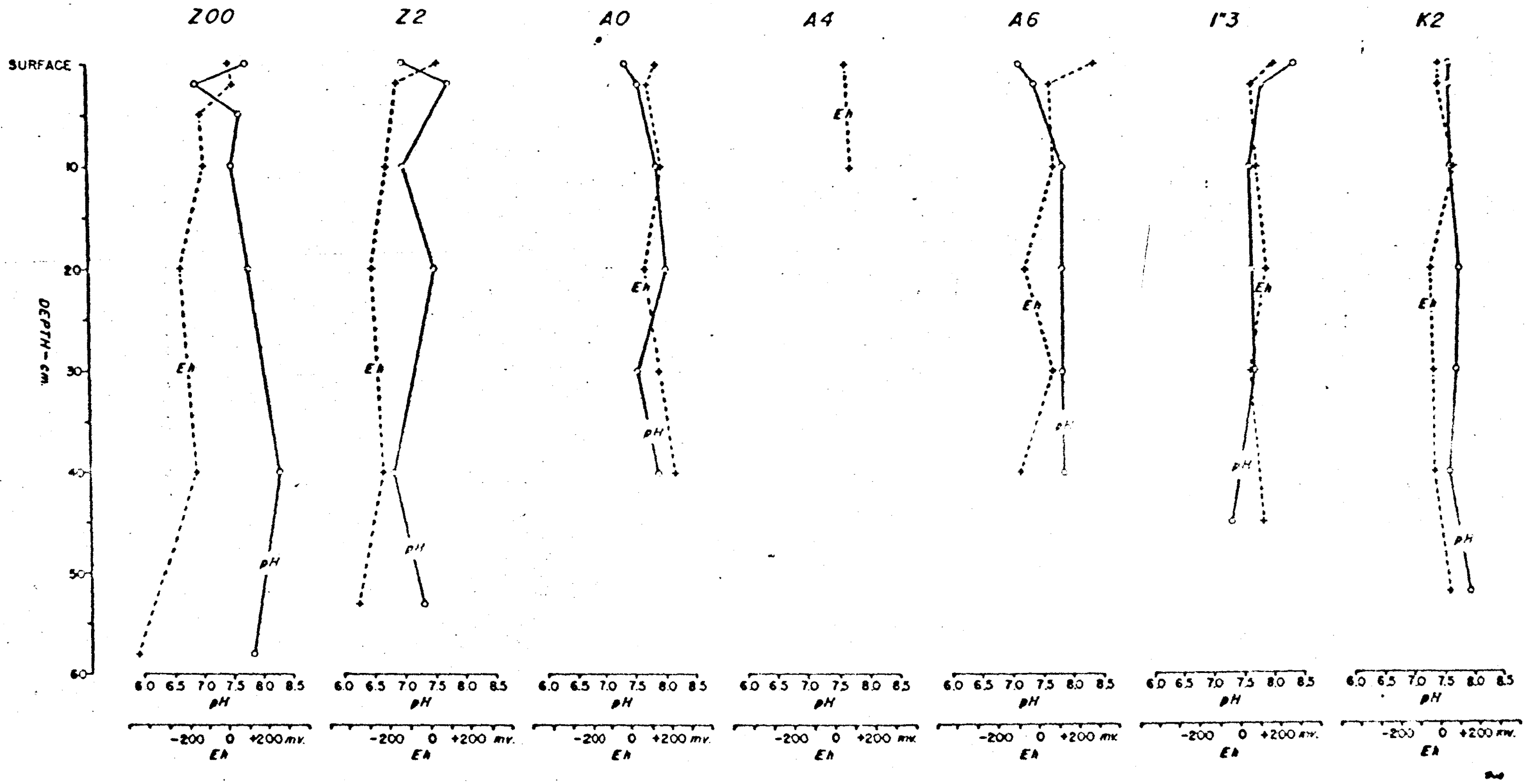


Figure 13- Eh and pH values with depth in sediments at stations Z00, Z2, A0, A4, A6, I"3 and K2.

3.0-3.5%, total phosphorus of 0.05-0.07%, calcium averaging about 1.3%, and magnesium averaging about 1.7%. Carbonate would be very low--less than 0.20%--except when shells are present.

COLOR AND MINOR STRUCTURES

The upper one-half inch of sediment on the bay floor consists of brown to olive-colored mud. Beneath the surface layer muds are commonly black for a thickness of 1-4 inches (2.5-10 cm) and grey-colored at greater depth. Cores from the sandy shoals are usually grey-green for their entire length. Sediment on the dredged channel floor was grey-colored. Inasmuch as grey mud extends to considerable depth, the bulk of most dredged material would be expected to consist of grey-colored mud unless aerated for some length of time.

Although color changes are striking with depth in mud cores from the area, structures and laminations are absent. Most of the sediments are homogeneous except locally in the zone of silty sand where mottles of sand and burrowing structures are present. In the dredged channel as well as in the spoil area, "lumps" of relatively firm mud are characteristic.

Scattered shell layers composed of *Mulinia lateralis* were penetrated at about 20- to 30-inch (50-75 cm) depths in cores. The layers were about ½ to 2 inches (1-5 cm) thick and many specimens were articulated, indicating that the shells were in their position of growth. Living *Mulinia* are widespread throughout the Chesapeake region. The shell layers were frequently found by Biggs (1967) in central Chesapeake Bay of Maryland so that they may make up a characteristic material of spoil deposits in certain areas of Chesapeake Bay.

MINERALOGY

Clay Fraction

X-ray diffraction analyses were performed on oriented samples of the < 2 μ fractions of a series of selected samples from gravity cores. Glycolation of the samples was undertaken and semi-quantitative estimates of the amounts of the main constituents were made from the diffraction tracings by Dr. J. L. Harrison. The results, to parts-in-ten, of the clay-mineral portion of the clay-sized fraction indicate that the major clay-mineral components were illite, chlorite, and mixed-layer minerals. The illite and chlorite are reported to be very degraded and the mixed-layer component is probably comprised of both illite-montmorillonite and chlorite-montmorillonite types. Traces of kaolinite were present in two core samples.

Most of the samples analyzed contained a substantial amount of quartz, usually more than 20%. Feldspar was also common in core D5 and in AO, which had more than 10%; however, the other samples had about 5% feldspar. The clay mineralogy is similar to that obtained by Nelson (1959) near the mouth of the Rappahannock River.

Sand Fraction

Microscopical analyses of the coarse fraction (> 62 μ) indicates that quartz is by far the most abundant mineral in clayey silt on the bay floor. On the shoals, quartz makes up more than 95% of the sand. The grains are subrounded to subangular. The next most abundant constituents in clayey silt are fecal pellets, an organic manure consisting of aggregates of silt, clay and organic detritus. When artificially dispersed for size analyses, these pellets contribute to the fine-grained clay or silt fraction. They may make up as much as

30% of the coarse fraction. Diatoms, siliceous microscopic plants, were relatively abundant in the mid-bay muds; locally, concentrations reach more than 20% of the coarse fraction. Minor constituents (less than 5%) in the coarse fractions on the bay floor consist of plant and wood fragments, cinder and coal, heavy and dark minerals, mica flakes, and silty aggregates. Among the minor organic constituents are different kinds of shell fragments and species of foraminifera and ostracods.

In a study of coarse fraction mineralogy of Chesapeake Bay, Ryan (1953) reports that heavy minerals range from 1.5 to 3.9% and the most common include hornblend, garnet and hypersthene. Glauconite is present locally and is probably derived from erosion of older deposits on the bay floor or along the shore. Where future channels are cut into older deposits, the mineralogy would be expected to be quite striking; for example, quartz grains may be iron-stained and glauconite and fossil microfauna may occur. The presence of these constituents would make a marked contrast to recent muds which lack these constituents except as natural contaminants in trace amounts. However, differences in the mineralogy of spoil consisting largely of recent sediment would be very small except where the sediment is of different grain size.

NATURAL RATE OF SEDIMENTATION

An estimate of the recent rate of sedimentation on the bay floor in the study area was made by determining the change in water depth along transverse profiles drawn on smooth boat sheets surveyed about 1900 and in 1950 by the U. S. Coast and Geodetic Survey. Generally, changes in depth over the area are very small, mostly less than 2 feet (0.6 m) in 50 years. A slight shoaling of 2-3 feet (0.6-0.9 m) due to sedimentation was found off the Rappahannock River mouth and also in the disposal area at about the 60- to 70-foot (18-22 m) depth. Farther north, off the Wicomico River and Smith's Point in water depths greater than 100 feet (31 m), the bay floor was lowered 4-20 feet (1.2-6.1 m) during the 50-year period, indicating scour of the bottom. In the Rappahannock Shoal channel area, at about the 38-foot depth (11.6 m), natural sedimentation is less than 2 feet per 50 years. This is a minimal rate expected in the channel as filling of a channel floor, cut below the natural depth, would be expected to be higher. Spoil dumped in an area of natural sedimentation may be expected to stay in the same place unless the quantity is so large that it reduces the cross section of the estuary. By contrast, spoil dumped on a bottom that is naturally scouring may be expected to be redistributed by currents.

Ryan estimates that the average rate of sedimentation in Chesapeake Bay during the last 10,000 years is over six million cubic yards per year. One quarter of this amount probably represents erosion of the ancient shore line (Carpenter, 1957). By measuring present amounts of suspended solids, Carpenter has estimated a sedimentation rate of 0.1 cm per year for the bay. Powers (1954) estimated the average sedimentation rate for the bay to be 0.25 cm per year.

FORAMINIFERA

Although foraminifera occur in small percentages in the bay sediments, they are fairly widespread and well known in the region (Nichols and Ellison, 1967). They have been found useful to trace coarse sediment and to determine major sites of sedimentation (Phleger, 1960).

The samples analyzed in the study area are representative of two facies or assemblages that approximately correspond to depth. On the sandy shoals of the west side are scattered specimens of arenaceous species, chiefly Ammobaculites crassus and a few marsh species present as contaminants. By contrast, on the mid-bay floor the foraminifera are mainly calcareous and consist largely of specimens of Elphidium incertum; in addition, there are a few Ammonia beccarii and scattered specimens of the arenaceous species Trochammina squamata. In general, there is a marked paucity of foraminifera on the bay floor in contrast to the adjacent estuaries. At depth in cores calcareous forams are very scarce while arenaceous forams are as numerous as on the surface. This loss may be attributed to the fact that the calcareous forams, when buried, are dissolved under slightly acid conditions just beneath the salient surface, whereas arenaceous specimens resist solution and other diagenetic changes. In some places, buried forams contained a filling of clayey silt or pyrite, and others displayed black sulferous coatings.

Because of the differences between foraminifera at depth in cores and on the sediment surface, these microfauna are potentially important in distinguishing both dumped and redistributed spoil. If spoil is derived from considerable depth, great contrasts between the modern and older faunas may be expected and these contrasts would enhance the detection of spoil.

APPLICATION TO SPOILING PRACTICES

The disposal of spoil material in open, deep-water areas or on shoals adjacent to a channel should be undertaken with caution inasmuch as such areas are exposed to natural forces. The material cannot be expected to remain in place for long, as it may be reworked and redistributed by bottom currents and wave agitation on the bay floor. Spoil dumped in an area of natural scour would be particularly susceptible to redistribution. Many of the deep holes in the Chesapeake Bay floor are maintained by tidal scour and therefore should be avoided as dumping grounds unless perhaps they are completely filled to their sill (brim). By contrast, spoil dumped on a site where sedimentation is taking place naturally may be more stable, particularly at depths below wave base--greater than about 20 feet (7 m) in mid-Chesapeake Bay.

When spoil is redistributed, it may be expected to be transported, in the average, either up the bay or locally into deeper parts of the bay floor where currents are reduced. Material dumped downstream (seaward of a dredged channel) may be transported back toward the channel by upstream density flow. Very fine-grained soupy material or "fluff" would be carried farthest, whereas coarse particles or aggregates of fine material would be left as a lag deposit in or near the dumping site. The ultimate distribution pattern of the material, however, would depend on the characteristics of the spoil as well as on the direction and magnitude of the processes acting to redistribute the material over a period of time. To predict the distribution pattern requires a study of both the local material as well as the physical processes active at each dumping site.

Spoil material in transport or in place on the bottom is often not readily recognized, especially when the spoil texture and composition are similar to that of the natural sediments. The most obvious indication of spoil is the development of a "double bottom" observed on fathometer records, consisting of loose spoil overlying more consolidated sediment. As previously reported, the dumping process tends to load underlying natural sediments causing shear failure with slumps and flows.

These characteristics may be noted from the strength and void-ratio anomalies or from a reduction in volume of the underlying sediments and corresponding liquidity in response to overconsolidation by spoil.

Inasmuch as most spoil is derived by cutting into natural bottom more than one foot, the bulk of the spoil may show the effect of early diagenetic chemical change or biologic reworking in contrast to recent undisturbed sediments on the surface. For example, spoil may have a lower organic carbon and carbonate content than natural sediment. Moreover, spoil would be grey-colored and would contain scattered fine-grained pyrite; calcareous foraminifera would be relatively scarce in spoil, whereas arenaceous specimens would be as numerous as in the surface sediment. Foram specimens in spoil may display black coatings or contain infillings of pyrite or clayey silt. Textural differences may be very subtle except when dredging produces aggregates of fine-grained material. Where dredges cut into old deposits, such as Pleistocene or Miocene material, the spoil may contain iron-stained particles, glauconite or fossil microfauna.

REFERENCES

Bass Becking, L. G. M., and D. Moore. 1959. The relation between iron and organic matter in sediments. J. Sed. Petrol. 29:454-458.

Biggs, R. B. 1967. The sediments of Chesapeake Bay, p. 239-267. In Lauff, G. H. (ed.), Estuaries. Am. Assoc. Adv. Sci.

Bond, G. C., and R. Meade. 1966. Size distributions of mineral grains suspended in Chesapeake Bay and nearby coastal waters. Chesapeake Sci. 7(4):206-212.

Burt, W. V. 1955. Distribution of suspended materials in Chesapeake Bay. J. Mar. Res. 14:47-62.

Carey, R. E., and M. L. Jackson. 1953. Silicate analysis by a rapid semi-microchemical system. Anal. Chem. 23:624-628.

Carpenter, J. H. 1957. A study of some major cations in natural waters. Chesapeake Bay Inst., Tech. Rep. XV, 80 p.

Carpenter, J. H., and D. G. Cargo. 1957. Oxygen requirement and mortality of the blue crab in Chesapeake Bay. Chesapeake Bay Inst., Tech. Rep. XII, 21 p.

Clarke, F. W. 1924. The data of geochemistry. U. S. Geol. Surv. Bull. 770, 841 p.

Deniges, G. 1920. Reaction de coloration extrement sensible des phosphates et des argenates des application. Compt. Rend. Acad. Sci. (Paris), 171:802-804.

Fitch, J. L., and M. A. Rosenfeld. Undated. Rapid chemical analysis of sedimentary rocks. Mobil Oil Co. Research Dept., Unpubl. report, 103 p.

Folk, R. L., and W. C. Ward. 1957. Brazos River bar: A study in the significance of grain size parameters. J. Sed. Petrol. 27:3-26.

Haight, F. J., H. Finnegin, and G. Anderson. 1930. Tides and currents in Chesapeake Bay and tributaries. U. S. Coast and Geod. Surv. Spec. Publ. 162, 143 p.

Hicks, S. D. 1964. Tidal wave characteristics of Chesapeake Bay. Chesapeake Sci. 5(3):103-113.

Hires, R., E. Stroup, and R. Seitz. 1963. Atlas of the distribution of dissolved oxygen and pH in Chesapeake Bay, 1949-1961. Chesapeake Bay Inst., Graph. Summ. Rep. 3, 412 p.

Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Englewood Cliffs, N. J., 498 p.

Jordan, G. F. 1961. Erosion and sedimentation eastern Chesapeake Bay and the Choptank River. U. S. Coast and Geod. Surv. Tech. Bull. 16:1-8.

Krumbein, W. C. 1936. Application of logarithmic moments to size frequency distributions of sediments. J. Sed. Petrol. 6:35-47.

Krumbein, W., and F. Pettijohn. 1938. Manual of sedimentary petrography. Appleton, N. Y., 549 p.

McHugh, L. 1967. Estuarine Nekton, p. 581-620. In Lauff, G. H. (ed.), Estuaries. Am. Assoc. Adv. Sci.

Moore, H. B. 1930. The muds of the Clyde Sea area. I. Phosphate and nitrogen content. J. Mar. Biol. Assoc. U. K., 16:595-607.

Mortimer, C. H. 1941. The exchange of dissolved substances between mud and water in lakes. I. J. Ecol. 29:280-329.

Nelson, B. W. 1959. Clay mineralogy of the bottom sediments. Rappahannock River, Virginia, p. 80-101. In Clays and clay minerals. Proc. 7th Natl. Conf. on Clays and Clay Minerals, 1958.

Nichols, M., and R. L. Ellison. 1967. Sedimentary patterns of microfauna in a coastal plain estuary, p. 283-288. In Lauff, G. H. (ed.), Estuaries. Am. Assoc. Adv. Sci.

Phleger, F. B. 1960. Ecology and distribution of Recent foraminifera. Johns Hopkins Press, Baltimore, Md.

Powers, M. C. 1954. Clay diagenesis in the Chesapeake Bay area, p. 68-80. In Swineford, A., and N. Plummer (eds.), Clays and clay minerals. Publ. 327, Natl. Acad. Sci., Nat. Res. Council, Washington, D. C.

Pritchard, D. W. 1952. Salinity distribution and circulation in the Chesapeake Bay estuarine system. J. Mar. Res. 11(2):106-123.

Pritchard, D. 1954. A study of the salt balance in a coastal plain estuary. J. Mar. Res. 13(1):133-144.

Rochford, D. J. 1951. Studies in Australian estuarine hydrology. Australian J. Mar. Fresh Water Res. 2:1-116.

Ryan, D. J. 1953. The sediments of Chesapeake Bay. Maryland Dept. Geol. Mines and Water Res. Bull. 12, 120 p.

Schwarzenbach, G., and W. Beidermann. 1948. Komplexone X. erdalkalikomplexe von O,O-dioxyazofarbstoffen. Haiv. Chim. Acta 31:678-685.

Shapiro, L., and W. W. Brannock. 1956. Rapid analysis of silicate rocks. U. S. Geol. Surv. Bull. 1036C, 55 p.

Shepard, F. P. 1954. Nomenclature based on sand-silt-clay ratios. J. Sed. Petrol. 24:151-158.

Shepard, F. P., and D. G. Moore. 1955. Central Texas coast sedimentation: Characteristics of sedimentary environment, recent history, and diagenesis. Bull. Am. Assoc. Petrol. Geol. 39:1463-1593.

Stroup, E. D., and R. J. Lynn. 1963. Atlas of salinity and temperature distributions in Chesapeake Bay, 1952-61, and seasonal averages, 1949-1961. Chesapeake Bay Inst. Graphical Summ. Rep. 2, 410 pp.

Stroup, E. D., and J. H. Wood. 1966. Atlas of the distribution of turbidity, phosphate, and chlorophyll in Chesapeake Bay, 1949-1951. Chesapeake Bay Inst. Graphical Summ. Rep. 4, 193 p.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The oceans. Prentice-Hall, Englewood Cliffs, N. J., 1087 p.

Young, D. K. 1962. Chemistry of Chesapeake Bay sediments. M.A. Thesis, College of William and Mary.

Table 1

Summary of Data Obtained from Size Analyses on Rappahannock Shoal Sediments

Station No.	Water Depth Meters	Textural Class (Shepard, 1954)	Predominant Fraction (Modal Class)	Median Diameter mm.	Median Diameter Ø
A0	11	Clayey silt	Silt	.017	5.9
A1	12	Clayey silt	Silt	.0225	5.5
A3	13	Sand-silt-clay	v.f. sand	.0255	5.3
A4	12	Sand-silt-clay	v.f. sand	.0365	4.8
A5	13	Sandy silt	v.f. sand	.051	4.3
A6	14	Sand-silt-clay	v.f. sand	.0295	5.1
A7	18	Silty sand	f. sand	.125	3.0
A8	13	Sand	m. sand	.355	1.5
A9	12	Sand	f. sand	.235	2.1
B0	13	Clayey silt	Silt	.013	6.3
B1	13	Clayey silt	Silt	.0295	5.1
B2	13	Clayey silt	v.f. sand	.0275	5.2
B3	14	Clayey silt	Silt	.021	5.6
B4	14	Clayey silt	Silt	.021	5.6
B6	16	Silty sand	v.f. sand	.072	3.8
B7	14	Silty sand	v.f. sand	.058	4.1
B8	16	Sand	m. sand	.285	1.8
B9	10	Sand	m. sand	.355	1.5
C2	16	Clayey silt	Silt	.0225	5.5
C3	18	Clayey silt	Silt	.024	5.4
C5	13	Clayey silt	Silt	.0195	5.7
C6	16	Clayey silt	v.f. sand	.0195	5.7
C7	--	Clayey silt	Silt	.0096	6.7
C8	24	Clayey silt	Silt	.0113	6.5
C9	12	Sand	m. sand	.41	1.3
D3	11	Sand	m. sand	.38	1.4
D4	21	Silty sand	f. sand	.165	2.6
D5	14	Clayey silt	Silt	.009	6.8
D6	16	Clayey silt	Silt	.014	6.2
D7	15	Clayey silt	Silt	.018	5.8
D8	15	Sand-silt-clay	f. sand	.0365	4.8
D9	14	Clayey silt	Silt	.012	6.4
D10	14	Clayey silt	Silt	.0148	6.1

Table 1 continued

Station No.	Water Depth Meters	Textural Class (Shepard, 1954)	Predominant Fraction (Modal Class)	Median Diameter mm.	Median Diameter Ø
E0	13	Clayey silt	Silt	.0096	6.7
E1	14	Sandy silt	Silt	.0096	6.7
E2	15	Clayey silt	Silt	.017	5.9
E3	15	Clayey silt	Silt	.0156	6.0
E4	14	Clayey silt	Silt	.0275	5.2
E5	14	Clayey silt	Silt	.024	5.4
E6	23	Clayey silt	Silt	.03125	5.0
E7	13	Sand	m. sand	.465	1.1
E8	13	Sand	m. sand	.41	1.3
E9	13	Sand	m. sand	.41	1.3
F0	12	Sandy silt	Silt	.0225	5.5
F1	13	Sandy silt	Silt	.0225	5.5
F2	13	Sandy silt	Silt	.03125	5.0
F3	19	Sand	m. sand	.218	2.2
F4	12	Sand	f. sand	.235	2.1
F5	13	Sand	f. sand	.19	2.4
F6	10	Sand	f. sand	.205	2.3
G1	10	Sand	f. sand	.218	2.2
G2	10	Sand	f. sand	.205	2.3
G3	14	Sand	m. sand	.27	1.9
G4	--	Silty clay	Silt	.0084	6.9
G5	30	Clayey silt	Silt	.017	5.9
G6	18	Clayey silt	Silt	.0068	7.2
G7	15	Clayey silt	Silt	.0096	6.7
G8	5	Sand	m. sand	.31	1.7
G9	4	Sand	f. sand	.178	2.5
HO	29	Silt	Silt	.0096	6.7
H1	17	Sand	m. sand	.31	1.7
H2	13	Sand	f. sand	.205	2.3
H3	9	Sand	f. sand	.218	2.2
H4	9	Sand	f. sand	.235	2.1
IO	15	Sand	f. sand	.25	2.0
I1	33+	Clayey silt	Silt	.0073	7.1
I2	33+	Clayey silt	Silt	.0096	6.7
I'1	29	Clayey silt	Silt	.0084	6.9

Table 1 continued

Station No.	Water Depth Meters	Textural Class (Shepard, 1954)	Predominant Fraction (Modal Class)	Median Diameter mm.	Median Diameter ø
I'2	18	Sand	m. sand	.25	2.0
I'3	20	Silty sand	f. sand	.178	2.5
I'4	20	Sand-silt-clay	f. sand	.0445	4.5
I'5	14	Clayey silt	Silt	.014	6.2
I"1	13	Silty sand	m. sand	.054	4.2
I"2	16	Clayey silt	Silt	.0148	6.1
I"3	16	Clayey silt	Silt	.018	5.8
I"4	15	Clayey silt	Silt	.0295	5.1
I"5	15	Clayey silt	Silt	.0096	6.7
I"6	14	Clayey silt	Silt	.0148	6.1
JO	17	Clayey silt	Silt	.03125	5.0
J1	27	Sandy silt	m. sand	.165	2.6
J2	31	Clayey silt	Silt	.012	6.4
J3	32	Clayey silt	Silt	.014	6.2
J4	32	Clayey silt	Silt	.0068	7.2
J5	28	Sand	f. sand	.19	2.4
XO	20	Sand	f. sand	.178	2.5
X1	18	Sand-silt-clay	f. sand	.0445	4.5
X2	16	Clayey silt	Clay	.0068	7.2
X3	14	Clayey silt	Clay	.0055	7.5
YO	18	Silty sand	m. sand	.165	2.6
Y1	24	Clayey silt	Silt	.0073	7.1
Y2	28	Clayey silt	Clay	.0068	7.2
Y3	30	Clayey silt	Silt	.0068	7.2
Y4	30	Clayey silt	Silt	.0096	6.7
ZO	29	Clayey silt	Clay	.0063	7.3
Z1	32	Clayey silt	Clay	.0048	7.7
Z2	34	Clayey silt	Clay	.0051	7.6
Z3	30	Clayey silt	Clay	.0068	7.2
Z4	21	Sand	m. sand	.285	1.8

Table 2

Chemical Data, Per cent by Weight

Sample	Organic carbon	Inorganic carbon	Total P	Total Fe	Na^+	K^+	Ca^{++}	Mg^{++}
A4 - surf.	0.66	0.07	0.0604	2.489	2.141	1.036	1.25	1.84
- 10 cm	0.54	0.32	0.0438	2.651	2.326	0.935	1.31	1.52
- 20 cm	0.35	0.21	0.0498	2.631	1.271	0.804	1.34	1.55
AO - surf.	0.85	0.39	0.0563	3.065	2.745	1.063	1.05	1.77
- 10 cm	1.03	0.23	0.0544	3.195	0.924	1.063	1.37	1.68
- 20 cm	1.03	0.20	0.0542	3.497	1.424	1.284	1.41	1.73
- 30 cm	0.78	0.31						
K2 - surf.	0.60	0.20	0.0614	2.944	0.898	0.973	1.16	1.89
- 10 cm	0.64	0.22	0.0655	3.070	0.850	0.975	1.26	1.89
- 20 cm	0.75	0.16	0.0702	3.348	0.859	1.084	1.37	1.89
- 30 cm	0.70	0.11	0.0616					
- 40 cm	0.63	0.16						
XO - surf.	0.32	0.02	0.0260	1.640	0.330	0.480	0.42	0.57
E7 - surf.	0.15	0.11	0.0124	1.118	0.220	0.384	0.21	0.46
- 7 cm	0.21	0.05						
G8 - surf.	0.16	0.03	0.0315	1.349	0.699	0.385	0.11	0.67
- 9 cm	0.26	0.04						
D4 - surf.	1.27	0.08	0.0622	3.494	1.249	1.148	0.95	1.47
- 10 cm	1.35	0.19	0.0623	3.418	0.809	1.124	0.95	1.56
- 20 cm	1.45	0.49	0.0602	3.672	2.051	1.251	1.09	1.54
- 37 cm	1.56	0.07						
I"3- surf.	0.56	0.03	0.0615	2.980	2.325	1.150	0.93	1.92
- 10 cm	0.76	0.16	0.0615	3.268	0.809	1.024	0.97	1.94
- 20 cm	0.80	0.05	0.0591	3.447	0.809	1.024	1.26	1.68
- 36 cm	0.64	0.03						

Table 2 continued

Sample	Organic carbon	Inorganic carbon	Total P	Total Fe	Na^+	K^+	Ca^{++}	Mg^{++}
A6 - surf.	0.89	0.16	0.0670	4.070	0.745	0.935	0.93	1.71
- 10 cm	1.01	0.03	0.0580	3.895	0.759	0.974	0.88	1.68
- 20 cm	0.87	0.01	0.0579	4.398	0.725	0.935	0.99	1.92
- 31 cm	0.78	0.08						
A12- surf.	1.14	0.13	0.0705	3.929	0.565	0.875	0.88	1.43
- 10 cm	1.52	0.10	0.0654	4.899	1.280	1.065	0.84	1.58
- 20 cm	1.10	0.10	0.0631	4.149	0.610	0.955	0.74	1.79
- 31 cm	0.86	0.02						
HO - surf.	1.17	0.19	0.0746	4.500	0.610	1.125	1.05	2.00
- 10 cm	1.60	0.05	0.0687	4.046	0.594	1.024	0.76	1.98
- 20 cm	1.60	0.08	0.0663	4.380	1.460	1.105	0.80	2.04
- 40 cm	1.53	0.26						
ZOO- surf.	1.76	0.11	0.0615	4.500	0.700	1.105	0.74	2.19
- 10 cm	2.12	0.01	0.0583	4.400	0.610	1.065	0.74	2.21
- 20 cm	2.17	0.03	0.0570	4.658	0.675	1.200	0.75	2.25
- 45 cm	1.57	0.06						
Z2 - surf.	1.83	0.09	0.0676	4.210	1.000	1.175	0.78	2.06
- 10 cm	1.99	0.11	0.0558	3.780	0.610	1.065	0.78	1.85
- 20 cm	1.88	0.03	0.0559	3.924	1.323	1.123	0.80	1.94
- 40 cm	1.87	0.08	0.0559	4.149	0.885	1.150	0.84	1.94
- 53 cm	1.46	0.11	0.0560	3.868	0.645	1.220	0.84	2.04
G6 - surf.	2.01	0.11	0.0672	4.450	0.610	1.150	0.84	2.19
- 10 cm	1.97	0.18	0.0600	4.480	0.625	1.200	0.84	2.02
- 20 cm	1.72	0.17	0.0587	4.479	0.710	1.330	0.84	1.92
- 40 cm	1.75	0.02	0.0547	4.445	0.700	1.425	0.80	2.15
- 60 cm	1.64	0.05	0.0590	4.470	0.610	1.220	0.74	2.32
- 90 cm	1.37	0.04	0.0607	4.496	0.609	1.249	0.74	2.23
FO - surf.	1.82	0.07						
- 10 cm	1.85	0.12						
- 55 cm	1.49	0.12						

Table 2 continued

Sample	Organic carbon	Inorganic carbon	Total P	Total Fe	Na^+	K^+	Ca^{++}	Mg^{++}
C5 - surf.	1.14	0.13						
- 10 cm	1.12	0.61						
- 30 cm	1.23	0.39						
- 52 cm	1.01	0.15						
EO - surf.	0.85	0.19						
- 10 cm	0.96	0.07						
- 36 cm	0.69	0.10						
BO - surf.	1.43	0.15						
- 10 cm	1.47	0.06						
- 32 cm	1.16	0.18						
E9 - surf.	1.37	0.21						
- 10 cm	1.28	0.31						
- 37 cm	1.01	0.02						

BIOLOGICAL STUDIES

BIOLOGICAL STUDIES

This report of a three-year study on the effects of dredging and spoil disposal on the marine environment in lower Chesapeake Bay summarizes and discusses results obtained on eight cruises of varying coverage. The first cruise was a pre-dredging survey and the next four covered all or a part of the same area. Most of the sixth and all of the last two cruises were devoted to study of the Rappahannock Shoals channel, with 16 samples taken from the upper part of York Spit channel in November 1963.

While the results of dredging and spoil deposition are extensively discussed, more space is devoted to faunistic analysis and comparison with other surveys.

METHODS AND GROSS RESULTS

Samples were taken with a Petersen grab covering 1/15 m^2. A total of 518 samples was taken, thus 34.5 m^2 of bottom were covered. Data for the 1 mm screen for the channel area survey of July 10-11, 1963, were lost after preliminary analysis, so only some combined 0.5 mm screen samples are fully reported on for that group of 50 samples. Samples were screened to 1.0 mm in 1961-62, and in 1963, 101 were screened to 0.5 mm and the remaining 65 to 1.0 mm (Table 1). A 2.0 mm screen was always placed above the 1.0 mm and usually this was the only one from which individuals were picked on the deck of the vessel. Its contents and those of the 1.0 mm screen were then combined and preserved with buffered formalin.

Samples were first taken with the aid of a hand winch operated from a 32-foot inboard boat. Later they were taken with a power winch from the R/V PATHFINDER or R/V LANGLEY. Extra weight was added to the grab initially but this was later found to be unnecessary.

Sediments were analyzed from the first and second cruises as reported elsewhere. Sediment relationships of the fauna utilized the data obtained from the first cruise.

AREA

Rappahannock Shoals and the designated spoil area are located near the upper limits of lower Chesapeake Bay (Figures 1 and 2). Apparently they lie far enough below the Potomac and are subject to current scour sufficient to mitigate deposition of silt from that river and headwaters of the Chesapeake. The sediments in the immediate area were mainly silty-clay, with combinations of these finer particle soils and sand along the periphery (Figure 3). Depths sampled ranged from 29 to over 100 feet.

Bottom salinity is sufficiently high to allow penetration up the bay of some animals more abundant near the mouth. However, the species present are predominantly estuarine, although only a few of those taken are primarily oligohaline.

Red tide conditions and oxygen deficient benthic waters do not seem to affect the lower bay noticeably although some evidence of anaerobic decomposition was noticed toward the western side in deeper water during winter and spring.

DISCUSSION

Of the 78,264 organisms taken in the 1 mm screen, 54,264 were taken on the June 1962 cruise, and Ensis directus accounted for 43,094

(79%) of these. Biomass figures for 1961 when the mean number of individuals per sample was 97, showed a mean value of 12.9 gms, while in June 1962 when the mean number of individuals was 572, the mean biomass was only 7.3 gms. The difference of mean weight per individual of 0.0843 gm results from the much larger size of the Mulinia and Molgula which dominated the 1961 samples in comparison to the small size of the Ensis in the June 1962 samples. Ensis juveniles had an individual weight of about 0.005 gm as determined by weighing a large sample. Molgula (45%) and Mulinia (23%) comprised 68% of the biomass in July 1961.

The area was characterized by large, apparently natural, fluctuations in numbers and thus, to some extent, in species composition. The most stable elements of the community appeared to be Nephtys incisa and Retusa canaliculata. Ampelisca vadorum and Molgula manhattensis were less stable members of adult communities. In summer, communities apparently are frequently dominated by juveniles of species with a high reproductive potential. Species having this ability were usually molluscs, with some polychaetes qualifying. For the 1 mm screen, Ensis directus, Mulinia lateralis, Macoma tenta, Lyonsia hyalina, and Pectinaria gouldi were abundant only during the summer. Yet the first two appeared in such large numbers that Ensis, which was rarely taken except on the June 1962 cruise, accounted for 55% of all animals taken in the 1 mm screen in 476 samples. In the latter cruise it comprised nearly 4/5 of the wet biomass.

The dominance of Ensis in the total figures is an artifact of sampling. On the basis of 11 stations which were sampled both in June and July 1962, the decrease in this species in one month was 98.8%.

Thus, since the individuals were so small in June that many were not retained in the 1 mm screen, a sampling date as near as two weeks earlier or later might have revealed much smaller numbers. Since the July survivors had reached lengths to 2 cm, it is possible that some escaped the grab by virtue of being deeper. However, large numbers of valves were present, indicating that most of the population had died. Ensis is typically an inhabitant of sand bottom areas (Figure 3) but was taken in at least small numbers over most of the area in June. Numbers decreased progressively with depth.

Mulinia lateralis, which also undergoes great fluctuations but with the populations usually more long-lived, appeared in numbers to 6,900/m^2 in July 1961 at the station with the highest silt content. In 1962 when the Mulinia population was generally low in the sampled area, a population of 23,000/m^2 was found in nearby Tangier Sound in August at a depth of 89 feet. Mulinia breeds both in fall and spring, with females apparently capable of reaching breeding size in the summer in about two months. Abbott (1954) reported this species to be common on sand bottom. However, in Chesapeake Bay and its tributary rivers, sandy-silt substrates seem preferred (Figure 4). Actually, the factors affecting setting and survival of Mulinia larvae are probably complex since a large population was found on the sandy sill at the mouth of the Rappahannock River in July 1963 when populations were low in the spoil area. While Nephtys incisa was occasionally found to have ingested small Mulinia, predation is not believed to be important in its fluctuations. Numbers of whole, undrilled valves are usually found in favored areas. While the species attains its greatest numbers in the offshore waters of the bay, it often disappears almost completely in winter or under adverse summer conditions in the same area. It is believed that repopulation occurs from the sparse populations occupying shoal areas. When croakers were abundant, this small clam may have constituted one of its principal foods.

Other bivalves occupying the soft bottom in lesser numbers but exhibiting the same general pattern of temporal and spatial distribution as Mulinia were Macoma tenta, Lyonsia hyalina, and Lucina multilineata. Juveniles of Mya arenaria occurred commonly when Ensis was abundant.

Retusa canaliculata, a small opisthobranch gastropod which feeds on detritus (Sanders, 1960), ranked fourth in abundance but second in frequency of occurrence. This species breeds during the summer, apparently in one long period, and produces "crawl-away" larvae (Wells, 1961). It reaches its greatest screenable numbers in late fall. Illustrative of this are the data for the 25 samples from outside the channel on November 20, 1963, when 42% of the 1,027 Retusa taken were in the 0.5 mm screen, whereas on January 30, 1964, only 3.1% were in the fine screen. Evidence of predation and some die-off is indicated in the 70% reduction in the population between the two dates. Much higher populations of this snail than were found in this survey have been sampled from silty-sand in shoaler areas of the York River (unpub. data). Retusa is an ubiquitous species in the Chesapeake estuary and without obvious substrate preferences (Figure 6). However, Sanders (1958) reported Retusa as the fifth most abundant animal in the soft-bottom community of Buzzards Bay and did not mention it from the sand community. A later study (Sanders, 1960) placed Retusa ninth in abundance, perhaps because screen pore size had been reduced from 0.5 to 0.2 mm. Harrison and Wass (1965) showed Retusa as preferring a sandy substrate.

Molgula manhattensis, the commonest ascidian in Chesapeake Bay, reaches peak numbers in late summer, dying off to a low in late winter. An example of its rapid increase was obtained in the 11 stations sampled in June and July 1962, when an 87.5% increase occurred in one month. Molgula is an epifaunal suspension feeder which increases rapidly in numbers once a population is established. As with the small clams, repopulation in the soft bottom likely occurs by larvae derived from shoreward colonies. Molgula was most abundant in July 1961, when it ranked second in numbers and fifth in frequency. Occasionally it is attached to bivalves, and it seems probable that masses of Molgula may frequently smother certain sedentary infaunal species.

The Rappahannock Shoals area appears quite similar to the Buzzards Bay area investigated by Sanders (1960). In that study samples were screened to 0.2 mm, whereas in our study samples were screened only to 1.0 mm except for 101 samples sieved to 0.5 mm. Sanders' data show that one species, Nucula proxima, constituted 59% of all the animals taken and that it ranked first in abundance (one tie) 19 times. In spite of this consistency, a variation in numbers per sample of 8 to 1,940 occurred. While the Buzzards Bay study covered only 1.74 m^2 and variation in numbers/m^2 based on individual samples was from 526 to 31,615 animals in Sanders' study, the samples were taken over a 2-year period and seem to indicate a more stable fauna than that which occurs in our area in point of species composition. His highest figures compare with the highest for the June 1962 cruise when at station I'-2 a population of 46,335 animals/m^2 was found. It is interesting to note that while Sanders' largest sample was taken in February, it not only exceeded in numbers of individuals but also in species (44). It is probably not coincidental that the station I'-2 sample of the June cruise contained 52 species, the most taken in any sample sieved only to 1 mm during the present study. This sample contained 2,630 Ensis and two other samples with over 2,200 Ensis had 34 and 35 species, respectively, although the mean number of species per station in June 1962 was only 19.6. Amont the 40 samples taken in April 1963 when populations were quite low, one sand sample contained 76 individuals belonging to 17 species, four more than in any other.

Mulinia seemed to affect other invertebrates in a manner contrary to that of *Ensis* in that the number of species dropped as the percentage of *Mulinia* rose (Figure 17). In July 1961, for example, the 33 stations in which *Mulinia* comprised less than 10% of the total had a number of species/sample ranging from 5 to 36, with a mean of 17.7. At 27 stations with 11-49% *Mulinia*, the species range was 6 to 29, the mean 12.3. Nearly a fourth of the stations (24) had *Mulinia* totaling over 50% of the sample. In these, the number of species range from 4 to 12, with a mean of only eight. The station with the most species (36) and second most individuals (440) had only 11 *Mulinia*, while the station with the most individuals (526) had 460 *Mulinia* but only eight species.

Nephtys incisa, a medium-sized, active polychaete, was the most frequently taken organism, although being exceeded in numbers by *Ensis* and *Mulinia*. Although Chesapeake Bay is the southern limit of this species (Pettibone, 1963), it obviously is well adapted to the area. Sanders (1960) found *N. incisa* in all 25 samples, with populations varying from 100 to 6,300/m^2. Even though he used a finer screen, the density of this species would appear to be much higher in Buzzards Bay.

The preference of this species for soft bottom is easily noted in Chesapeake Bay (Figure 5). Sanders (1960) called this species a non-selective deposit feeder. However, Stone (1963) ascertained it to be selective, the gut being filled with green material.

Animals are seldom randomly distributed in nature (Cole, 1946). Holme (1950) used a coefficient of dispersion formula to test for random distribution of Tellina tenuis. If unity is obtained, a completely random distribution is indicated while less than unity indicates even distribution and more than unity indicates aggregation. Mulinia, when tested by this formula for July 1961, had a C. of D. of 140.72. Since this was significant at 1 $\pm$ 0.91, Mulinia is shown to exhibit a highly clumped distribution. It seems likely that many other species, particularly clams, would also exhibit this trait. For instance, Table 2 shows the aggregative tendencies of Nucula proxima, a clam quite uncommon in Virginia as compared with Massachusetts (Sanders, 1960; Sanders et al., 1962).

Sanders used a trellis diagram based on comparing percentage composition of each species in different samples to study the affinity between samples. The method is simple, but since the number of comparisons is equal to $n(\frac{n-1}{2})$, only a small number of stations can easily be compared. High correlations occur if one or two species together comprise over half the number of individuals in compared samples. For example, the 11 duplicated stations sampled in June 1962 showed percentage correlations with a range of 35 (58-93) and a mean of 76, but when Ensis was removed from consideration, the range was 66 (12-78), and the mean only 37.5, less than half the first. If Nucula were removed from Sanders' (1960) data, the results would surely be similar. Thus, a supposedly high faunal affinity will usually depend largely on abundance of only one species.

While the disappearance of Ensis may have had an adverse effect on other organisms, it is probable that conditions were adverse to many other species as well. The percentage correlations without Ensis showed a decline from 37.5 on June 7 to 29.0 on July 7 for the 11 duplicated stations. Numbers of species/sample fell from a mean of 21 to 15, while individuals dropped from 742 to 83 at these stations, indicating some reduction in diversity along with great loss in redundancy.

When a bio-index (Sanders, 1960) based on ranking the three most prevalent species in each sample is calculated for the 1 mm screen samples through July 1963, Nephtys incisa receives a value of 496, over twice as high as the second species, Ensis. N. incisa ranked second in Sanders' (1960) bio-index. Ensis owes its place entirely to the June 1961 cruise. Retusa (3) and Ampelisca vadorum (4) were taken more frequently. Mulinia (5) and Pectinaria (6) were common and, while certainly more permanent than Ensis, were found in abundance only in the summer.

Under conditions of low populations, many more species are involved in a bio-index than when high numbers occur. The latter are characteristic of northern latitudes and estuaries under optimal conditions. In June 1962, when 93 stations were sampled, only 15 species received rank in the index, against 23 only a month later when only 26 stations were sampled. The greatest disparity occurred in January-February 1962, the only major winter cruise, when 37 species entered the index. The total of 116 species taken on this latter cruise further attests to the diversity existing at that time.

While the bio-index may be a valid way of determining the constant and dominant members of a community during the more normal parts of the year, it may not be as good as an index of dispersion. This can be done simply by dividing the total by the frequency of occurrence. Arranging 34 species, including the most abundant (Table 2), according to their lack of dispersion places Ensis with a very low value because of its abundance when present, while some uncommon forms approach unity. One notes that the stable animals ranking high in the index range from 0.08 to 0.11.

When the formula $\frac{S-1}{\log_e N}$ (Jones, 1961) is used with these individual species and frequency (F) substituted for species (S), much higher values are obtained than when the formula is used for individual samples where 50 species is about the maximum obtained in our latitude. Both N. incisa and Retusa occurred in over 50% more samples than did Ampelisca vadorum, the third most frequent animal. Their ranks of one and two indicate the importance of frequency in this formula. The placement of the clam, Macoma tenta, and the brittle-star, Amphiodia, as third and fourth rates these two as important members of the soft-bottom community. Pseudeurythoe, a common but well dispersed polychaete, ranks fourteenth in total numbers but sixth in this analysis, indicating its even distribution. The razor clam, Ensis, explosively abundant in June 1962, ranked twenty-fourth, a seemingly more appropriate position than some other commonly used rating would have allotted to it. Ampelisca vadorum, fifth, and Lyonsia hyalina, seventh, are more properly members of another faunal group which might be characterized by its physical nature as the fine-sand community (Stone, 1963).

During the entire survey 190 species of animals were identified, with polychaetes comprising 34%, crustaceans 24%, and mollusks 22%. Identifications were not possible on a few specimens, some of which represent new species.

The remaining 19% includes species in several phyla. Of this latter group, only the brittle-star, Amphiodia, and the tunicate, Molgula, were present in abundance.

The list of species arranged alphabetically within phyla is given in Table 5. This list, consisting almost entirely of benthic animals, includes a much greater number than that given by Cowles (1930), even though a relatively small portion of Chesapeake Bay was covered. Unfortunately, Cowles was not able to report on the mollusks collected in the Bureau of Fisheries survey. The 42 molluscan species taken in this study were nearly evenly divided between pelecypods and gastropods, a proportion quite different from that existing in the entire phylum (Abbott, 1954) but perhaps typical of a temperate estuary. Except for Busycon, the snails collected were small to minute as were nearly all the clams.

Of the 193 named animals and several unidentified species, only about 46 are believed to find their optimum habitat in the soft bottom covering most of the survey area. The remaining species were taken more frequently in the sandier margins or were represented in more brackish, more saline, or shallower parts of the estuary. It is possible that several species may not have represented breeding populations. Larger numbers of species per grab are commonly taken in shallower areas, such as the Zostera and Clymenella communities. Common species more abundant in the sandier areas were Cyathura polita, Turbonilla interrupta, Ampelisca macrocephala, A. vadorum, Lyonsia hyalina, Gemma gemma, Nucula proxima, Oxyurostylis smithi, Paraprionospio pinnata, and Glycera americana.

Polychaetes, outnumbering mollusks by 50% or more in numbers of species for every cruise, were usually much less abundant.

SEDIMENT RELATIONSHIPS

To facilitate analysis of sediment relationships while at the same time providing permanent data storage, all biological data were placed on IBM punch cards. All species from the first three cruises were then sorted according to the following seven categories based on mean sediment size: (1) .2 mm, (2) .19-.1 mm, (3) .09-.05 mm, (4) .049-.03 mm, (5) .029-.02 mm, (6) .019-0.1 mm, and (7) .009-.005 mm.

Table 6 is based on those species which occurred at least ten times or in numbers of 15 or above. This includes only about one-third of the total number of species taken. The tabulations were made by an IBM 407 accounting machine. The 68 species selected by this procedure constitute only about a third of the total found. Of these more common species, relatively few showed a marked preference for certain sediments. The data indicate that epifaunal species, e.g., the abundant Molgula, have no preference. The most frequently taken species, Nephtys incisa, and the common ophiuroid, Amphiodia atra, apparently prefer intermediate sediments. This possibly gives them an advantage over species which prefer either coarser or finer sediments.

One would expect juveniles to be more widely and randomly dispersed, and while this appears often to be the case, as with Ensis and Mulinia, the data from January 1962 samples indicate numerous species which are quite evenly distributed along the sediment spectrum. Thus, it appears that adults may sometimes exhibit less selection than do larvae.

While these sediment data are impressive for certain species, since the number of stations in each type is much greater toward the ends of the size spectrum, further statistical analyses would be needed in order to check the significance of the findings.

ANALYSIS OF 0.5 mm SCREEN RESULTS

More species and individuals are normally taken in the 0.5 mm screen than are recovered from the 1 mm size. This distribution is subject to considerable seasonal variation. In comparing overall data from this study, the total results are obscured again by the large Ensis population. Had the fine screen been used in the June 1962 cruise, it seems probable that fewer individuals would have been taken in it than in the larger screen. The mean number of 150 animals/sample for the 1 mm screen becomes 74 when Ensis is removed. This compares well with 83 for all 0.5 mm screen samples, but the latter figure is biased by over half the samples coming from the channel disclimax. If only samples from outside the channel are considered, the mean is 105, a more realistic number as compared with results obtained in the York River (unpub. data).

Most of the fine screen samples were procured in November when numbers are about average or lower (Table 3). This affects comparisons with data from the 1 mm screen which includes summer juvenile populations. The mean number of species for the channel area is 11.8, two greater than for the larger screen. Barring samples from the channels proper, this mean becomes two species higher. A considerable reduction usually occurs in winter in the smaller organisms. This may be due mainly to death but could also result from growth to a size sampled by the larger screen, as reported for Retusa. In November, with data combined, the 1 mm screen contained only 38.7% of the total number of animals, but by January it held 48.9%. Extrapolation is involved in the latter figure but the results are as expected from previous experience. The samples from York Spit showed less discrepancy between the two screens, the number taken in the channel being 628 in each screen, while the number found outside was 27% greater in the fine screen.

The dominant animals were characteristically different for each screen at each sampling date in the Rappahannock Shoals area. In July, Heteromastus, a small polychaete worm, was most abundant, although 85%

were taken in only 5 samples. By November, Retusa dominated in both screens outside the channel but within it, Retusa was foremost only in the first screen and sixth in the finer. The remaining species making up the five most common forms for both areas were different between the two screens except that minute clams, identified only as Tellinidae, were probably juveniles of Macoma tenta. In January, Retusa and N. incisa were the most abundant forms in both screens outside the channel and in the 1 mm screen in the channel. A microscopic capitellid worm, possibly identified as Heteromastus in July and probably representing a species new to the Atlantic Coast, was the most common organism in the 0.5 mm screen from the channel. Turbonilla stricta, a pyramidellid snail, was abundant in the channel fine screen in both months, while in July another member of this family, Acteon punctostriatus, was second.

The York Spit area, perhaps because of its coarser sediments, presents a size distribution pattern contrasting with that of Rappahannock Shoals in that the dominant species were the same in both coarse and fine screens, even occupying the same relative positions, except that Retusa and T. stricta, respectively, held fifth place in the channel. Mollusks were much more abundant at York Spit (Figures 12 and 13), with juvenile Tellinidae, probably Tellina agilis, easily outnumbering any other species in all screens.

The fine screen, except for two November stations, showed greater numbers of individuals and species in the undisturbed area outside the channel, as with the larger screen. The difference was greater immediately after dredging (Figure 16).

SEASONAL VARIATION

Although few benthic studies have covered a sufficient time period to determine seasonal or cyclic population fluctuations, results of this investigation bear out the supposition of high summer populations under normal conditions. That these may become so high as to over emphasize the Malthusian principle is shown by the aforementioned *Ensis* figures. Excluding this phenomenon, it appears that summer populations tend to be about twice as high as those of winter (Table 1), with lowest populations possibly occurring in late winter. Numbers of species also decrease but much less proportionately. Thus, if the number of species is divided by the number of individuals on a per sample basis, rather low figures (0.03-0.19) are obtained for summer, including November, in the Rappahannock Shoals area. Winter ratios of 0.23-0.26, except for the high figures of the freshly dredged channel in January, probably are representative of those normally expected in benthic surveys made during the months of January to May in portions of temperate estuaries having a salinity range of 10-25 ‰. The November figures for York Spit for the 1 mm screen (0.23 and 0.26) and the fine screen (0.21 and 0.14) possibly indicate two things: first, the greater species diversity and lowered redundancy as one proceeds toward the ocean, and second, the generally smaller size of animals living in coarser sediments, hence the large number of animals taken in the 0.5 mm screen. This size preference relationship of animals with sediments probably does not hold for protozoa and nematodes but seems to do so for meiofauna and smaller macrofauna.

The sector diagram covering all 1 mm samples (Figure 14) except for July 1963 and York Spit shows that mollusks comprised over half the animals during the summer regime (June-November) and also the area outside the channel in January. The latter numbers resulted from a large juvenile tellinid population. An exception was the very low fraction of mollusks present in July 1962, after the Ensis demise. Worms also usually decrease in winter, but since their fluctuations are much smaller, they comprise a larger segment of the community when mollusks are reduced. Generally, only two species in the miscellaneous category are common. These are the brittle-star, Amphiodia atra, and the ascidian, Molgula manhattensis. Of these two, the first is much more stable in numbers. Figures 7-11 indicate a substantially greater variation in the channel; however, the extremes for the January 0.5 mm screen (Figure 11) result from being based on single samples rather than five as in Figures 7-10.

This survey is one of the largest ever made over such a small area and with as fine screens. This is not meant to imply that it is the most complete. There appear to be two obvious ways of checking faunal coverage. One method is to accumulate the species added with each succeeding sample or cruise (Jones, 1961). A second would be to check the percentage of species taken only once or a few times. Of the 88 species found in 20 samples taken at one site by Sanders (1960), 20 (23%) were only found once. However, the areas covered and number of samples are scarcely comparable to this study. Accumulation of species as an index has been used several times and is more illustrative of coverage. The first sample period (July 1961) contained 105 species in the 100 samples. The next cruise, although having less than half as many individuals, yielded 41 species not previously taken. The 126 samples of June and July 1962 added only 29 species. While 166 grabs were analyzed by use of the 1 mm screen since then, only 11 species have been added. Use of the third screen has added only three more, although six more unidentified animals were found. The addition of these and nine unidentified forms from the 1 mm screen bring the total to 204. Plotting these points on a curve indicates that probably at least 600 more samples taken during the warmer months would be needed to bring the number of species found in this area to 250. However, the fact that so many species were found only once would seem to indicate that a number of others must yet remain to be taken. Unless these were forms which usually passed through the screens, one would not expect them to occur normally in the area.

EFFECT OF SPOIL DEPOSITION ON BENTHIC FAUNA

Prior to July 1963, the number of stations at which spoil was definitely encountered was only two--G-5 and J-2. Both of these were in the lower part of the designated spoil area. Stone (1963) has tabulated the data for these stations. The first survey, done prior to dredging, showed normal populations, while the second, a few months after the dredging, indicated the lowest populations in that survey. By the following summer, recovery was dramatic, particularly at G-5 where 27 species were included in the 294 individuals, giving this station a rather high species to individuals ratio in that series. Species/individuals per station for that cruise averaged 0.03, while at G-5 the ratio was 0.09. More significant perhaps are the biomass ratios per station, 0.013 being the cruise mean, while at G-5 with 35.8 gms the ratio was 0.062. Only 41% of the animals at G-5 were *Ensis*. At this station the stiff clay lumps were most conspicuous. The large size of the individuals in June 1962 may have resulted from the inability of predators to get at the animals in the crevices of the unconsolidated substrate. It is interesting that this was the only station in that transect at which Molgula occurred. These were not weighed separately but based on the average wet weight of individual Molgula in the previous summer (0.42 gm), they would have comprised at least one-fifth of the total weight.

Further evidence of recovery is given by data obtained from the short cruise of April 1963 when 40 samples were taken at 13 stations. The stations could not be located exactly and at the boundary between the sandier shoals and the soft bottom, great variation between samples frequently occurred. However, seven samples were judged to be spoil by their consistency, 27 were non-spoil but from the soft bottom, and 6 contained noticeable sandy sediment. The means for these three groups are tabulated below.

	Weight	Number species	Number individuals
Spoil	2.1 gm	4.9	18.1
Non-spoil	1.5 gm	4.1	15.3
Sandy	1.8 gm	8.8	33.5

These data further evidence the recovery and apparent slight advantage of the spoil samples over the ooze-covered normal substrate in the deeper portions of the Chesapeake. The reader should note the low figures in the table. Some of the non-spoil samples smelled of sulfides and a dead hog-choker was obtained in one grab. Winter dieoffs of flatfish and invertebrates would go unnoticed in deeper water since these organisms do not float. The data exonerate spoil as a factor in the generally low populations of early April 1963 when water temperatures had not warmed enough to stimulate reproduction.

Samples taken three months later, four in spoil and six in non-spoil, show practically no difference in their means: species 13, individuals 119 for spoil; species 11, individuals 124 for non-spoil.

Perhaps the discrepancy between numbers of species reflects the disclimax or ecotonal nature of the spoil deposits. However, it would seem that physical factors and biological activity would rather quickly return this area to its normal climax condition.

No survey of the spoil site was made after the January 1964 deposition. Since the depth of dredging was so much greater then, perhaps four to five times as much spoil was dumped. The nature of the channel bottom after this work indicated that some of the sediments dredged might have differed from those dumped in 1961.

EFFECT OF DREDGING ON INFAUNA

The location of the proposed Rappahannock Shoals Channel was not exactly known at the time of the first survey. Marker buoys had not been placed and the chart provided by the Army Engineers did not have the channel located correctly in relation to its final position. Furthermore, perhaps because of the presumably greater area to be covered by spoil, the planning placed more emphasis on spoil analysis. In July 1963, it was felt that further attempts to study spoil, in view of the noted faunal recovery, would be unwarranted. Consequently, studies were mainly concentrated on the channel, with a small study of the York Spit Channel.

The only regular station believed to have been located within the channel was I''-3. Stone (1963) gave data to indicate this. He also analyzed results of the 1 mm screen samples for July 1963 statistically before the data were lost. The difference between the channel fauna and that outside was very striking, with no overlap occurring in the ranges of variation in numbers of individuals. Species differences were not analyzed although Stone did report low numbers of clams for the channel. Results for the fine screen will be discussed later.

Results obtained from the July cruise were unusually discordant between the two screens (Table 3). The number of animals taken in the 1 mm screen was 6.6 times more outside the channel than in. However, while only 33.6% of the individuals taken in the channel were found in the larger screen, out of the channel 52.8% were in this screen. The 19.2% difference between proportions of numbers found in the separate screens was much greater than for York Spit (5.8%), and Rappahannock Shoals in November (1.4%) and January (4.4%). The reason behind the disparity in July seems inexplicable. Obviously, one or more factors were deleterious to juveniles outside the channel on undisturbed bottom, e.g., clams and other suspension feeders may have been abundant enough to destroy most larvae. Conversely, within the channel the dredged bottom and turbulence created by passing ships may have been detrimental to adults while presenting a sparsely occupied area for larval setting. Phoronid worms, common in the channel, seemed to act as "pioneers" in this situation, their long, tough tubes aiding in stabilizing the sediment.

The erratic data for November, little more than four months later, may be attributable to sampling error in that samples taken from a drifting vessel may have come from too near the edge of the channel. Also, some contagiously distributed species which occur in abundance, such as Retusa canaliculata, could have affected the data. By mid-winter Retusa is too large to be taken in a 0.5 mm screen. Between July and November, it increased 44% in the channel and 48% outside in 0.5 mm samples, but by January had decreased 93% and 98%, respectively, from July. Since the 1 mm screen decreases of Retusa between November and

January were 94% in the channel and 51% outside, the 98% decrease in the fine screen for the latter site must be attributed to growth of the animal.

Statistical analyses of the data for the 1 mm screen for November 1963 revealed that the number of individuals was not significantly different between shoal and channel samples. However, a lthough the number of species per sample ranged from 2 to 14 in the channel and from 8 to 20 on the shoal, the differences were significant.

Analyses of the data for the 1 mm screen for January samples showed that a significant difference in the number of individuals existed between channel and shoal samples at buoys 1, 2, 3, and 4. A significant difference also existed in the number of species between channel and shoal samples at buoys 1, 3, and 4.

In November and January all shoal samples were significantly different between months at all buoys, while samples from the channel were significantly different between the two months only at buoys 1 and 4. Table 4 shows the variability in the mean number of individuals at each buoy.

It is evident from this table that samples from the shoal for November were less variable than channel samples. This variability inside the channel may be the explanation for finding no significant difference at three of the buoys. The combined total numbers for each date show a loss between 3.1 times as great for the channel as for the adjacent undisturbed shoal. The differences between November and January are graphically portrayed in Figure 15. Dredging to a depth of 45 feet minimum clearance, an increase of 5 feet over the previous channel depth, had been completed just a week prior to the last sampling.

If all channel data are made comparable by extrapolation of partial fine screen data in July and January, the combined data for each screen show the number of animals taken by the larger screen to be 2.6 times as great on the shoal as in the channel. The fine screen showed less difference, with exactly twice the organisms from the shoal as in the channel.

Data for the channel were the more consistent, as shown in Figures 16 and 17. The fauna on the undisturbed shoal showed a steady decrease from the July high, while in the channel there was an approximate increase of 100% between July and November. Decreases after dredging were 36 and 19% greater in the channel for the two screens, respectively, than on the outside.

CONCLUSIONS

1. Spoil deposited in a deep estuarine area has an immediate but not a lasting effect on benthic fauna.
2. A dredged and regularly used channel probably will never support a fauna comparable to that of the adjacent shoal.
3. Temperate estuarine habitats are subject to pronounced seasonal variation, with the lowest numbers occurring in winter.
4. Species with a large reproductive potential may produce enough juveniles to skew otherwise rather even distributions in a community.
5. The number of species taken in over 50% of the samples is greater in summer than in winter.
6. Screening to a size smaller than 1.0 mm is not justified in a survey with a purpose such as this one had.
7. Maximum information is obtained when samples, including fractions from different pore size sieves, are analyzed separately:

a. Reproductive periods can be more accurately determined by use of a finer screen.

b. The proportion of small forms to large is greatest in summer.

c. Smaller forms are more numerous in sandy areas.

8. The soft-bottom community of Chesapeake Bay contains a relatively small number of species, although probably twice as many may rarely occur.

9. The sand community contains more species and usually more individuals than does the silt clay bottom.

ACKNOWLEDGMENTS

Assisting in laboratory sorting and in identification of the more common and easily determined invertebrates were Dorothy Guild, Donna Hindelang, Howard Hunt, Donald Keith and Richard Stone. James Feeley did most of the work involved in putting data on forms for punch cards.

Dr. Marian H. Pettibone of the United States National Museum determined representatives of some of the polychaetes, describing three new species in the family Pilargidae. Dr. Charles E. Cutress, University of Mayaguez, Puerto Rico, determined specimens of three species of anemones, Dr. William Clench of the Museum of Comparative Zoology determined *Ensis directus*, and Dr. Kenneth Boss of the Fish and Wildlife Service identified material of *Macoma phenax* and *Tellina agilis*.

The Scientist in Charge of Biological Studies is nevertheless responsible for all reported identifications. During the last two years crustacean identification was done by Mr. McCain, who also did much of the statistical work. In the 1963-64 academic year, Mr. Kerwin

identified and enumerated the mollusks. The junior authors sorted nearly all of the material collected in 1963 and 1964, compiled the data and produced the graphs.

REFERENCES

Abbott, R. T. 1954. American Seashells. D. Van Nostrand Co., New York, 541 p.

Cole, L. C. 1946. A theory for analyzing contagiously distributed populations. Ecology 27:329-341.

Cowles, R. P. 1930. A biological study of offshore waters of the Chesapeake Bay. Bull. U. S. Bur. of Fish. 46:277-381.

Harrison, W., and M. L. Wass. 1965. Frequencies of infaunal invertebrates related to water content of Chesapeake Bay sediments. Southeastern Geol. 6(4):177-187.

Holme, N. A. 1950. Population-dispersion in Tellina tenuis da Costa. J. Mar. Biol. Ass. U. K. 29(2):267-280.

Jones, M. L. 1961. The benthic fauna off Point Richmond, California. Univ. of Calif. Pub. Zool. 67(3):219-320.

Pettibone, M. H. 1963. Marine polychaete worms of the New England region. 1. Aphroditidae through Trochochaetidae. Bull. 227, U. S. Nat. Mus., 356 p.

Sanders, H. L. 1958. Benthic studies in Buzzards Bay. I. Animal-sediment relationships. Limnol. Oceanogr. 3:245-258.

Sanders, H. L. 1960. Benthic studies in Buzzards Bay. III. The structure of the soft-bottom community. Limnol. Oceanogr. 5: 138-153.

Sanders, H. L., E. M. Goudsmit, E. L. Mills, and G. E. Hampson. 1962. A study of the intertidal fauna of Barnstable Harbor, Massachusetts. Limnol. Oceanogr. 7:63-70.

Stone, R. B. 1963. Benthic fauna in lower Chesapeake Bay. M.A. Thesis, School of Marine Science of the College of William and Mary, p. 1-31.

Wells, H. W. 1961. The fauna of oyster beds, with special reference to the salinity factor. Ecol. Monogr. 31:239-266.

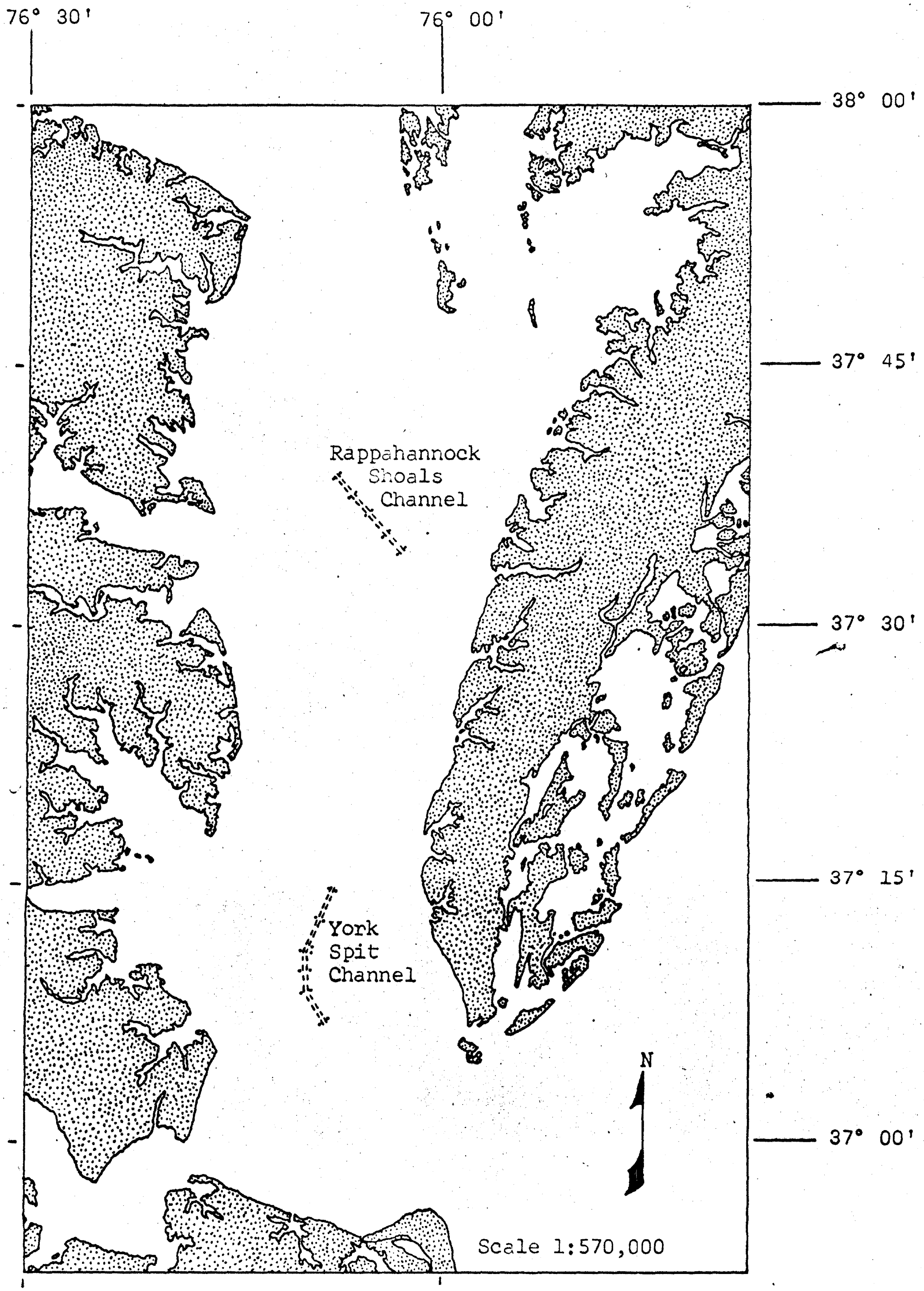


Figure 1. Location of the York Spit and Rappahannock Shoals channels, Chesapeake Bay, Virginia. November 23, 1963.

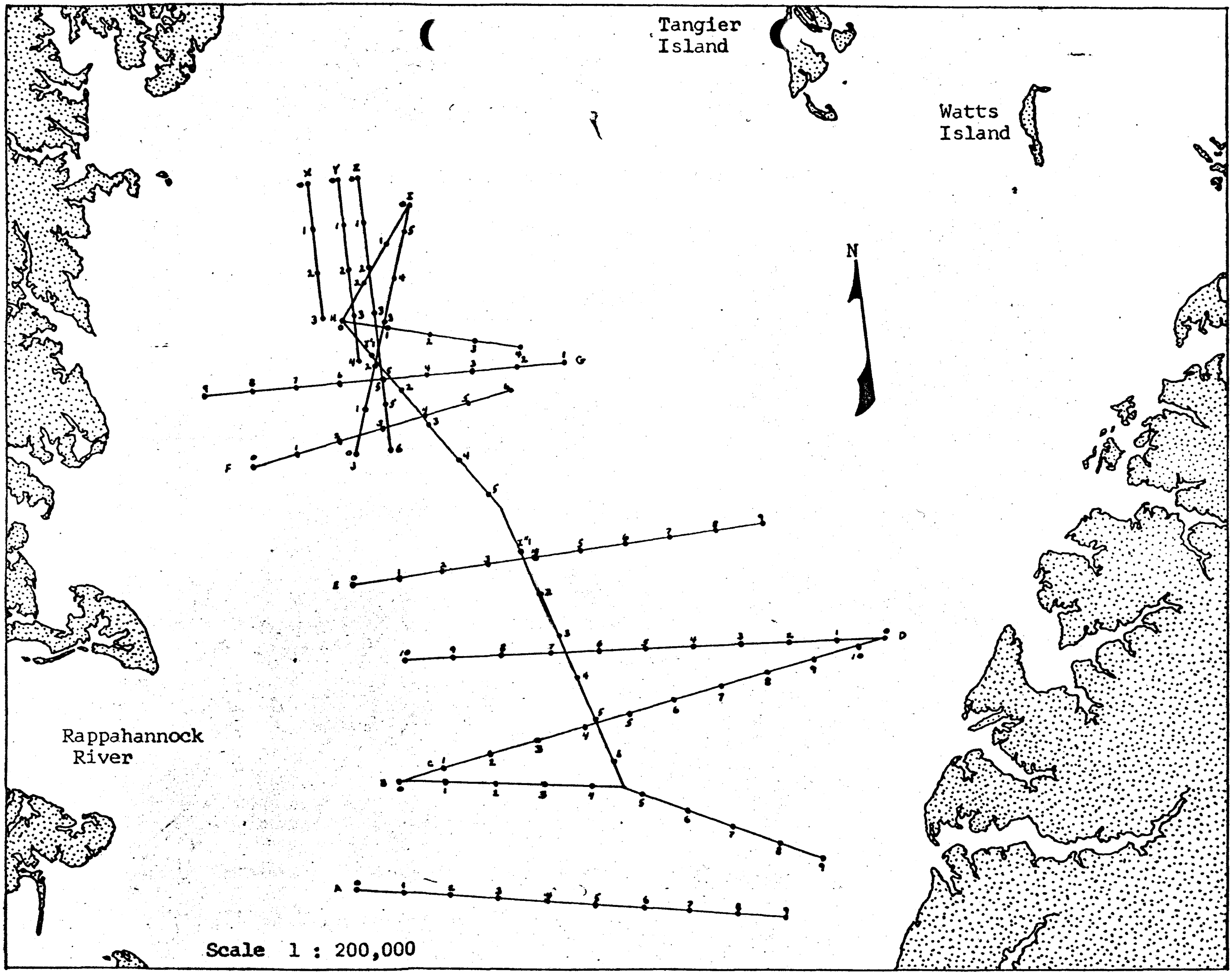


Figure 2
Transect and sample locations on the Rappahannock Shoals survey, Chesapeake Bay, Virginia, 1961-62.

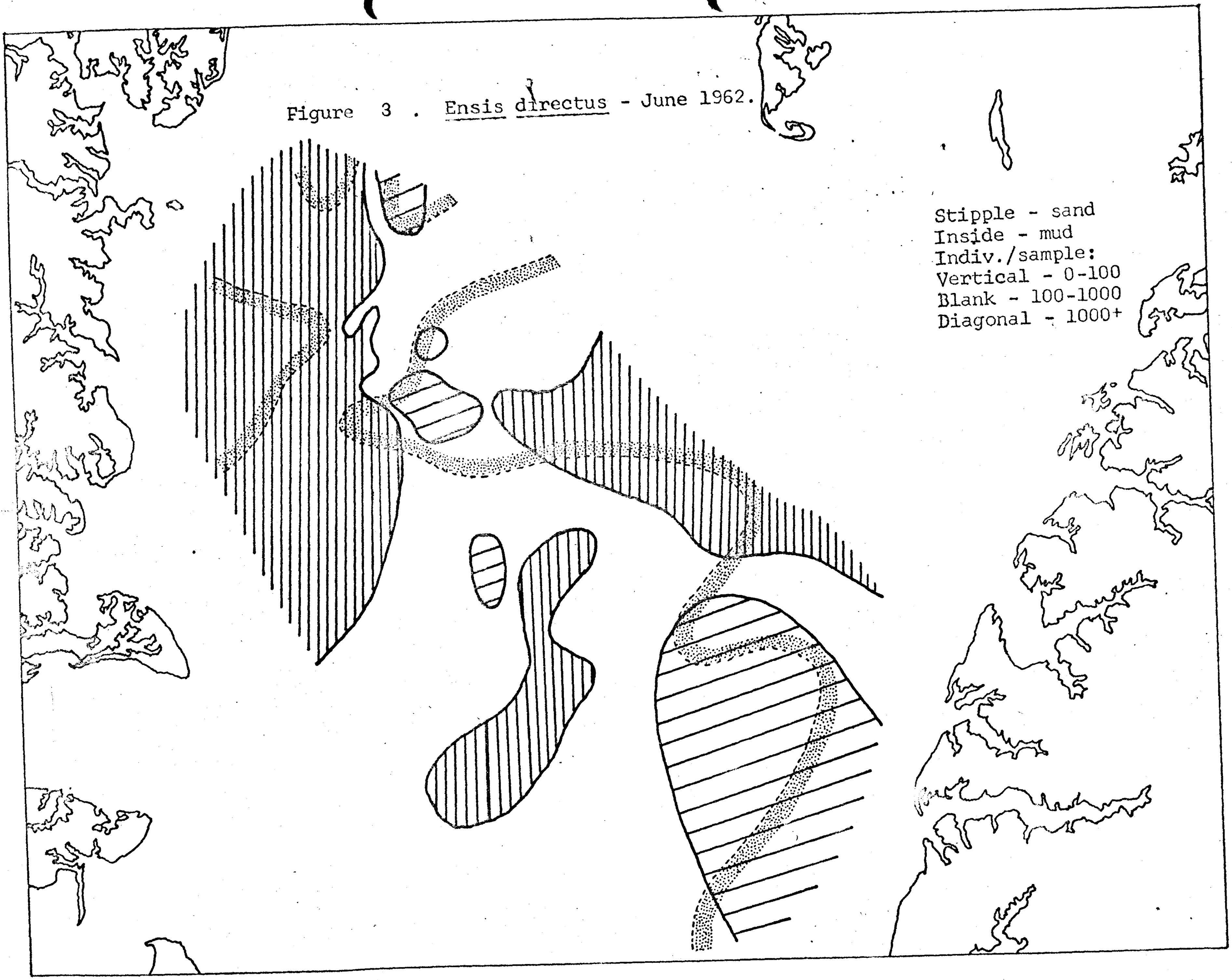
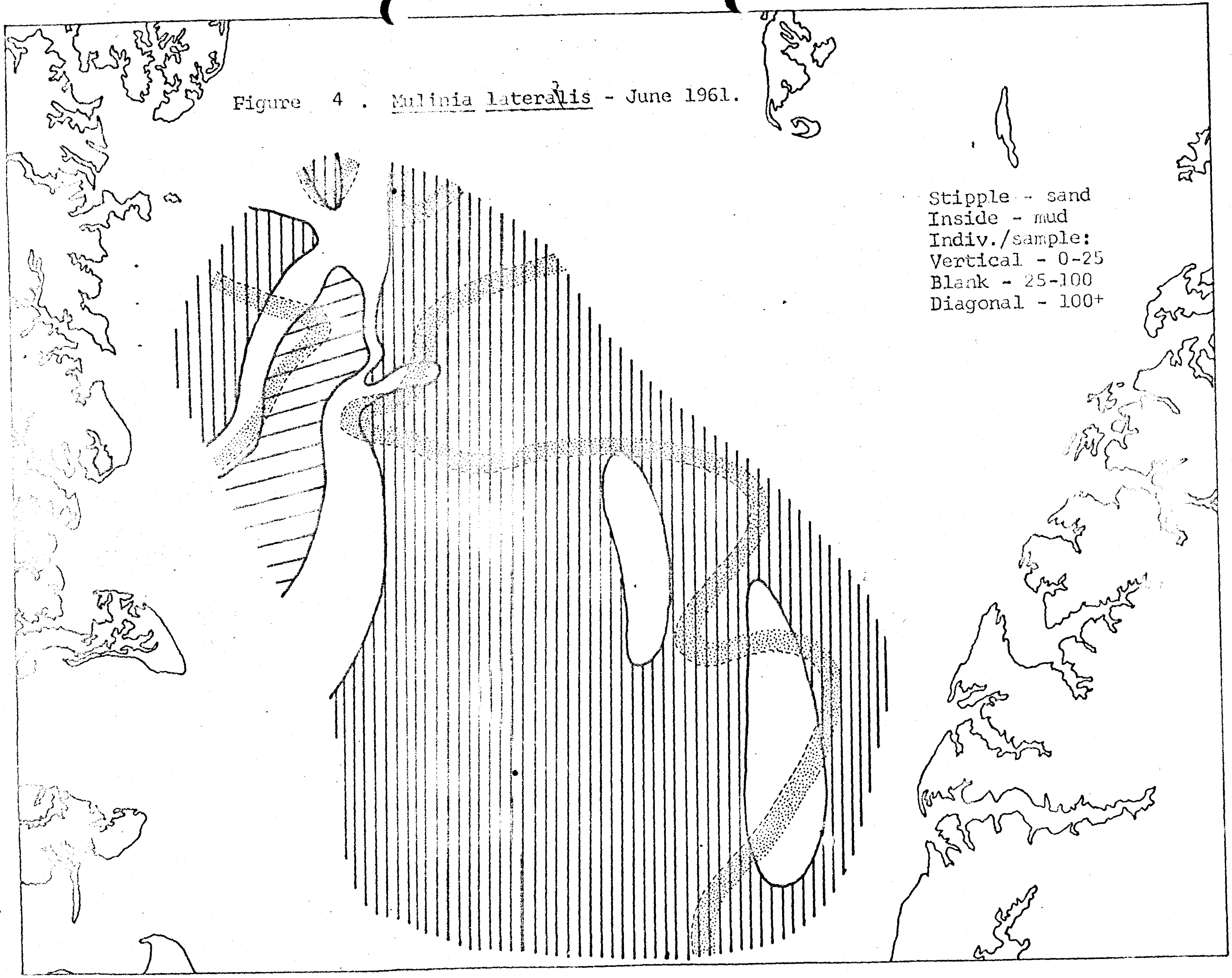


Figure 3 . *Ensis directus* - June 1962.

Figure 4 . *Mulinia lateralis* - June 1961.



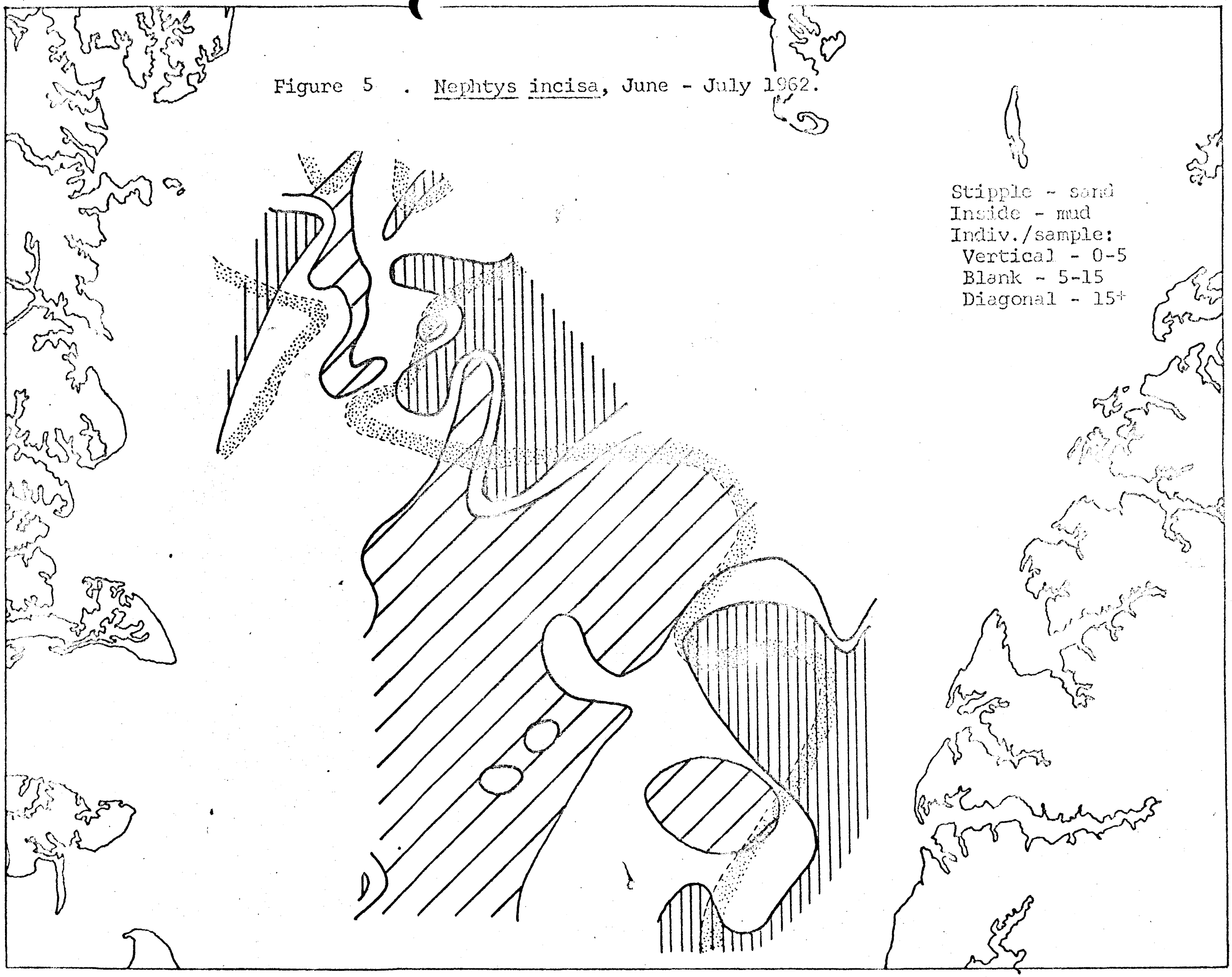


Figure 5 . *Nephtys incisa*, June - July 1962.

Figure 6 . *Retusa canaliculata*, Jan.-Feb., 1962.

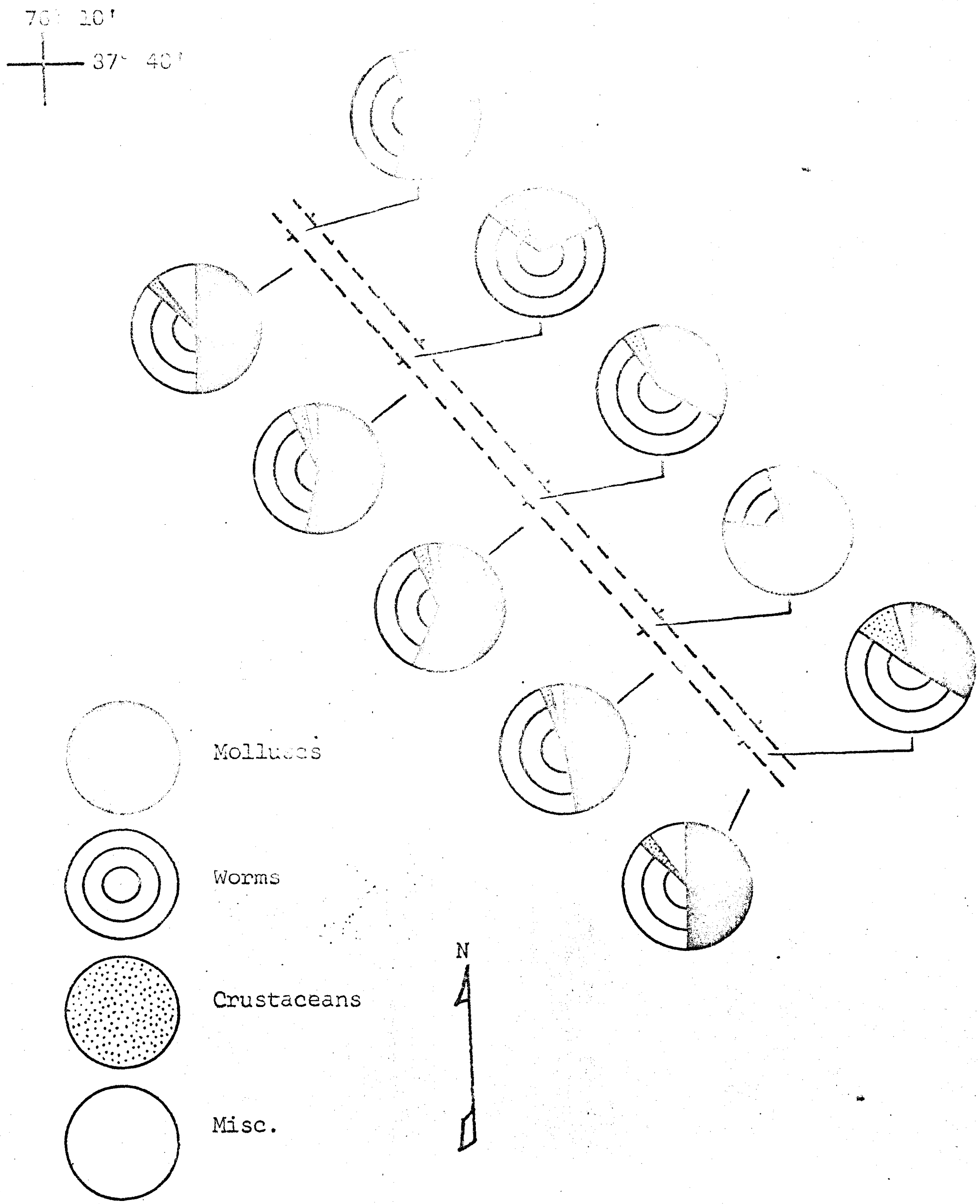


Figure 7. Sector diagram comparison of the major faunal groups from the Rappahannock Shoals survey (inside versus outside channel), 1 - [illegible] mm [illegible], November [illegible].

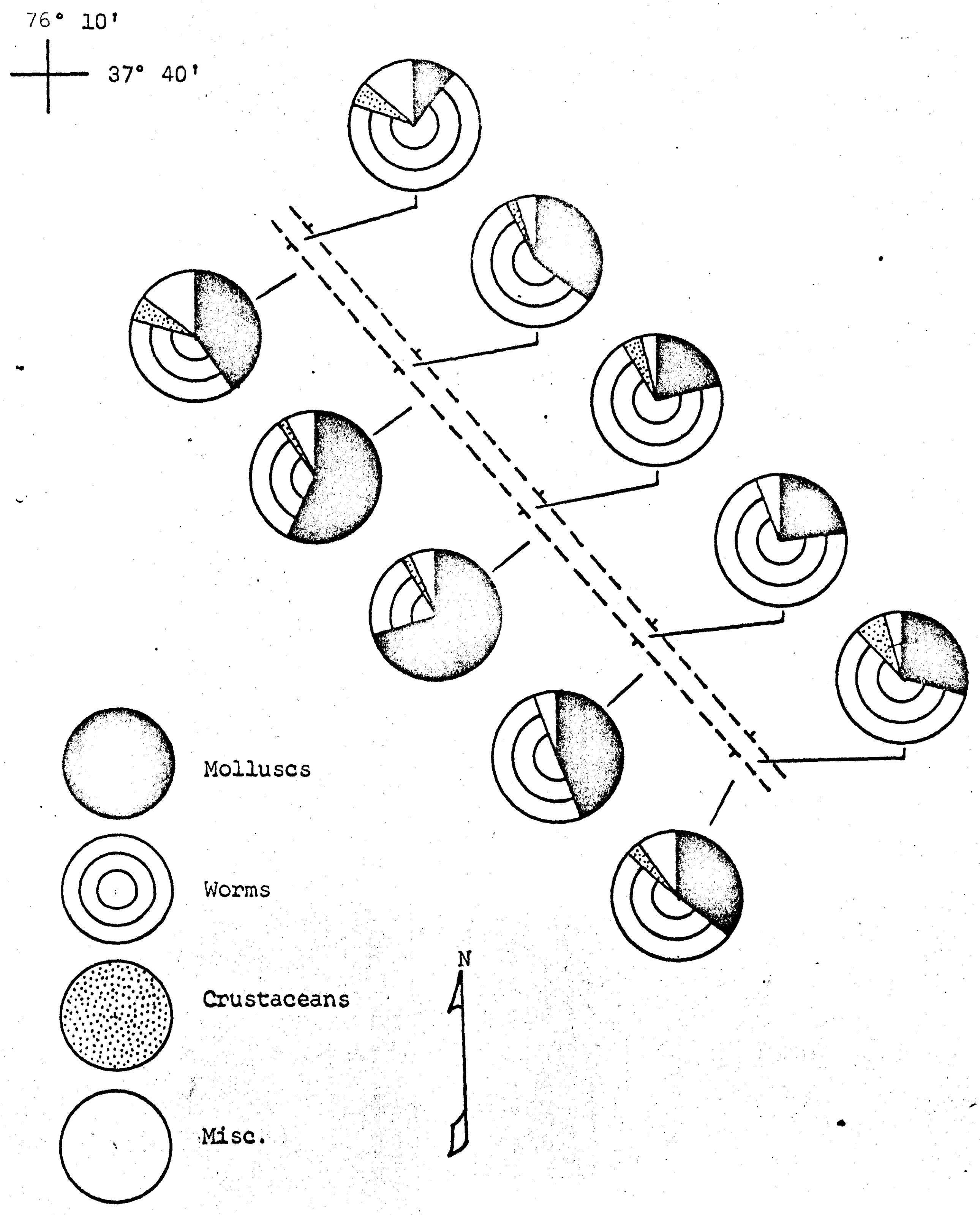


Figure 8 . Sector diagram comparison of the major faunal groups from the Rappahannock Shoals survey (inside versus outside channel), 1 - 2 mm screens, January 1964.

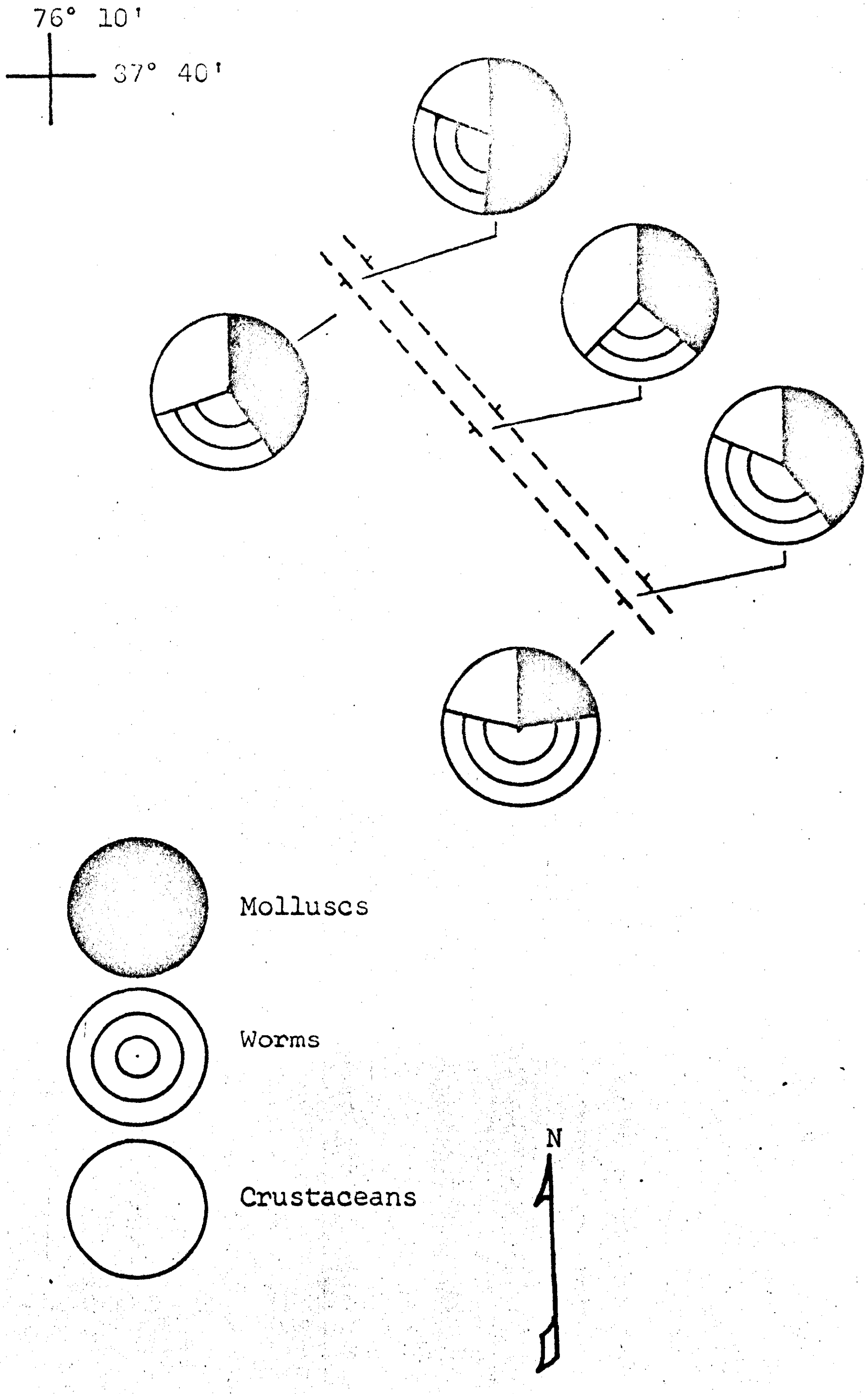


Figure 9 . Sector diagram comparison of the major faunal groups from the Rappahannock Shoals survey (inside versus outside channel), 0.5 mm screen, July 1963.

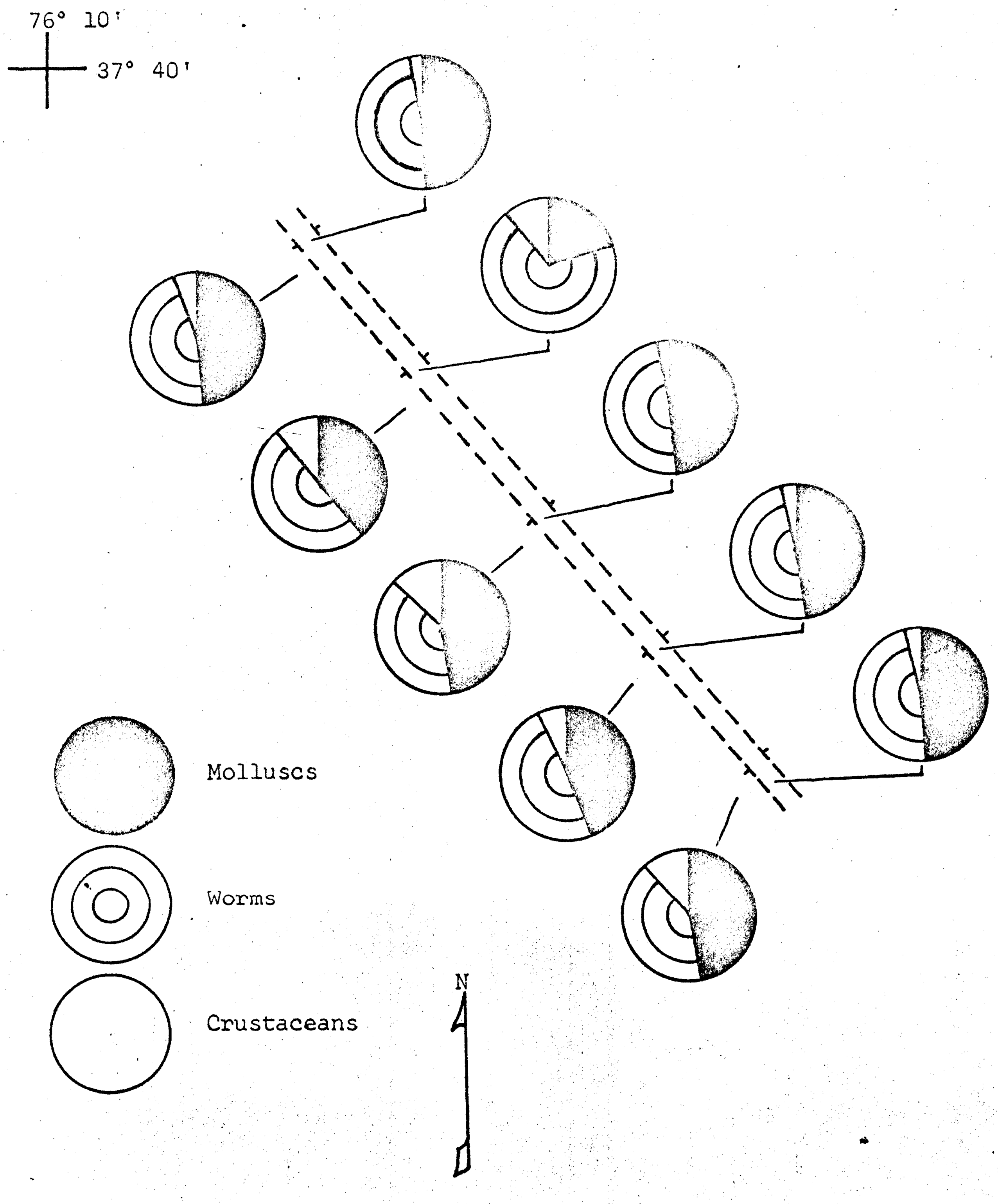


Figure 10 . Sector diagram comparison of the major faunal groups from the Rappahannock Shoals survey (inside versus outside channel), 0.5 mm screen, November 1963.

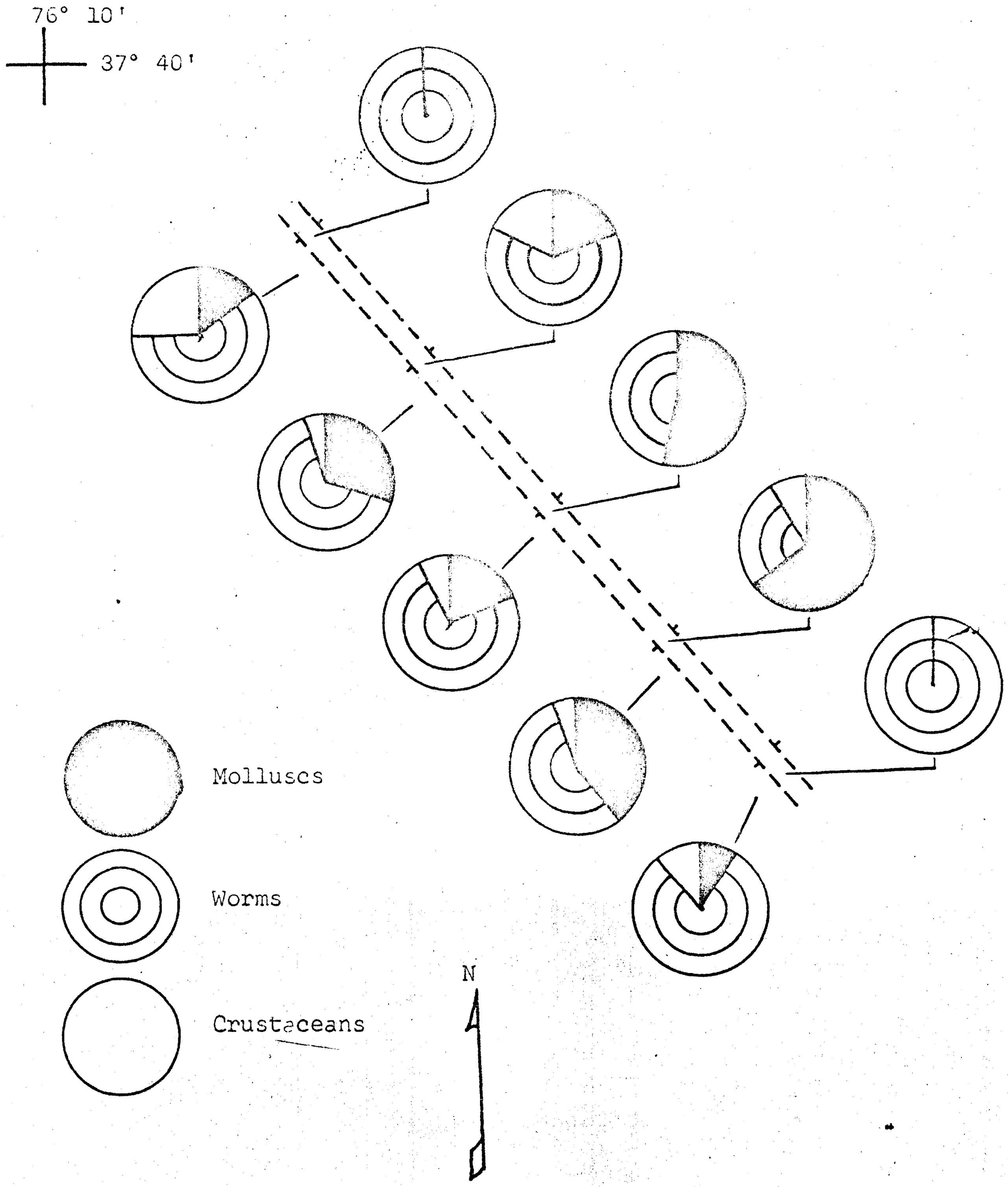


Figure 11 . Sector diagram comparison of the major faunal groups from the Rappahannock Shoals survey (inside versus outside channel), 0.5 mm screen, January 1964.

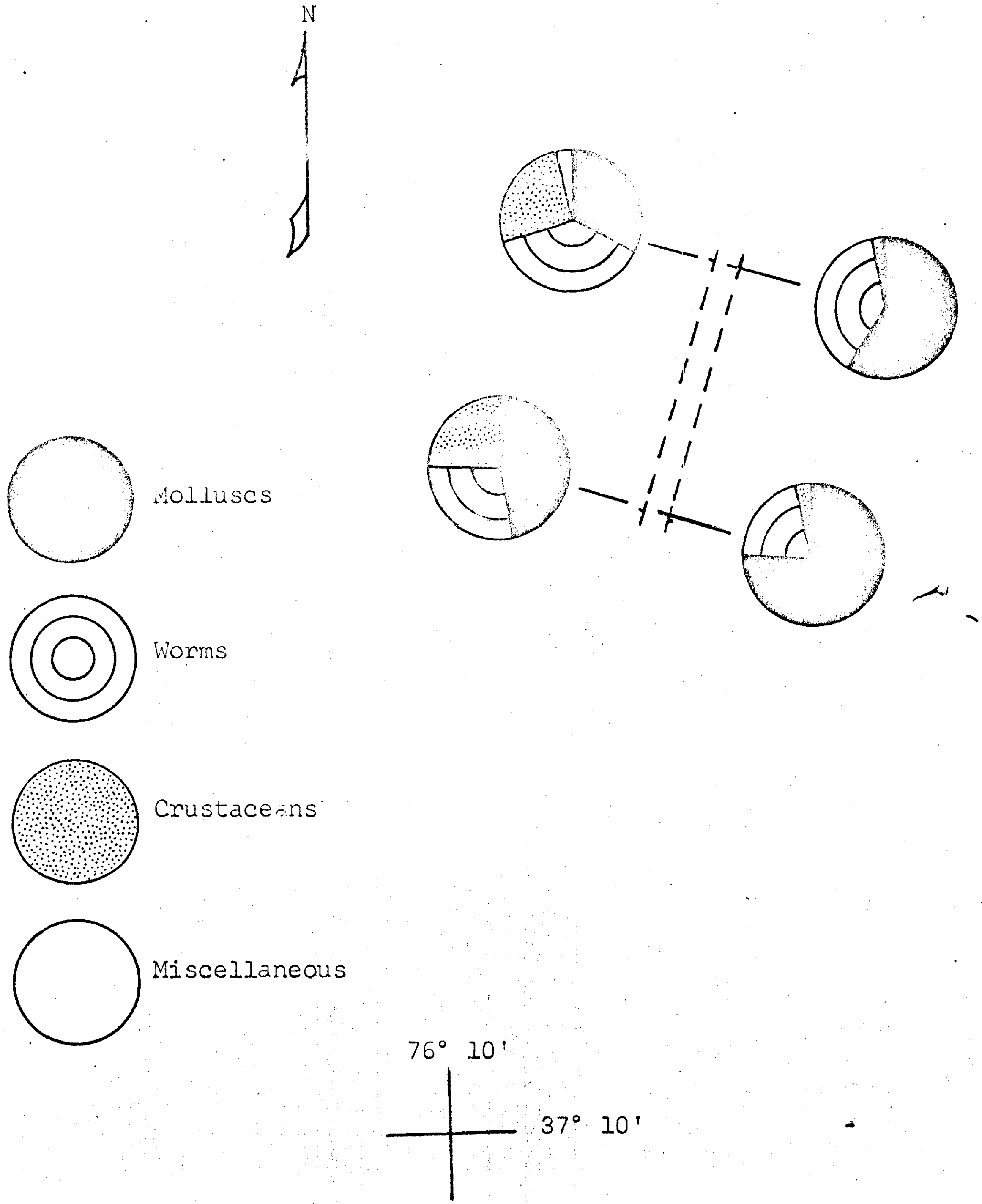


Figure 12. Sector diagram comparison of the major faunal groups from the York Spit channel area. (Inside versus outside channel) 1.0 mm screen, November 1963.

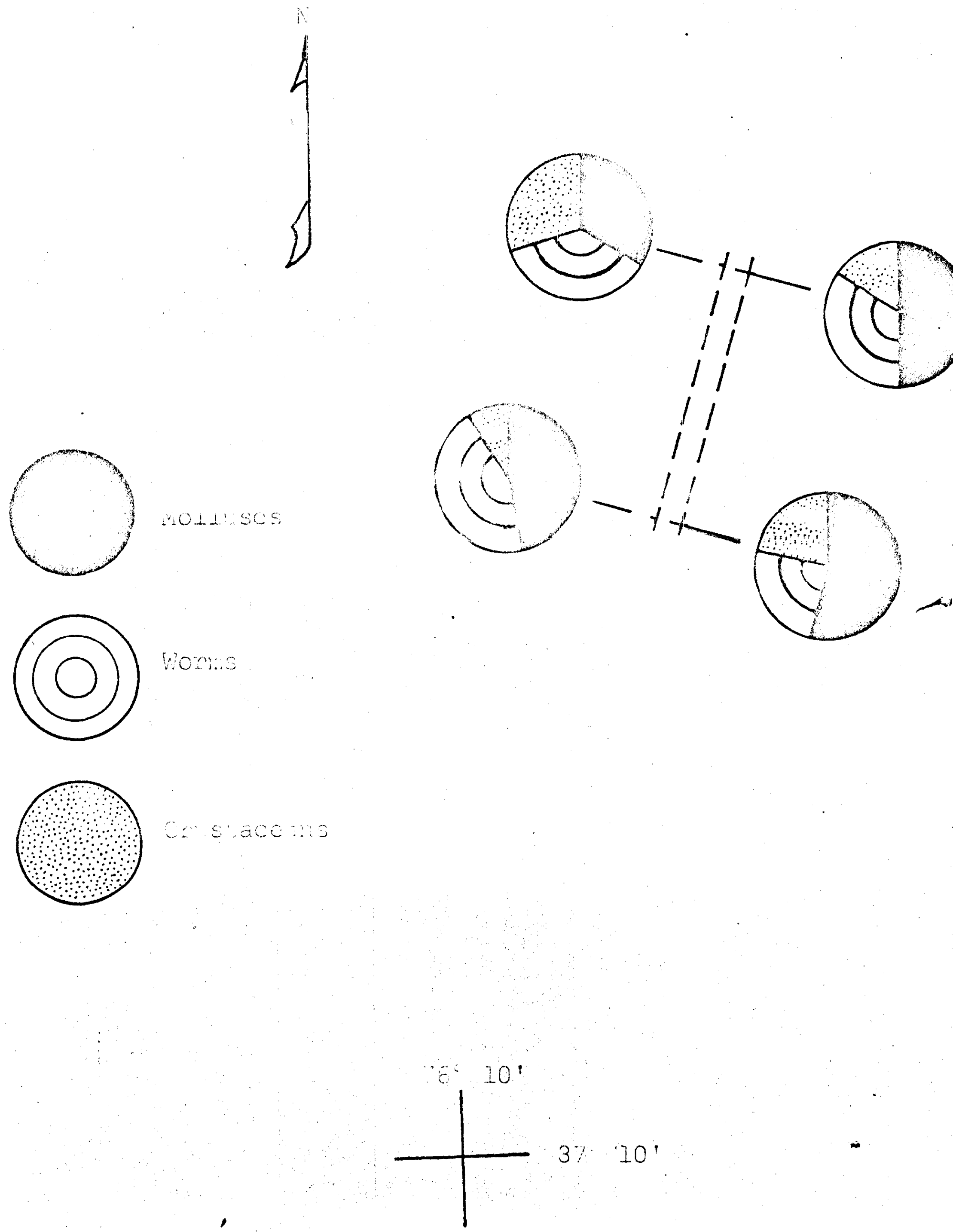


Figure 13. Sector diagram comparison of the major faunal groups from the York Spit channel area (inside versus outside of channel) 0.5 mm screen, November 1963.

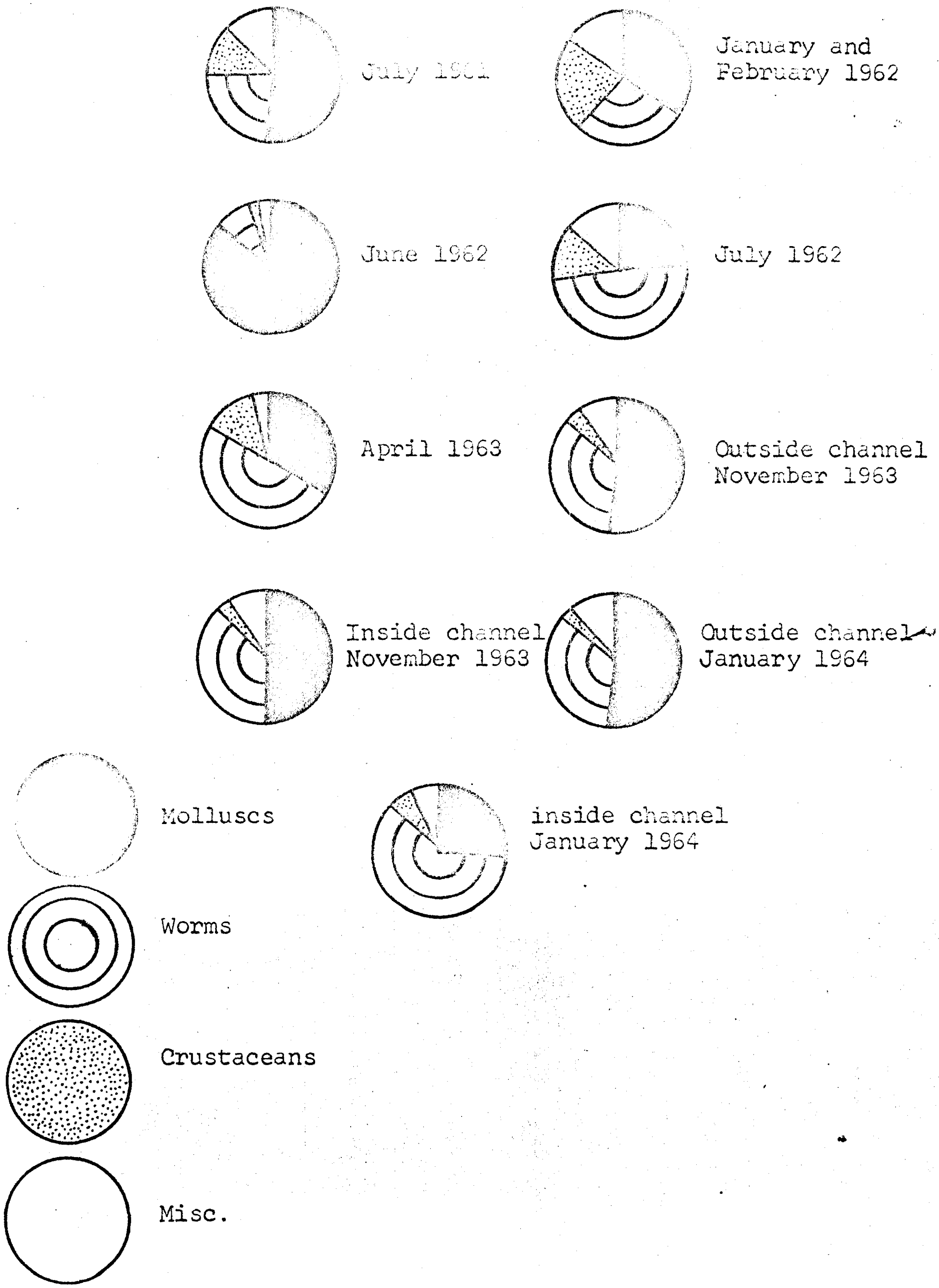


Figure 14. Sector diagram comparison of the major faunal groups from the Rappahannock Shoals survey. 1 mm screen.

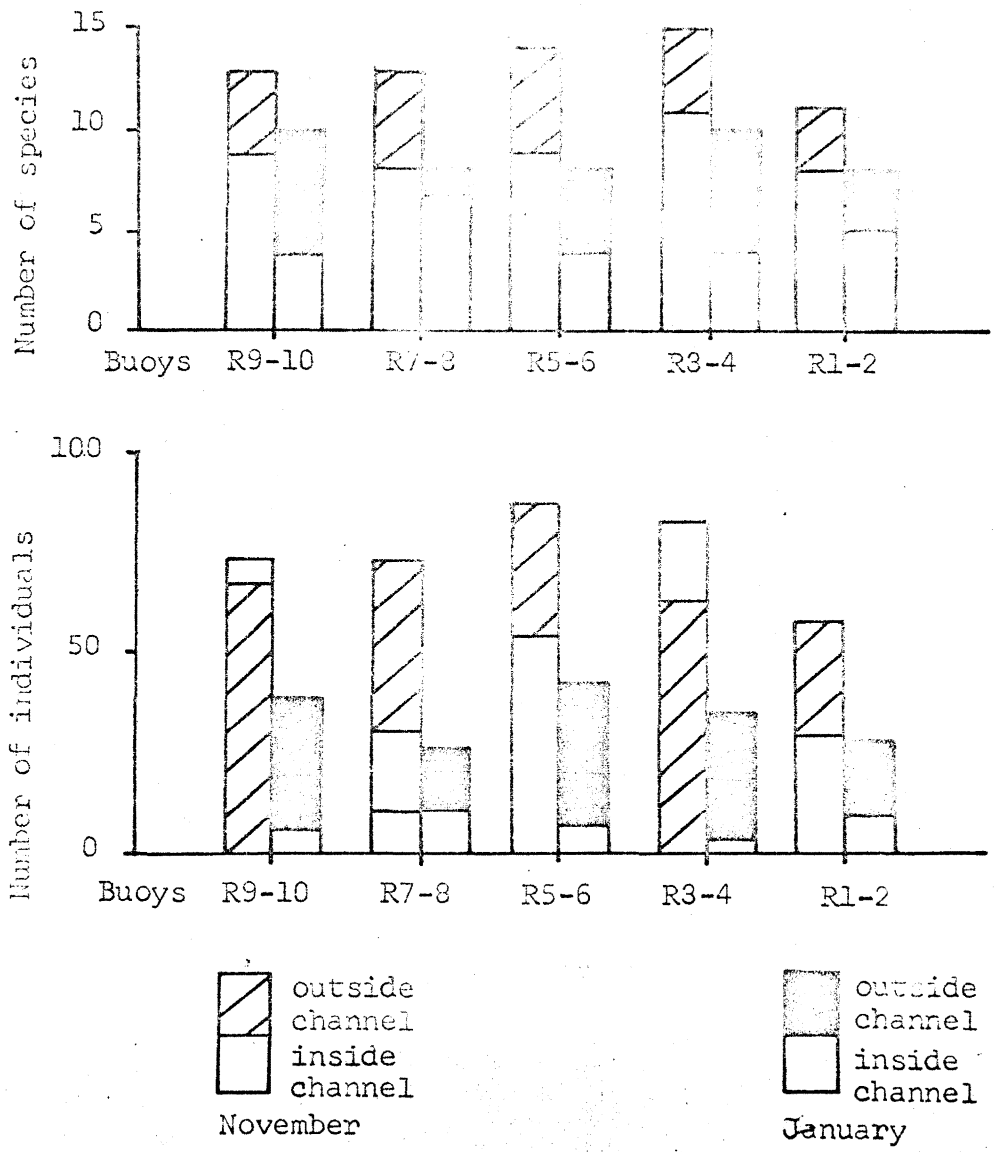


Figure 15.

Relationship between samples taken November 20, 1963, and January 30, 1964, from the Rappahannock Shoals Channel area (1 mm screen, average of 5 samples at each pair of buoys).

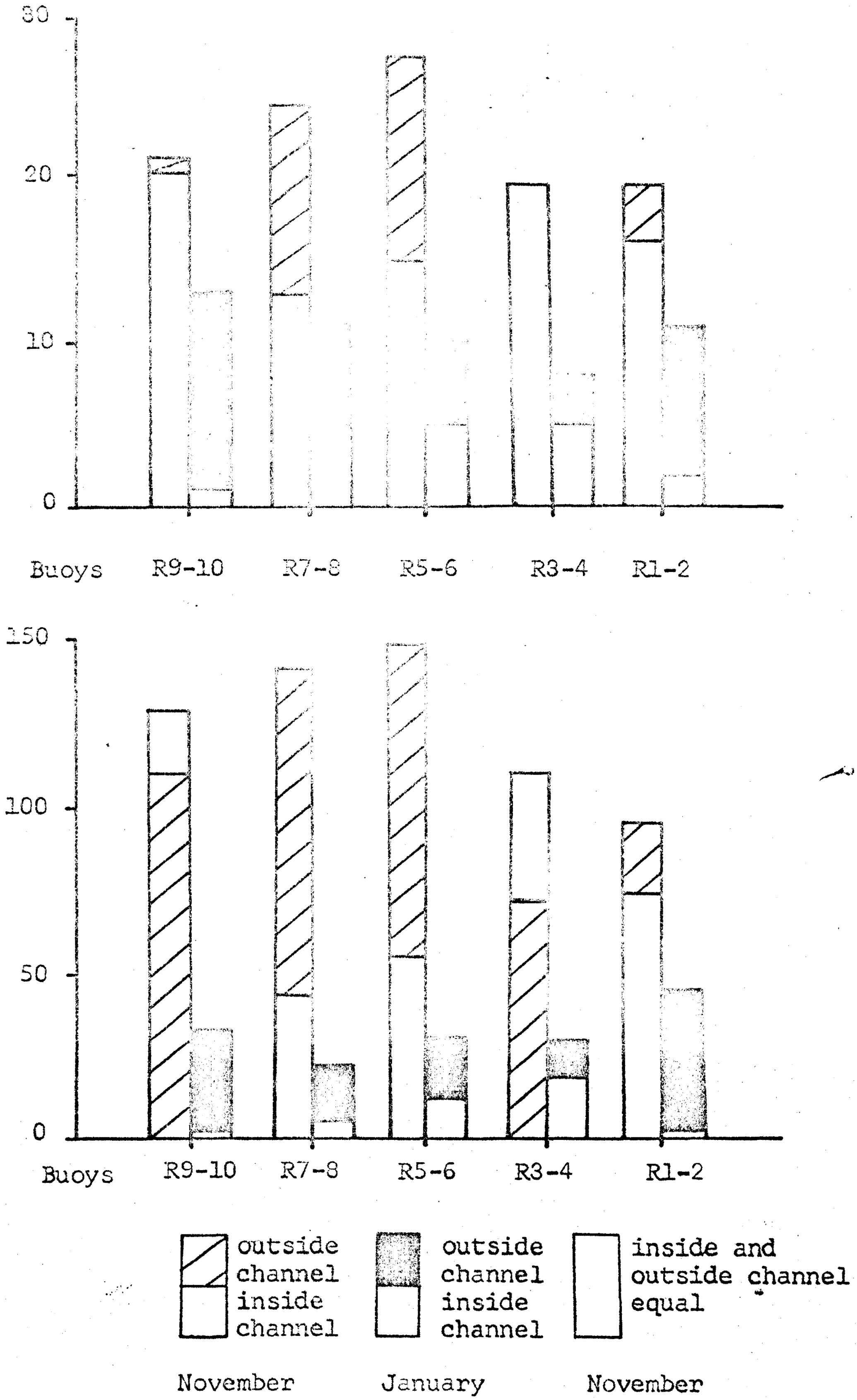


Figure 16.

Relationship between samples taken November 20, 1963, and January 30, 1964, from the Rappahannock Shoals Channel area (0.5 mm screen, average of [illegible] samples at each pair of buoys).

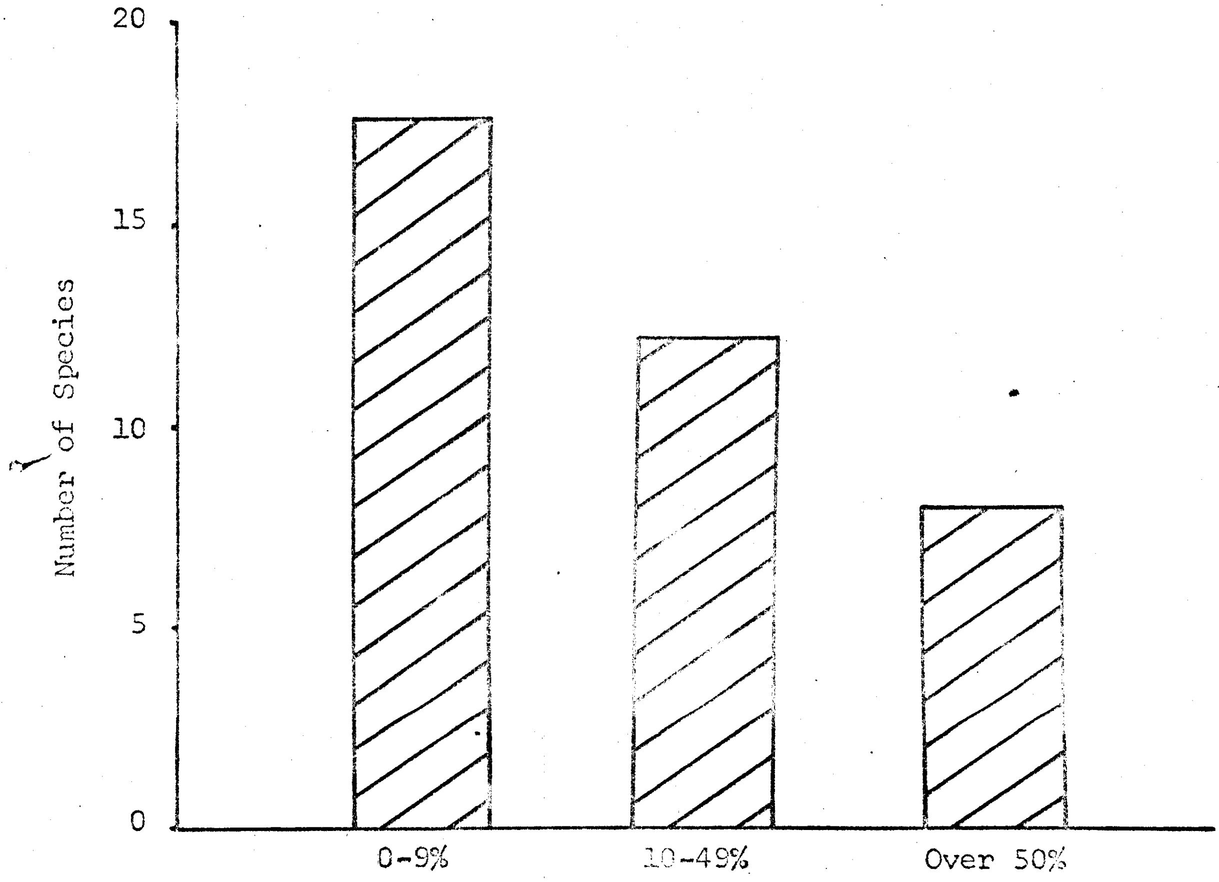


Figure 17. _Mulinia lateralis_ - inverse correlation with numbers of species per station.

Table 1

1 mm pore screen data

Date	No. grabs	Total indiv.	Average indiv. per grab	Average species per grab	Species / Indiv.
July 1961	100	9739	97	12.3	.13
Jan. 1962	90	4700	52	11.7	.23
June 1962	93	53264	573	19.4	.03
July 1962	26	2195	84	15.6	.19
Apr. 1963	41	743	19	4.9	.26
July 1963	10	1222	122	11.7	.10
Rappahannock Shoals Channel					
July 1963	25-in	data lost after partial analysis			
	25-out	data lost after partial analysis			
Nov. 1963	25-in	1354	54	8.8	.16
	25-out	1729	69	12.9	.19
Jan. 1964	25-in	175	7	4.0	.57
	25-out	891	34	8.8	.26
York Spit Channel					
Nov. 1963	8-in	301	38	8.9	.23
	8-out	433	54	14.0	.26
Total	526	76746	161	9.8	
$\bar{x}$-in channel			32	6.7	.21
$\bar{x}$-out channel			53	11.5	.22
0.5 mm pore screen data					
July 1963	15-in	681	46	combined samples	
	10-out	1349	135	combined samples	
Nov. 1963	25-in	2059	54	8.8	.16
	25-out	2824	69	12.9	.19
Jan. 1964	5-in	40	8	3.4	.43
	5-out	161	32	10.6	.25
York Spit Channel					
	8-in	628	79	16.3	.21
	8-out	1084	136	18.8	.14
Total	101	8826	83	11.8	
			64	9.7	
			105	13.9	

Table 2

Diversity analysis of common animals taken in the 1.0 mm screen, based on 476 samples*

Species	Freq.	Number	F/N	F-1/$\log_e N$	Rank	Bio-index	Rank
Nephtys incisa	379	4259	0.09	45.2	1	633	1
Retusa canaliculata	358	3334	0.11	44.0	2	420	2
Ampelisca vadorum	239	3181	0.08	29.5	5	131	7
Macoma tenta	223	996	0.22	32.2	3	94	8
Mulinia lateralis	215	4788	0.05	25.2	9	220	4
Pectinaria gouldi	211	2875	0.07	26.4	7	137	6
Amphiodia atra	210	703	0.30	31.9	4	64	11
Lyonsia hyalina	190	1745	0.11	25.3	8	69	9
Pseudeurythoe pauci-branchiata	175	459	0.38	28.4	6	35	13
Molgula manhattensis	164	2276	0.07	21.1	12	166	5
Cirriformia filigera	149	755	0.20	22.3	11	65	10
Turbonilla interrupta	139	292	0.47	24.1	10	12	18
Ensis directus	119	42252	0.003	11.0	25	239	3
Loimia medusa	109	211	0.52	20.2	13	6	
Phoronis architecta	102	438	0.23	16.6	14	19	16
Ampelisca macro-cephala	96	536	0.18	15.0	15	36	12
Mya arenaria	89	432	0.21	14.5	17	5	
Melinna maculata	84	253	0.33	14.2	19	15	17
Edwardsia leidyi	75	157	0.48	14.6	16	2	
Nereis succinea	71	138	0.51	14.2	18	12	18
Asabellides oculata	69	589	0.11	9.9	27	20	15
Anadara transversa	67	242	0.28	12.0	21	8	20
Ericthonius brasil-iensis	60	296	0.20	10.4	26	10	19
Lucina multilineata	57	189	0.38	11.0	24	6	
Oxyurostylis smithi	55	103	0.53	11.6	22		
Glycera (2 species)	54	79	0.68	12.1	20		
Paraprionospio pinnata	52	93	0.56	11.1	23	7	
Batea catharinensis	48	134	0.35	9.0	30	3	
Polycirrus eximius	26	429	0.06	4.1	37	8	20
Nucula proxima	45	225	0.20	8.1	32	15	17
Nephtys picta	45	135	0.33	9.0	31	8	
Cyathura polita	36	123	0.29	7.3	34	30	14
Scolecolepides viridis	23	123	0.19	4.6	35		
Spiophanes bombyx	22	120	0.18	4.4	36		
Corophium tuber-culatum	38	108	0.35	7.9	33	1	
Unciola irrorata	45	114	0.39	9.3	29		
Yoldia limatula	47	102	0.46	9.9	28		

*Animals taken in over 10% of the samples or in numbers over 100.

Table 3

Comparison of screen data for the two channels

Area	screen	in	%	out	%	Diff.
York Spit	1.0	628	50.0	1084	55.8	5.8
	0.5	628	50.0	860	44.2	
Total		1256		1944		
Rappahannock Shoals	1.0	575	33.6	3775	52.8	19.2
July	0.5	1135	66.4	3377	47.2	
Total		1710		7152		
November	1.0	1355	39.5	1733	38.1	1.4
	0.5	2080	60.5	2820	61.9	
Total		3435		4553		
January	1.0	175	46.7	841	51.1	4.4
	0.5	200	53.3	805	48.9	
Total		375		1646		

Differences in Rappahannock Shoals numbers

	screen	in		out	
July vs. November	1.0	$\frac{1355}{575}=$	42.4	$\frac{1733}{3775}=$	45.9
			135.6 incr.		54.1 dec.
	0.5	$\frac{2080}{1135}=$	54.6	$\frac{2820}{3377}=$	83.5
			83.2 inc.		16.5 dec.
November vs. January	1.0	$\frac{175}{1355}=$	12.9	$\frac{841}{1733}=$	48.5
			87.1 dec.		51.5 dec.
	0.5	$\frac{200}{2080}=$	9.6	$\frac{805}{2820}=$	28.5
			90.4 dec.		71.5 dec.

Totals	screen	in	out	
	1.0	2733	7209	(2.6)
	0.5	4043	8086	(2.0)
		6776	15295	

Table 4

Mean number of individuals at each buoy

Buoy Number	Channel		Shoal	
	November	January	November	January
1	73.2	5.6	66.8	38.4
2	30.4	10.2	71.6	28.8
3	54.8	6.0	87.2	41.8
4	83.4	4.2	62.8	36.0
5	29.0	9.0	57.5	27.2
$\bar{x}$	54.0	7.0	69.2	34.4

TABLE 5. Feeding type, substrate, habit, size, abundance in area, numbers, frequency, and means of organisms encountered on the Rappahannock Shoals Channel Survey. 1961-1964.

Species	Feed. type	Sub-strate	Habit	Size	Area Abun.
Porifera					
1. Craniella crania	S	S	A	L	R
Coelenterata					
2. Aiptasia eruptaurantia	CM	Si-S	I	S	S
3. Ceriantheopsis americanus	C	Si-C	I	L	C*
4. Diadumene leucolena	CM	Sh	A	S	Ac
5. Edwardsia leidyi	CM	Si-S	I	S	C*
6. Leptogorgia virgulata	CM	Sh	A	LC	Ac
7. Paranthus rapiformis	C	S	I	L	Ac
8. Thuiaria argentea	CM	Si-S	A	LC	S
Platyhelminthes					
9. Stylochus ellipticus	C	Sh-D	M	S	S
Rhynchocoela					
10. Amphiporus bioculatus	CM	Si-S	I	M	R
11. A. caecus	CM		I	M	R
12. Carinoma tremaphoros	CM	Si-C	I	M	A*
13. Carinomella lactea	CM	Si-C	I	M	S*
14. Cerebratulus luridus	C	Si-S	I	L	C*
15. Lineus bicolor	C	Si-C	I	S	R
16. Micrura leidyi	C	Si-S	I	L	R
17. M. rubra	C		I	S	R
18. Nemertean unid.					
19. Oerstedia dorsalis	C		I	M	R
20. Tubulanus pellucidus	C		I	S	R
21. Zygeupolia rubens	C		I	M	R
Ectoprocta					
22. Aeverrillia armata	S	Sh	A	LC	R
23. Alcyonidium polyoum	S	Sh	A	SC	R
24. A. verrilli	S	S-Sh	A	LC	R
25. Amathia convoluta	S	Sh-D	A	LC	R
26. A. vidovici	S	Sh-D	A		R
27. Bugula turrita	S	Sh-D	A	LC	R
28. Crisia eburnea	S	Sh	A	LC	R
29. Membranipora tenuis	S	Sh	A	EC	Ac
Phoronida					
30. Phoronis architecta	S	Si-S	I	S	S
Annelida					
Oligochaeta					
31. Oligochaeta unid.			I	S	S
Polychaeta					
32. Aglaophamus verrilli	C	S	I	SL	S
33. Amphidura sp.		Si-S	I	M	R
34. Amphitrite ornata	SD	Si-S	I	L	R
35. Ancistrosyllis bassi		Si-S	I	S	C
36. Arabella iricolor	C	Si-S	I	L	R*

	1.0 mm screen			0.5 mm screen		
	Total Indiv.	Freq.	Avg. No. per sample	Total Indiv.	Freq.	Avg. No. per sample
1.	75	4	18.8			
2.	17	16	1.1			
3.	53	38	1.4			
4.	5	4	1.3			
5.	157	75	2.1	4	4	1.0
6.	3	2	1.5			
7.	1	1	1.0			
8.	3	3	1.0			
9.	61	32	1.9			
10.	13	11	1.2			
11.	1	1	1.0			
12.	29	15	1.9	449	50	9.0
13.	28	15	1.5			
14.	39	36	1.1			
15.	1	1	1.0			
16.	3	2	1.5			
17.	8	8	1.0	3	3	1.0
18.	55	29	1.9	67	28	2.4
19.	4	1	4.0			
20.	11	9	1.2	2	2	1.0
21.	1	1	1.0			
22.	5	5	1.0			
23.	4	4	1.0			
24.	10	10	1.0			
25.	8	8	1.0			
26.	1	1	1.0			
27.	1	1	1.0			
28.	9	9	1.0			
29.	2	2	1.0			
30.	438	102	4.3	26	14	1.9
31.				9	4	2.3
32.	39	18	2.2	7	7	1.0
33.				5	4	1.3
34.	7	6	1.2			
35.	50	34	1.5	48	23	2.1
36.	1	1	1.0			

Species	Feed. type	Sub-strate	Habit	Size	Area Abun.
37. Aracidea sp.		Si-C	I	M	R
38. Asabellides oculata	SD	Si-C	I	MS	S*
39. Asychis elongata	NSD	Si-C	I	SL	C*
40. Axiothella catenata	NSD	S	I	S	S
41. Brania wellfleetensis		Si-D	I	M	R
42. Capitella capitata	NSD	Si-S-D	I	S	R
43. Chaetopterus variopedatus	S	Si-C	I	L	S*
44. Cirriformia filigera	SD	Si	I	SL	A*
45. Clymenella torquata	NSD	Si-S	I	SL	R
46. Cossura sp.		Si-C-S	I	M	R
47. Diopatra cuprea	C	Si-C-S	I	L	R
48. Drilonereis longa	C	S	I	S	Ac
49. Eteone heteropoda	C	Si-S-D	I	S	R
50. Euclymene collaris	NSD	Si-S	I	S	R
51. Eumida sanguinea	C	Si-S	I	S	R
52. Eupomatus uncinatus	S	Sh	A	M	R
53. Eusyllis fragilis	C		I	M	R
54. Exogone dispar	C	Si-S	I	M	R
55. Glycera (2 sp.)	SD	Si-S	I	S	S
56. Glycinde solitaria	C	Si-S	I	MS	R
57. Gyptis vittata	C	Si-C	I		R
58. Harmothoe extenuata	C		M	S	R
59. Harmothoe sp.	C	Si-C-D	MC?	MS	A*
60. Heteromastus filiformis	NSD	Si-S	I	M	R
61. Lepidametria commensalis	C	Si-S	IC	S	R
62. Lepidonotus sublevis	C	S-D	M	S	S
63. Loimia medusa	SD	Si-C	I	SL	A*
64. Lumbrineris tenuis	NSD	Si-C-S	I	SL	Ac
65. Melinna maculata	SD	Si-S	I	S	C*
66. Nephtys incisa	SD	Si-C	I	SL	A*
67. N. magellanica	SD	Si-S	I	S	C
68. N. picta	SD	S	I	SL	C
69. Nereis arenaceodonta			I	M	R
70. N. grayi			I	S	R*
71. N. succinea	SDC	S-D	I	SL	S
72. Notomastus latericius	NSD	Si-S	I	S	Ac
73. Ophelia bicornis	NSD	S	I	S	R
74. Orbinia ornata	NSD	S	I	S	R
75. Owenia fusiformis	S	S	I	S	R
76. Paleanotus heteroseta	C	Si-S	M	S	R
77. Paraprionospio pinnata	SD	Si-S	I	S	S
78. Pectinaria gouldi	NSD		I	SL	C*
79. Phyllodoce arenae	C	S	I	S	R
80. Pista cristata	SD	S	I	S	S
81. P. maculata	SD	S	I		R
82. P. palmata	SD	S	I	S	R
83. Platynereis dumerilii	H	Z	M	S	Ac
84. Podarke obscura	C	Si-D	I	S	R
85. Polychaetes unid.					
86. Polycirrus eximius	SD	Si-S	I	S	C
87. Polydora ligni	SD	D-Sh	A	M	S
88. Prionospio cirrifera	SD	Si-C	I	M	C*
89. Pseudeurythoe paucibranchiata	C	Si-S-C	I	S	A*

	1.0 mm screen			0.5 mm screen		
	Total Indiv.	Freq.	Avg. No. per sample	Total Indiv.	Freq.	Avg. No. per sample
37.	1	1	1.0	1	1	1.0
38.	589	69	8.5	1	1	1.0
39.	50	36	1.4			
40.	28	13	2.2			
42.	3	3	1.0			
43.	38	31	1.2			
44.	755	149	5.1			
45.	83	29	2.9			
46.				4	2	2.0
47.	4	4	1.0			
48.	1	1	1.0			
49.	4	4	1.0			
50.	25	13	1.9			
51.	2	2	1.0			
52.	2	2	1.0			
53.	1	1	1.0			
54.	1	1	1.0	5	5	1.0
55.	79	54	1.5	19	13	1.5
56.	6	5	1.2	13	11	1.2
57.	5	4	1.3	22	17	1.3
58.	18	13	1.4			
59.	55	45	1.2	124	41	3.0
60.	5	4	1.3	1	1	1.0
61.	3	3	1.0			
62.	21	14	1.5			
63.	211	109	1.9			
64.	2	1	2.0			
65.	253	84	3.0			
66.	4259	379	11.2	28	17	1.6
67.	85	33	2.6	184	38	4.8
68.	135	45	3.0			
69.	3	3	1.0			
70.	9	7	1.3	6	6	1.0
71.	138	71	1.9	35	12	2.9
72.	5	3	1.7			
73.	12	1	12.0			
74.	3	1	3.0			
75.	12	6	2.0	1	1	1.0
76.	4	3	1.3	6	6	1.0
77.	93	52	1.8	30	17	1.8
78.	2875	211	13.6	2	2	1.0
79.	7	5	1.4	4	4	1.0
80.	20	9	2.2			
81.	1	1	1.0			
82.	7	6	1.2			
83.	York Spit					
84.	3	3	1.0			
85.				502	50	10.0
86.	429	26	16.5			
87.	78	31	2.5	131	33	4.0
88.	10	3	3.3	239	41	5.8
89.	459	175	2.6	383	35	10.9

Species	Feed. type	Sub-strate	Habit	Size	Area Abun.
90. Sabella microphthalma	S	SD	A	S	Ac
91. Sabellaria vulgaris	S	S-Sh	A	S	Ac
92. Scolecolepides viridis	SD	S-Si-D	I	S	R
93 Scolelepis bousfieldi	SD	Si-C	I	M	C*
94. Scoloplos robustus	NSD	S	I	ML	R
95. Spio setosa	SD	S	I	M	R
96. Spiochaetopterus oculatus	S	Si-S	I	S	R
97. Spiophanes bombyx	SD	S	I	M	S
98. Sthenelais boa	C	S	I	L	S
99. Streblospio benedicti	SD	Si-D	I	S	R
100. Tharyx setigera	SD	S	I	M	R
101. Travisia carnea	NSD	S	I	M	R
Hirudinea					
102. Piscicola funduli	C		M	S	Ac
Echiuroida					
103. Echiuroid unid.	NSD	Si-C	I	S	R*
Mollusca					
Pelecypoda					
104. Aligena elevata	SD	Si-S	IC	S	R
105. Amygdalum papyria	S	Si-C	I	S	Ac
106. Anadara transversa	S	Si-S	AM	SL	C*
107. Cardiomya glypta		Si-C	I	S	R*
108. Dosinia discus	S	Si-C	I	L	Ac
109. Ensis directus	S	Si-S	I	MS	S
110. Gemma gemma	S	S	I	S	S
111. Laevicardium mortoni		S	I	S	S
112. Lucina multilineata		Si-S	I	S	S*
113. Lyonsia hyalina		Si-C-S	I	S	C*
114. Macoma balthica	SD	Si-C-S	I	L	Ac
115. M. phenax	SD	Si-C	I	S	Ac
116. M. tenta	SD*	Si-C-S	I	SL	A*
117. Mercenaria mercenaria	S	Si-C	I	L	R
118. Mulinia lateralis	S	Si-C	I	SL	A*
119. Mya arenaria	S	Si-S	I	S	R
120. Mytilus edulis	S	Si-C-D	AM	SL	Ac
121. Nucula proxima	SD*	S	I	S	S
122. Pandora trilineata		S	I	SL	S
123. Tellina agilis	SD	Si-S	I	S	S
124. Yoldia limatula	SD*	Si-S	I	S	S*
Gastropoda					
125. Anachis avara	SD	C-S	M	SL	Ac
126. Anachis transversa	SD	Si-S	M	S	C
127. Bittium alternatum	H	Z	M	M	Ac
128. Busycon canaliculatum	C	S	M	L	R
129. Caecum pulchellum		S	I	M	C
130. Crepidula fornicata	S	Sh	A	SL	Ac
131. Cylichna alba		Si-C	M	M	C*
132. Epitonium rupicola		Si-S-C	M	S	C*
133. Eupleura caudata	C	Si-S-Sh	M	SL	R
134. Mangelia cerina		Si-S	M	S	Ac
135. M. plicosa		S	M	S	Ac
136. Mitrella lunata	H	Z	M	S	Ac
137. Nassarius vibex	D	SD	M	L	S

	1.0 mm screen			0.5 mm screen		
	Total Indiv.	Freq.	Avg. No. per sample	Total Indiv.	Freq.	Avg. No. per sample
90.	14	10	1.4			
91.	3	2	1.5			
92.	123	23	5.3			
93.	2	2	1.0	39	23	1.7
94.	10	7	1.4			
95.	13	7	1.9			
96.	38	22	1.7	1	1	1.0
97.	120	22	5.5	1	1	1.0
98.	10	9	1.1			
99.	37	16	2.3			
100.	5	1	5.0			
101.	6	4	1.5			
102.	2	1	2.0			
103.	2	2	1.0			
104.	5	4	1.3			
105.	1	1	1.0			
106.	242	67	3.6			
107.	21	14	1.5			
108.	1	1	1.0			
109.	42252	118	358.0			
110.	84	13	6.5			
111.	33	18	1.8			
112.	189	57	3.3	101	36	2.8
113.	1745	190	9.2			
114.	1	1	1.0			
115.	2	1	2.0			
116.	996	223	4.5			
117.	3	3	1.0			
118.	4788	215	22.3	1	1	1.0
119.	432	89	4.9			
120.	20	11	1.8			
121.	225	45	5.0	1	1	1.0
122.	22	12	1.8			
123.	49	13	3.8	11	5	2.2
124.	102	47	2.2			
125.	1	1	1.0			
126.	74	33	2.2			
127.	3	3	1.0			
128.	1	1	1.0			
129.	4	1	4.0			
130.	4	4	1.0			
131.	23	13	1.8	48	20	2.4
132.	51	40	1.3	2	2	1.0
133.	14	12	1.2			
134.	1	1	1.0			
135.	1	1	1.0			
136.	25	14	1.8			
137.	44	33	1.3			

Species	Feed. type	Sub-strate	Habit	Size	Area Abun.
138. Odostomia bisuturalis		Si-S	M	MS	S
139. O. hendersoni		Si-C	M	M	A*
140. O. impressa	C	Si-S	M	MS	[illegible]
141. Retusa canaliculata	SD	Si-C-S	M	MS	A*
142. Turbonilla interrupta		Si-S	M	MS	C
143. T. stricta		Si-C	M	M	A*
144. Urosalpinx cinerea	C	Si-S	M	L	Ac
145. Vitrinella sp.		Si-C	M	M	R*
Arthropoda					
Ostracoda					
146. Cylindrolebris mariae		SD	M	M	Ac
147. Sarsiella texana		Si-C	M	M	R*
148. S. zostericola		Si-C	M	M	S*
Cirripedia					
149. Balanus eburneus	S	Sh-D	A	S	Ac
150. B. improvisus	S	Sh-D	A	S	Ac
Pycnogonida					
151. Callipallene brevirostris		D	M	M	R
Mysidacea					
152. Neomysis americana	S		M	S	Ac
Cumacea					
153. Leucon nasica	SD	Si-C	MI	M	Ac
154. Oxyurostylis smithi	SD	S	MI	S	C
Isopoda					
155. Chiridotea coeca	SD	Si-S	M	S	Ac
156. Cyathura polita	SD	S	MI	S	S
157. Edotea triloba	SD	S-D	M	S	R
158. Erichsonella attenuata	H	Z	M	S	Ac
159. Idothea baltica	H	Z	M	S	Ac
Amphipoda					
160. Ampelisca macrocephala	S	Si-S	I	MS	C
161. A. vadorum	S	S	I	M	A
162. Amphipods unid.					
163. Batea catharinensis		D-A	M	M	S
164. Caprella equilibra	HC	H-A	M	S	R
165. C. geometrica	HC	H-A	M	S	R
166. Carinogammarus mucronatus	HD	Si-S	M	S	Ac
167. Cerapus tubularus	SD	Si-C	M	M	R*
168. Corophium tuberculatum	SD	Si-D	M	MS	R*
169. Cymadusa compta	H	Z	M	S	Ac
170. Elasmopus pocillimanus	HD	Si-S	M	S	Ac
171. Ericthonius brasiliensis	HS		AM	S	C*
172. Gammarus fasciatus	D	Si-S-D	M	S	Ac
173. Haustorius arenarius	S	S	MI	S	R
174. Listriella clymenellae	D	Si-S	MC	M	R
175. Melita fresneli	H	D-A	M	S	Ac
176. Monoculodes edwardsi	S	S	MI	S	S
177. Paracaprella tenuis	HD	Si-D	M	S	C*
178. Parametopella cypris		Si-D	M	M	R
179. Paraphoxus spinosus	S	S	MI	S	S
180. Unciola irrorata		Si-S-D	M	S	S
Decapoda					
181. Callinectes sapidus	C		M	L	R

	1.0 mm screen			0.5 mm screen		
	Total Indiv.	Freq.	Avg. No. per sample	Total Indiv.	Freq.	Avg. No. per sample
138.	33	18	1.8	269	48	5.6
139.	4	4	1.0	125	20	6.3
140.	5	5	1.0	45	20	2.3
141.	3334	358	9.3	576	43	13.4
142.	292	139	2.1	99	37	2.7
143.	2	2	1.0	477	50	9.5
144.	2	1	2.0			
145.	5	4	1.3	1	1	1.0
146.				July 1963		
147.	1	1	1.0	14	13	1.1
148.	1	1	1.0	167	39	4.3
149.	1	1	1.0			
150.	2	2	1.0			
151.	5	3	1.7			
152.	4	4	1.0			
153.	1	1	1.0			
154.	103	55	1.9	19	18	1.1
155.	1	1	1.0			
156.	123	36	3.4			
157.	6	6	1.0			
158.	4	1	4.0			
159.	4	3	1.3			
160.	536	96	5.6			
161.	3181	239	13.3	85	38	2.2
162.				29	16	1.8
163.	134	48	2.8	27	10	2.7
164.	26	12	2.2			
165.	87	31	2.8			
166.	19	10	1.9			
167.	8	7	1.1	16	7	2.3
168.	108	38	2.8	1	1	1.0
169.	1	1	1.0			
170.	37	11	3.4	1	1	1.0
171.	296	60	4.9	8	4	2.0
172.	14	10	1.4			
173.	1	1	1.0			
174.	4	4	1.0			
175.	2	2	1.0			
176.	22	8	2.8			
177.	86	35	2.5	27	8	3.4
178.	2	1	2.0	8	4	2.0
179.	16	9	1.8			
180.	114	45	2.5			
181.	1	1	1.0			

Species	Feed. type	Sub-strate	Habit	Size	Area Abun.
182. Crangon septemspinosa		S	M	SL	S
183. Eurypanopeus depressus	CSC	Sh-D	M	S	R
184. Hexapanopeus angustifrons	CSC	Sh-S-D	M	S	S
185. Libinia dubia	HSC	Si-S-D	M	SL	R
186. Ogyrides limicola	SD	Si-C	M	S	R*
187. Pagurus longicarpus	SC	S	M	SL	R
188. Panopeus herbsti	CSC	Sh-S-D	M	SL	S
189. Pinnixa chaetopterana	SD	Si-C	MC	S	S*
190. P. retinens	Si-C-D	Si-C	MC	MS	R*
191. P. sayana	SD		MC	S	R
192. Rhithropanopeus harrisi	CSC	Si-C-S	M	S	R
193. Upogebia affinis	SD	Si-C-S	M	L	R*
Echinodermata					
194. Amphiodia atra	SDC	Si-C-S	M	SL	A*
195. Cucumeria pulcherrima	SD	Sh	M	L	Ac
196. Leptosynapta inhaerens	NSD	Si-S	I	SL	R
Hemichordata					
197. Saccoglossus kowalevskii	NSD	Si-S	I	S	Ac
198. Stereobalanus canadensis	NSD	Si-C	I	L	S*
Urochordata					
199. Molgula manhattensis	S	Si-S	A	SL	C*
Cephalochordata					
200. Branchiostoma caribaeum	SD	S	MI	SL	R

In addition to the 189 forms identified to species and those named to genus or phylum in the above list, there are 193 animals, mostly minute tellinids from the channel, which were not identified below a higher taxa. These, plus 628 organisms from the unlisted York Spit site, bring the 1.0 mm total to 76,485. Extrapolation from the means derived before loss of the data from the July 1963 channel area survey adds another 4,300 animals to make an approximate total of 80,785.

Addition of 860 specimens from York Spit and 2,032 from the July 1963 combined samples brings the 0.5 mm screen animals to 7,632.

	1.0 mm screen			0.5 mm screen		
	Total. Indiv.	Freq.	Avg. No. per sample	Total Indiv.	Freq.	Avg. No. per sample
182.	13	11	1.2			
183.	7	6	1.2			
184.	28	18	1.6			
185.	2	2	1.0			
186.	13	10	1.3			
187.	1	1	1.0			
188.	44	32	1.4			
189.	7	6	1.2			
190.	2	2	1.0			
191.	3	3	1.0			
192.	2	2	1.0			
193.	6	5	1.2			
194.	703	210	3.3			
195.	1	1	1.0			
196.	20	17	1.2			
197.	9	3	3.0			
198.	23	20	1.2			
199.	2276	164	13.9			
200.	4	4	1.0			
Total:	75669		394.0	4562		74.8
Species:	193			61		

Explanation of symbols used in Table 5

a. Feeding type:

C	- carnivorous
CM	- carnivorous on minute animals
D	- detritus
H	- herbivorous
S	- suspension feeder, also filter-feeding amphipods
SD	- selective deposit feeders
NSD	- non-selective deposit feeders

b. Substrate:

A	- algae
C	- clay
D	- detritus
S	- sand
Sh	- shell
Si	- silt
Z	- *Zostera*

c. Habit:

A	- attached
C	- commensal
I	- infauna
M	- motile

d. Size:

C	- colonial
E	- encrusting
L	- large
M	- minute
S	- small

e. Abundance in area:

A	- abundant
Ac	- accidental
C	- common
R	- rare
S	- scarce
*	- part of soft-bottom community

The categories for each division are more or less subjective, particularly for feeding, substrate, and abundance. Some of the feeding types are taken directly or inferred from Sanders (1960), Pettibone (1963), or Mangum (1964). None are based on gut examinations.

Substrate preferences are better known for the more abundant organisms, less so for those more rare. Depth and salinity preferences are not given but these may be as important as substrate.

Size determinations refer to the sizes most commonly taken, which for several species may have been juveniles. They are intended to be relative to general sizes in a group.

Abundance determinations were based on overall knowledge of lower Chesapeake Bay and its tributaries. However, forms designated as rare are generally poorly known in Chesapeake Bay. Those listed as accidental have been found elsewhere in much greater abundance. Judgments are relative to the size and distribution of the group. Ensis, for example, even though it comprised most of the population during one cruise, is listed as scarce. However, it normally is rare in the area sampled. Amphiodia, however, is called abundant because the numbers found seemed near maximum in favorable seasons.

Table 6

Sediment relationships of the most common animals

Species	Cruise no.*	Total no.	Freq.	Sediment type with estimate of number m² in each						
				1	2	3	4	5	6	7
PORIFERA										
Craniella crania	1	71	2	1,050	15					
COELENTERATA										
Ceriantheopsis americanus	3	36	13	110		30	15	15	15	30
Edwardsia leidyi	1	77	39	23	38	23	30	33	20	32
	2	30	14	20	60	60	15			28
	3	32	15	18	90	23	15	82		20
PLATYHELMINTHES										
Stylochus ellipticus	3	48	21	46	15		15		19	20
RHYNCHOCOELA										
Carinoma tremaphorus	3	26	12	37		15	45	34	30	
Carinomella lactea	3	20	14	26	15			15	15	15
Nemertean unid.	1	39	13	58		30	135	15	15	
	3	23	9	15	15	30	165	15	60	15
ECTOPROCTA										
Crisia eburnea	3	18	2	135						
PHORONIDA										
Phoronis architecta	1	52	22	28	60	60	30	40	52	30
	3	60	20	55	15	15	67	15	35	
ANNELIDA										
Polychaeta										
Aglaophamus verrilli	2	25	10	48	30		45			15
Ancistrosyllis bassi	3	38	24	27	15	15	30	26	13	15
Asabellides oculata	3	586	66	72	75	180	161	158	167	79
Asychis elongata	1	16	13	15	15	15		30	15	19
Cirriformia filigera	1	138	28	117	51	15	30	39	105	
	2	97	18	15	30	60	172	75	96	15
	3	277	46	35	60	87	162	74	122	105

Table 6 continued

Species	Cruise no.*	Total no.	Freq.	Sediment type with estimate of number m^2 in each						
				1	2	3	4	5	6	7
ANNELIDA										
Polychaeta (continued)										
Clymenella torquata	2	23	10	43	23	30	15			
	3	43	12	62	15					
C. zonalis	1	17	6	48	15					
	3	38	20	35	38	23	30	19	30	15
Glycera (2 sp.)	2	16	13	21	15		15			15
	3	31	16	40	15				15	
Harmothoe sp.	3	22	19	15	15	25	20	15	15	
Loimia medusa	1	17	13	20	15	23	15	23	15	
	2	61	32	29	30	15	90	25	20	19
	3	65	31	30	25	15	25	65	45	15
Melinna maculata	1	69	19	58	75		20	38		
	2	131	32	77	69	105	38		54	28
	3	60	24	32	90	15		15	34	35
Nephtys incisa	1	951	77	159	161	310	150	173	161	157
	2	568	65	80	157	172	180	158	120	122
	3	1,627	96	254	215	451	232	282	240	210
N. magellanica	2	20	6	40	30		135			15
	3	44	12	48	30				98	
N. picta	2	59	19	33	37			15	70	71
	3	53	17	54	15			15	15	53
Nereis succinea	2	21	14	28	15		15		15	15
	3	37	15	47	15			15	15	53
Paraprionospio pinnata	1	28	18	22	15	15		33		15
	2	25	10	39	15		15			67
	3	30	14	23	53				15	60
Pectinaria gouldi	1	296	55	126	115	45	37	33	51	25
	2	109	38	31	60	90	60	20	58	40
	3	2,056	95	222	146	858	195	119	477	391
Platynereis dumerilli	1	75	24	23	144	15	45	30	19	15
Polycirrus eximius	1	20	4	75						
	3	404	19	491	15	15				135
Polydora ligni	2	48	12	85	23		60		45	15
	3	19	12	26		15		15	23	
Pseudeurythoe paucibranchiata	1	119	43	30	64	38	15	18	42	62
	3	217	71	63	68	15	33	34	38	44

Table 6 continued

Species	Cruise no.*	Total no.	Freq.	Sediment type with estimate of number m^2 in each						
				1	2	3	4	5	6	7
ANNELIDA										
Polychaeta (continued)										
<u>Scolecolepides viridis</u>	1	29	5	135	15					
	3	92	16	85			15			128
<u>Spiophanes bombyx</u>	3	92	14	104	30					
<u>Streblospio benedicti</u>	3	32	15	42		15	15		19	
MOLLUSCA										
Pelecypoda										
<u>Anadara transversa</u>	1	54	14	37	135		15		23	15
	2	111	19	143	135		30		23	78
	3	68	28	25	20	15	15	15	23	128
<u>Ensis directus</u>	1	63	21	47	45				15	
	3	43,276	93	12,300	8,980	4,220	4,870	4,710	9,300	2,900
<u>Gemma gemma</u>	1	61	6	171	60					
	3	17	5	70	30				15	
<u>Laevicardium mortoni</u>	2	23	11	38	38		15			15
<u>Lucina multilineata</u>	1	76	22	57	30	15		45		30
	2	73	19	38	465		30		45	15
	3	51	17	40	105					52
<u>Lyonsia hyalina</u>	1	599	75	184	218	135	63	58	49	141
	2	27	17	24	30	15	37	15	15	15
	3	1,089	89	262	218	210	103	60	135	163
<u>Macoma tenta</u>	1	361	58	132	106	60	84	75	27	34
	2	134	45	58	42	52	30	38	36	46
	3	220	55	74	45	65	40	33	96	36
<u>Mulinia lateralis</u>	1	3,487	86	180	319	920	716	503	183	1,557
	2	106	21	18	52	75	25	15	15	197
	3	1,168	99	199	180	202	130	124	140	202
<u>Nucula proxima</u>	1	71	11	124	15	15		45		
	2	74	12	162	30		15		15	15
	3	128	23	127	25	15		15	37	30
<u>Pandora trilineata</u>	3	20	10	34					15	15
<u>Tellina agilis</u>	3	50	14	61				15	15	30
<u>Yoldia limatula</u>	1	16	11	15	15	15		45	19	15
	3	88	39	39	15	45	30	30	38	31

Table 6 continued

Species	Cruise no.*	Total no.	Freq.	Sediment type with estimate of number m² in each 1	2	3	4	5	6	7
Gastropoda										
Anachis translirata	2	25	10	23	15	15	15	85	15	15
Epitonium rupicola	2	24	19	20	23		15	21	20	15
Mitrella lunata	2	16	7	42				15		15
Nassarius vibex	2	15	12	23	15				15	
Retusa canaliculata	1	406	75	66	68	110	177	90	71	73
	2	810	76	162	83	120	138	157	208	169
	3	502	94	100	27	75	95	73	78	48
Turbonilla interrupta	1	30	16	24	15	23		40	40	15
	2	87	44	25	23		30	52	38	21
	3	100	42	42	40	25	24	41	45	18
ARTHROPODA										
Cumacea										
Oxyurostylis smithi	2	25	12	33	37				15	
	3	65	33	36	15	15	20	15	25	15
Isopoda										
Cyathura burbancki	2	66	14	30	135				75	15
	3	40	14	50		15			30	30
Amphipoda										
Ampelisca macrocephala	1	237	19	206	23					
	2	150	30	71	140		158	23	20	70
	3	40	14	50		15			30	30
A. vadorum	1	905	68	560	183	300	105	113	111	73
	2	594	59	221	95	90	186	49	80	183
	3	1,205	86	28	22	175	129	93	156	249
Batea catharinensis	2	89	18	84	97	15	15	30	15	145
	3	24	10	30	15			83		15
Caprella equilibra	3	18	7	49	15				15	45
C. geometrica	2	25	10	50			15	15		23
	3	57	16	73	15			15	15	30
Corophium tuberculatum	1	48	20	26	15	38	30	30	34	60
	2	44	16	60	23		90		15	19
	3	31	11	66			15		15	262

Table 6 continued

Species	Cruise no.*	Total no.	Freq.	Sediment type with estimate of number m² in each: 1	2	3	4	5	6	7
ARTHROPODA										
Amphipoda (continued)										
Elasmopus pocillimanus	2	18	3	90						
Ericthonius brasiliensis	2	47	10	36	15					128
	3	221	44	90	38	68	90	122	27	32
Monoculodes edwardsi	3	16	5	53	30					
Paracaprella tenuis	3	48	23	39	15	23	19	15	65	15
Unciola irrorata	3	78	23	47	23				30	60
Decapoda										
Panopeus herbsti	2	26	19	17	15	15	30	15	22	38
ECHINODERMATA										
Amphiodia atra	1	114	40	21	75	120	64	45	52	21
	2	158	45	46	45	60	90	86	36	23
	3	152	49	31	115	60	41	52	43	15
UROCHORDATA										
Molgula manhattensis	1	975	64	206	193	127	780	211	186	231
	2	453	36	220	288	30	105	23	133	23
	3	492	46	171	75	68	165	226	118	120

*Cruise 1--Summer 1961.
Cruise 2--Winter 1962.
Cruise 3--Summer 1962.