SOME EFFECTS OF DREDGING ON POPULATIONS OF MACROBENTHIC ORGANISMS

EUGENE H. KAPLAN,[1] J. R. WELKER,[2] AND M. GAYLE KRAUS[3]

ABSTRACT

Populations of epi- and infauna were studied from 10 mo before to 11 mo after a navigation channel was dredged through a small, shallow lagoon. A new sampler which penetrated 20-30 cm into the substratum was used.

Current velocities and sedimentation patterns were changed due to an altered distribution of tidal currents, although flushing time was not appreciably altered.

Values of certain particulate and dissolved nutrients changed after dredging, but no correlation was observed between animal populations and fluctuations in nutrients.

Significant reductions in standing crop figures and species and specimen numbers occurred in both the bay and the dredged channel. *Mercenaria mercenaria* populations were reduced, but there was no evidence of mass mortality. Recovery of biomass in the channel was affected by sediment composition, but seasonal and sediment type variations were not significant in the bay as a whole.

Goose Creek had a high predredging epi- and infaunal standing crop estimated at 36.83 g/m², but the number of organisms/m² was relatively low, indicating a preponderance of large forms.

Productivity of Goose Creek was calculated at 89.87 g/m²/yr before dredging and 31.18 g/m²/yr after dredging. Productivity figures for the mixed peripheral marsh were calculated and the annual loss due to replacement of 10.87 ha of marsh by spoil areas was estimated at 49,487 kg. Altered land usage patterns tended to fix this loss on a permanent basis.

The unusually profound effects of dredging reported for Goose Creek are attributed to its small size and shallowness.

In 1965, Suffolk County, N. Y., obtained the services of a consortium of universities to study the characteristics of a small embayment before and after a channel 22.8 m wide × 2.1 m deep × 1,037 m long was dredged from the narrow inlet through most of the bay. The investigations reported in this paper are confined to the population dynamics and ecology of the macrobenthic organisms. Reference will be made to the other areas of investigation only as they affect the macrobenthos.

The following phenomena will be considered in relation to their effects on epi- and infaunal population dynamics:

1. Changes in the hydrodynamics of Goose Creek as the result of the introduction of the newly dredged channel.
2. Changes in the morphology of the sediment effected by the dredging process.
3. Changes in physical and chemical characteristics of the water associated with the dredging process.
4. Changes in populations of macrobenthic organisms which occurred during 1966 and 1967.

The Study Area

Goose Creek is a small, shallow lagoon located on the north fork of Long Island in the town of Southold, N. Y. (lat. 41°03'00"N, long. 72°25'23" W). Its dimensions are 1,464 m east-west by 533 m north-south, a total area of about 0.32 km². A channel approximately 30.5 m wide at the eastern end opens into Southold Bay, thence into Shelter Island Sound, an arm of Little Peconic Bay (see Figure 1).

The mean high water depth before dredging was 1.7 m, but much of the bay was extremely shallow and at low water it was impossible to navigate even a small boat in the western half of the bay. Mean tidal range was 68.5 cm, and the mean depth at mean low water was 1.0 m.

The prevailing wind is from the southwest in

[1]Biology Department, Hofstra University, Hempstead, NY 11550.
[2]Institute of Marine Sciences, Southampton College, Southampton, NY 12837.
[3]Zoology Department, University of Rhode Island, Kingston, RI 02881.

Manuscript accepted September 1973.
FISHERY BULLETIN: VOL. 72, NO. 2, 1974.

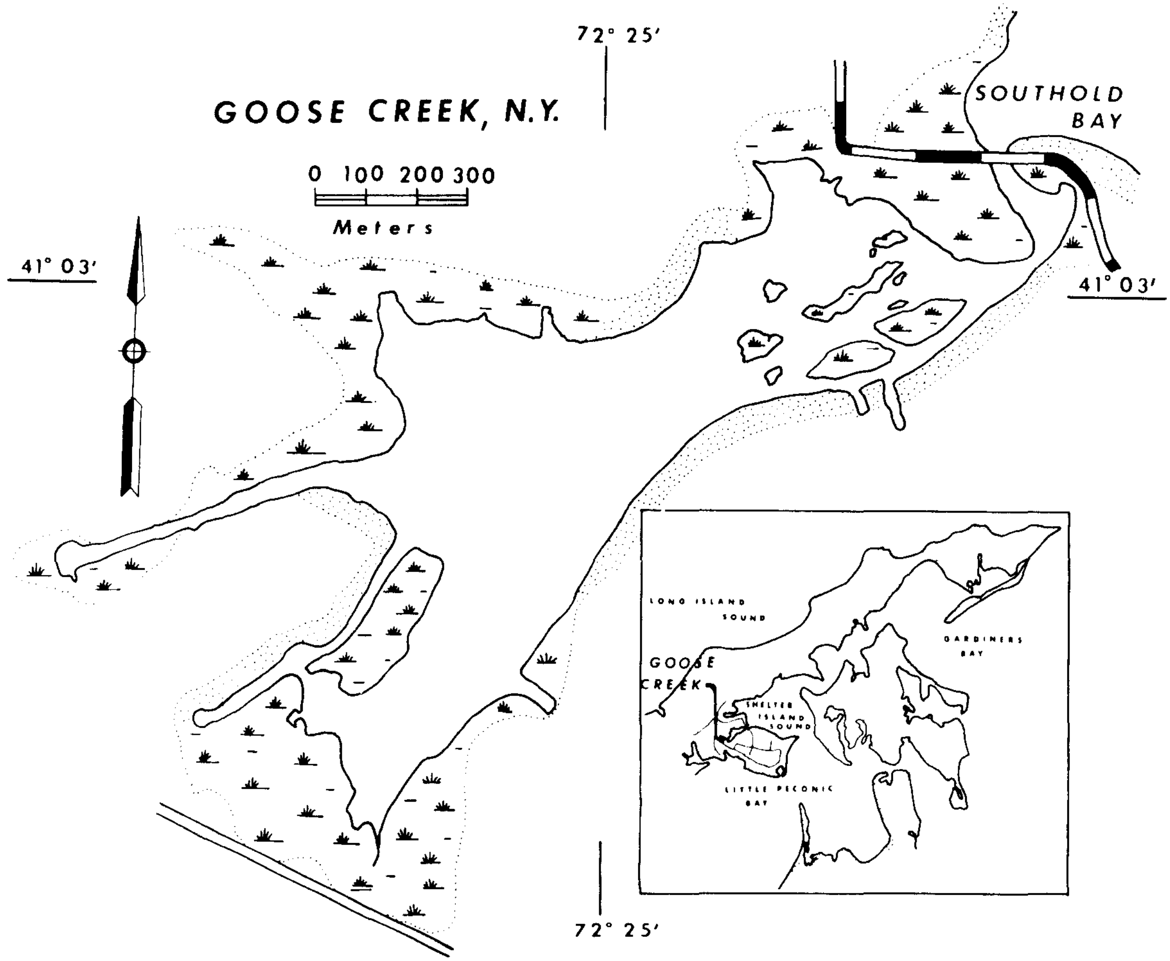

FIGURE 1.—Location map of Goose Creek, N.Y.

the summer months and from the northwest in winter.

There are four "minor" and five "major" islands in Goose Creek, the largest of which is 115.6 m by 42.4 m. They sustain a heavy growth of *Spartina alterniflora* with dense colonies of *Modiolus demissus* and *Uca pugnax.*

The entrance of Goose Creek was dredged from a mean low water depth of 0.8 m to a minimum of 2.1 m below mean low water. In cross section the channel was changed from a gentle depression to a steep-sided U. As a consequence of dredging the channel, the main water flow was shifted from one channel to another and current velocities dropped approximately one-half, except in the western half of the bay where previously negligible velocities increased.

The substratum of the bay consists of coarse gravel and sand in the main channel before it trifurcates into channels A, B, and C, which are characterized by sand grading into fine sand and mud in areas with reduced current velocity. The bottom sediments in the western half of the bay consist of thick silt over gray clay mixed with shell and sand.

The surrounding upland consists of *Spartina* marsh edged by stands of *Phragmites communis.* Before dredging, the south shore was almost completely developed, with small summer homes along the shores. The north and west shores were undergoing partial development with year-round homes. Five years after the dredging (1972), the area was almost completely developed, much of the marsh having been replaced by areas filled for homesites.

In 1966-1967 salinities ranged from a mean low of 26.79 ‰ to a mean high of 28.34 ‰. The pH ranged from 7 to 8. The dissolved oxygen levels varied seasonally and from station to station from a low of 4.50 ml O_2/liter to a high of 9.95 ml O_2/liter. Readings were always at saturation. The mean temperature range was between −1.0°C and 26.18°C over the 2 years; the bay is too shallow to exhibit a pronounced thermocline. Portions of the surface were frozen solid during parts of the months of February and March, 1966, and January, February, and March, 1967.

The tidal currents were relatively rapid in the eastern section of the bay, reaching a velocity of 56.7 cm/sec at station 1, at the confluence of the three channels, but they rapidly lost velocity until negligible readings were recorded in most of the western half of the bay.

Yearly rainfall (1967) amounted to 126.09 cm. Pollution by effluents from cesspools along the southern periphery of the bay consisted of fecal material, other organic material, and detergents as indicated by coliform bacteria and phosphate levels.

Previous Dredging of Goose Creek

Goose Creek was chosen for this investigation because of its unspoiled nature. This is a relative term, however, and on Long Island, with its high population density, it is unlikely that any bay or inlet has escaped some form of dredging operation.

There have been a number of private drag-line dredgings in Goose Creek reported by local residents. The earliest incident described was a dredging operation along channel A in 1930; a 1904 map of the region reveals, however, that the general contours of the bay remained unchanged.

The first officially recorded dredging in the environs of Goose Creek performed by Suffolk County occurred in November, 1959. A channel approximately 500 m long and 30 m wide was dredged from the bridge east by southeast into Southold Bay as an aid to small boat navigation. The depth of the channel was increased from approximately 0.5 m to 3 m mean depth below mean low water, and 35,653 m³ of spoil were placed along the southeast shore of the inlet, covering 20,920 m² of *Spartina* marsh.

Another area, smaller in size, received some spoil from this dredging. It was contiguous with what was to become spoil area C.

The second dredging operation began on 27 June 1967 and ended on 2 August 1967. The effects of that operation are the subject of this investigation.

A channel 23 m wide by 825 m long was dredged from the bridge at the inlet to the bay in an easterly direction along Channel B. A total of 57,383 m³ of spoil was removed and placed on spoil areas A, B, and C. Spoil area A covered approximately 6,000 m² of *Spartina* and *Phragmites* marsh adjacent to a previously used spoil area of approximately 26,000 m² covered to a maximum height of 3 m above mean low water. Spoil areas B and C in the southwest corner of Goose Creek covered 44,640 m² and 23,250 m² of *Spartina* marsh respectively.

A third dredging took place from 22 December 1967 to 12 April 1968. A 15.25–m wide channel was dredged to extend the previously constructed channel across the bay to the cut opening into the eastern shore. A small extension to an existing channel was also dredged through the center of Thyone Cove. The combined dimensions of these extensions were 427 m × 15.25 m and 8,508 m³ of substratum were removed and placed on spoil area B.

During the spring and summer of 1970, drag-line operations in the northwest corner of Goose Creek obliterated 13,950 m² of *Spartina* marsh along a frontage of 152 m as site preparation for a housing development. This was part of the largest portion of the original peripheral marsh which remained after the dredging operations of 1967-1968. The only remaining marsh in Goose Creek at the time of this writing was an area approximately 16,000 m² bordering the northwestern edge of the bay (see Figure 2).

Estimates of the areas of marsh covered by dredge spoil along the periphery of Goose Creek can be seen on Table 1.

An estimate of the remaining marsh in Goose Creek comes to 43,826 m² (islands) plus 23,715 m² (peripheral) or a total of 67,541 m². This is 31.4% of the total acreage covered by marsh in 1959. Excluding the islands, only 10.7% of the 1959 peripheral marsh remains. Examination of a map of the Goose Creek area drawn in 1904 reveals that the entire periphery of the bay was surrounded by extensive marshes. Probably less than

FIGURE 2.—Aerial photograph of Goose Creek, May 1972. Note straight edge of northwest shoreline (light area) caused by 1970 private dredge and landfill operation. Upper embayment is Jockey Creek. Note dredged channels in both bays and virtually complete eradication of marsh around Jockey Creek.

1% of the original Goose Creek marsh is still present.

METHODS AND MATERIALS

In order to determine what changes occurred in the macrobenthic population in Goose Creek, 23 stations were established in the bay, exclusive of the area to be dredged for the deepened channel. Fifteen additional stations were located at 30 m intervals in the path of the proposed channel.

The present study was initiated 1 yr before the scheduled dredging operation. Since a complete characterization of Goose Creek was necessary before the onset of dredging, it was deemed necessary to use a sampling procedure which could cover the whole of Goose Creek once every month. As the western half of the bay is uniform in bottom composition, being composed of deep, gray-black silt over muddy gray sand, there is little need to sample it as extensively as the eastern half of the bay, which is characterized by frequent changes in sediment type caused by variegated current flow patterns and topographic variability. Faunistic distribution was found to be dependent on the nature of the sediment, whose characteristics were, in turn, dependent on the erosion and deposition rates of the overlying tidal currents. Consequently, it was decided to divide the bay into zones of high, medium, and low current velocities, sampling each region by

TABLE 1.—Dimensions of known dredging operations in Goose Creek.

Dredged area	Spoil area	Area covered	Amount of spoil
Navigation channel in Southold Bay to bridge.	Edge of Southold Bay on either side of inlet to Goose Creek.	20,920m²	35,653m³
June-August 1967 dredging of channel through Goose Creek.	Spoil areas A, B, and C.	73,842m²	57,383m³
Dec. 1967-April 1968 dredging of spur channel to western shore, plus navigational channel through Thyone Cove.	Spoil area B.	Included above.	8,508m³
Spring-summer, 1970 private drag-line operation in NW corner of Goose Creek.	Northwest edge	ca. 13,950m²	Unknown
Totals		108,712m²	101,544m³

means of transects across the zone. In addition, a number of intertidal stations were set up, and a "characterization" survey was embarked on which sampled the intertidal area 2 m from shore and the sublittoral 6 m from shore every 30 m around the periphery of the bay. Using data from the preliminary surveys, sampling stations were established as representative of major substratum categories in Goose Creek. The advantages of placing greater sampling emphasis on certain areas rather than randomly sampling or using established as representative of major substratum (1967), Stickney and Stringer (1957), and Lee (1944).

Figure 3 indicates the positions of the stations in Goose Creek.

Each station was sampled with a "suction-corer" (Kaplan, Welker, and Kraus, In press-a) once a month for 9 mo preceding dredging and 11 mo after dredging terminated. A small shallow-draft vessel was propelled to the stations by an outboard motor. Locations were fixed by triangulation.

Once the vessel was located over a station, "spuds" consisting of 7.62 cm OD galvanized pipes were lowered fore and aft to keep the barge from swinging with current or wind. The sampler consisted of a chamber 36 cm in diameter by 30 cm high from which extended a hydraulic hose leading to a 3 hp pump on the deck of the barge. The corer was then lowered through a hole in the center of the deck until it reached the bottom. The pump was started and the water was withdrawn from the coring chamber. The evacuated chamber had negative pressure relative to the water column above it; this pushed it into the bottom. In practice depth of penetration varied, but a sample was not considered adequate unless the chamber had penetrated to a minimum depth of 20 cm. After maximum penetration the chamber was inverted by means of a winch and the sample was hauled to the deck where it was emptied onto a 60 cm × 90 cm sieve of 1.4 mm mesh size and washed. The screenings were placed in gallon bottles and formaldehyde was added to a concentration of 10%.

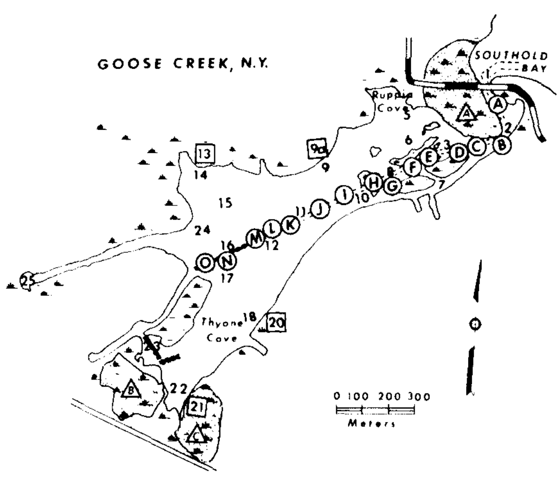

FIGURE 3.—Location of stations, Goose Creek. Letters in circles represent channel stations; letters in squares represent intertidal stations; letters in triangles represent spoil areas. Shaded extension of channel represents 1968 dredging.

Holme (1953) and Reish (1959) established that 1.5 mm and 1.4 mm mesh sieves recovered 90% of the biomass from their samples, respectively. In view of the importance of large forms in the Goose Creek species composition, it is likely that the 10% potential error described by Reish and Holme is a conservative estimate. Since the purpose of this investigation required an accurate estimate of total standing crop, with special emphasis on such commercially important species as *Mercenaria* and *Mya*, no attempt was made to separate the "large" and "small" forms by using an arbitrary cut-off point, as the 0.2 g of Sanders (1956). Thirty-eight stations and the once-a-month sampling schedule produced over 400 separate samples; this large N helped compensate for statistical inaccuracies introduced by the presence of large forms.

After a minimum of 1 yr of storage the specimens were identified, weighed (blotted wet weight), and dried at 40°C until uniform dry weight was obtained. Pelecypods were shelled, but crustaceans did not have their carapaces removed, since many were too small for this procedure to be performed with precision. Instead the major weight factor of the shells, the carbonates, was substantially removed by the acidic action of the unbuffered formaldehyde. The use of an acidic medium to remove carbonates was employed by Sanders (1956), Holme (1953), and others.

The data were expressed as number of organisms/wet weight/dry weight (biomass) per m² of substratum, including all animals recovered, according to the recommendation of Lee (1944).

RESULTS

Hydrography of Goose Creek

The hydrographic data recorded below were obtained from the reports of Hair (1968), Fazio (1969), and Black (pers. comm.). Salinity was measured by a portable Beckman salinometer (Model RS 5-3),[4] dissolved oxygen and temperature readings were taken with a portable oxygen meter (Electronic Instruments Ltd. Model 15 A) and pH was determined with a portable Orion Instruments Specific Ion Meter (Model 401). Light penetration was measured by a Secchi disc.

[4]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Water Temperature

Average daily temperatures ranged from 25.5°C to 0.5°C in the bay in 1967-68. The lowest individual reading was −1.5°C on 11 January 1968 and the highest 29.0°C on 7 July 1967. In January, February, and March, the bay was often covered by ice.

Salinity

Maximum salinity values occurred in mid-July to mid-October with a 1966-1968 high of 30.12‰. Low salinities occurred from mid-January to mid-April, with the 1966-68 low of 18.38‰ recorded on 28 March 1968.

Mean 1966-67 salinity in the bay proper (excluding the relatively less saline cut extending from the west shore) was 28.37‰.

pH

Average daily pH in Goose Creek ranged from 7.1 to 8.3 (excluding the somewhat more variable western cut) in 1967 and 7.7-8.2 in 1966. The highest individual value in 1967 was 8.6, occurring during a phytoplankton bloom in Thyone Cove, on 27 July 1967. The highest individual value for 1966 was 9.0 during a dinoflagellate bloom.

Light Penetration

Secchi disc readings were taken at weekly intervals throughout the duration of the study. In the bay itself the photic zone usually reached to the bottom, since the total water column was never more than 3.5 m. Virtually the entire bay could be considered euphotic except during the month in which the dredging took place, July 1967, when the minimum light penetration as recorded by the Secchi disc was 0.4 m (Fazio, 1969). It appears, then, that light penetration values were not substantially affected by the introduction of suspended materials into the water as the result of dredging. This is not surprising in view of the shallow nature and relatively rapid flushing time of the region of the bay most severely affected by the dredging, the eastern half. On the other hand, deposition of a canopy of flocculent material on the leaves of the *Ruppia* and the thalli of the *Enteromorpha* was observed during and after the dredging process.

This factor almost certainly reduced available light to the plants despite the relative clarity of the water.

Current Velocity

Readings of current velocities were taken on 9 June 1967, before dredging, and on 19 July 1968, after the new channel was completed. Attempts were made to match the tide height and wind direction and velocity on both occasions so as to minimize variables related to natural fluctuations of water level and current velocity. During both readings the wind was from the southwest and differences in wind velocity between the two days were not greater than 10 mph. The wind velocity was slightly higher during the post-dredging series (7 mph vs 15 mph) as was the tidal range (70 cm vs 73 cm). These factors would tend to increase the velocity of the flood tide rather than decrease it. Since current velocities decreased, this effect cannot be attributed to the influences of wind and/or tide.

The bridge readings were made with an Ekman current meter at 20 min intervals, 0.5 m beneath the surface and 0.5 m above the bottom of the channel. The meter was allowed to run for 120 sec and the readings were converted into centimeters per second according to the standard formula.

The readings in the channels were taken with Price meters on hand-held rods. The meters were set at 0.5 m above the bottom. Maximum depth of water at any station was approximately 1.2 m so that lamination or stratification according to current velocity was minimized. Maximum intervals between readings at the same station were less than 30 min.

The data consisted of the number of revolutions of the wheel during a 70 sec interval converted into centimeters per second from a nomograph calibrated to each meter. One replication of each measurement was taken as a check on the accuracy of the meters.

Table 2 and Figure 4b compare current velocities before and after dredging. Figure 4a indicates the current velocity sampling stations.

Maximum current velocity before dredging was through channel A. After dredging, the most westerly portion of channel A still has the maximum current velocity, but approximately 100 m east of the point of trifurcation at stations 4 and

TABLE 2.—A comparison of current velocities at flood tide in Goose Creek, before and after dredging.

Station	Before (cm/sec)	After (cm/sec)	Difference (cm/sec)
1	56.7	25.8	-30.9
7	41.4	13.1	-28.3
6	40.2	7.2	-33.0
2	55.2	25.2	30.0
[1]3	43.9	2.6	-41.3
4	23.2	13.1	-10.1
5	17.2	18.0	+ 0.8
1D	28.8	NA	NA
2D	38.4	5.5	-32.9
3D	12.1	2.7	- 9.4
4D	Neg (0)	5.5	+ 5.5
5D	Neg (0)	4.8	+ 4.8
Bridge	92.0	47.2	[2]-44.8
Bridge	83.8	39.6	[3]-44.2

[1]Station 3 was a sand bar with a thin, rapid flow. The water was never more than 30 cm deep over this bar. It was removed by the dredging operation and replaced by a 2.1 m deep channel.
[2]Maximum surface velocity.
[3]Maximum bottom velocity.

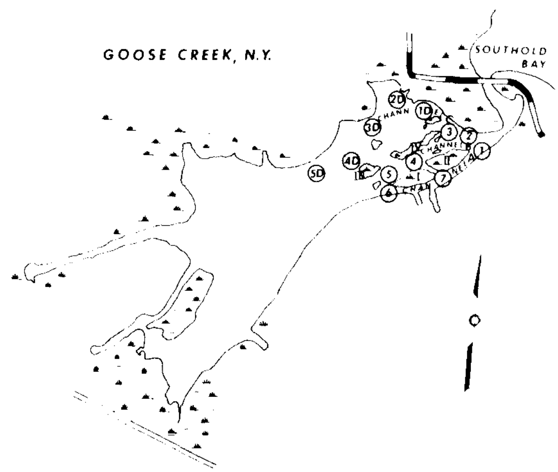

FIGURE 4 a.—Map of current velocity sampling stations.

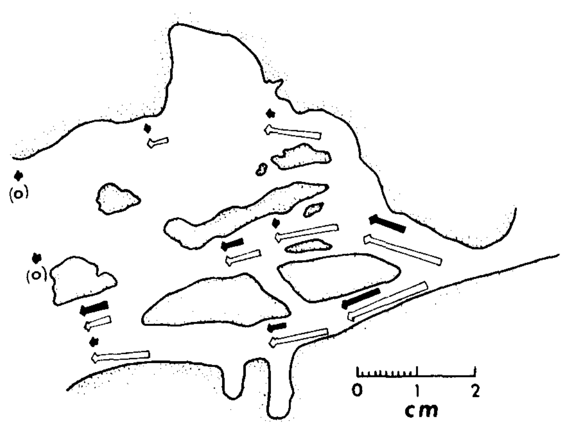

FIGURE 4 b.—Map of current velocity differences before (open arrows) and after (solid arrows) dredging. Each millimeter represents 4 cm/sec current velocity.

7, the current velocities in channels A and B were matched at 13.1 cm/sec. Thereafter, the post-dredging velocity in channel B was greater than in channel A, i.e., 18.0 cm/sec at station 5 and 7.2 cm/sec at station 6. Thus, maximum flow was changed from channel A to channel B as a result of the dredging.

Channel B was converted from a shallow, wide passage with maximum surface area in contact with the current (hence maximum friction and impedance of water flow) to a deep channel, whose depths at mean low water before and after dredging were 0.4 m and 2.1 m at the entrance.

The substratum of channel A was gravel and sand at the most westerly end, changing to sand for most of the length of the channel as it passed islands I and II, after which it gradually became muddy sand. Near Thyone Cove only the shoreline and 3 m of littoral remained muddy sand; below this level the substratum was gray sand covered by 2 cm of silt.

As indicated earlier, channel B had a lower velocity before dredging than channel A. The transitional area was compressed in channel B; the area of sand at the westerly end merged rapidly into muddy sand, then silt, a short distance past the easterly end of island I.

Channel C, both pre- and postdredging, was characterized by an initial high velocity (55.17 cm/sec at station 2 and 38.40 cm/sec at station 2D), but this rapidly dissipated over the sand flats and eddies north of islands III and IV.

Maximum surface and bottom velocity was halved after dredging at the inlet to the bay. This, of course, would have a most profound influence on transport of materials, since it represented a section of water approximately 22 m wide by 2.8 m deep. Since the original mean depth of the channel was approximately 1 m, the cross section of the dredged channel was approximately three times greater than the original channel, increasing its volume commensurately.

Isaac (1965) stated that current velocities of 0.6 to 1.3 ft/sec (18.29 to 39.62 cm/sec) are sufficient to resuspend bottom deposits with 1.0 mm particle diameter. According to changes in current velocity at Goose Creek, the deposition of such particles would have taken place at the following stations after dredging, although not before dredging: station 7 (41.4 to 13.1 cm/sec), station 6 (40.2 to 7.2 cm/sec), station 3 (43.9 to 2.6 cm/sec), station 4 (23.2 to 13.1 cm/sec) and station 2D (38.4 to 5.5 cm/sec).

Mass Movement of Water

Hair (1968) calculated the volume of water moving in and out of Goose Creek during each phase of the tidal cycle. Assuming the average depth to be 1.3 m at high tide with a tidal range of 0.8 m and an area of $2.59 \times 10^5 m^2$, he calculated the volume of the bay at high tide to be $3.88 \times 10^5 m^3$. At low tide the corresponding calculation was $1.44 \times 10^5 m^3$. The volume lost at each falling tide would then represent approximately 60% of the volume at high tide. Fazio (1969) recalculated the tidal exchange on the basis of the increased volume of the bay caused by the construction of the dredged channel. His volumes were $7 \times 10^5 m^3$ at high tide and $3.1 \times 10^5 m^3$ at low tide. This represents a loss of 66% at each ebb and is considered by Fazio as a corroboration of Hair's calculations.

Of importance in any consideration of the benthos in Goose Creek is the fact that during the 6 h of ebb tide roughly 60% to 66% of the total volume of water in Goose Creek (approximately $2 \times 10^5 m^3$ before dredging and $4 \times 10^5 m^3$ after dredging) flowed out of the bay. All of this water passed through channels A, B, and C which, at a maximum value of 23 m wide and 3.0 m deep for channel B and 30 m × 1.5 m for the combined channels A and C, represents a total cross-sectional volume of 114 m^3 for the passage of ca. $3.9 \times 10^5 m^3$ of water. The relatively small volume of channels A, B, and C and the 244 m channel formed by their confluence and flowing eastward into Southold Bay accounts for the rapid current velocity in the eastern half of Goose Creek.

On 21 May 1966, an attempt was made to determine the proportion of water exchanged in various parts of the bay. Rhodamine B was released into the easternmost portion of Goose Creek (near the bridge) on an incoming tide, so that the average dilution was approximately 27 ppm after 2 h over the entire surface area of the bay. Six weeks later the readings on the fluorometer revealed values of the order of 1.7 ppm in most of the eastern half of the bay while Thyone Cove and the western shore of Goose Creek had readings as high as 9.6 ppm and lows rarely below 6.3 ppm.

Figure 5 demonstrates that the exchange of water, as revealed by residues of Rhodamine B, was greater in the eastern half of the bay, with areas of Thyone Cove and the west shore having maximum values for the dye and, therefore, a comparatively low exchange rate.

Dissolved Nutrients

Fazio (1969) and Hair (1968) studied the distribution of certain nutrients in Goose Creek before and after the dredging operation. The results of their investigations are summarized in Table 3 and fluctuations in pre- and post-dredging concentrations of chlorophyll *a*, silicate, dissolved organic phosphate, and nitrite are depicted in Figure 6.

Fazio reported that there were significant changes in the values of particulate phosphorus, silicates, and chlorophyll *a* as a result of the dredging. He demonstrates high correlations between particulate phosphorus and chlorophyll *a* ($r = 0.83$), but is unwilling to suggest a direct relationship between this nutrient and phytoplankton productivity.

Instead, he explains the congruent increases in particulate phosphates and chlorophyll *a* as either a suspension of living benthic organisms introduced into the water by the disturbance of the sediment, or resuspension of detrital material and/or land runoff. Analysis of the water near a leaking spoil area revealed great amounts of particulate phosphorus and chlorophyll *a* were being added to the water column.

The distribution of silicates was shown to be related to the dredging process since highest readings were associated with stations in the vicinity of the dredge pipe and spoil areas; these high readings shifted down the bay following the movements of the dredge. There was, however, a low positive correlation between silicates and chlorophyll. Coupling high concentrations of chlorophyll *a* with extreme turbidity and very low light penetration in the vicinity of the dredge, Fazio (1969) concludes that the chlorophyll is not necessarily an indicator of the presence of phytoplankton, since the opacity of the sediment-laden water would prevent photosynthesis and limit phytoplankton production. Instead, he suggests that plant detritus in the spoil runoff is the main source of the high chlorophyll *a* readings and that phytoplankton populations might be very low.

Examination of Figure 6 reveals a second high in chlorophyll *a* readings in December 1967-

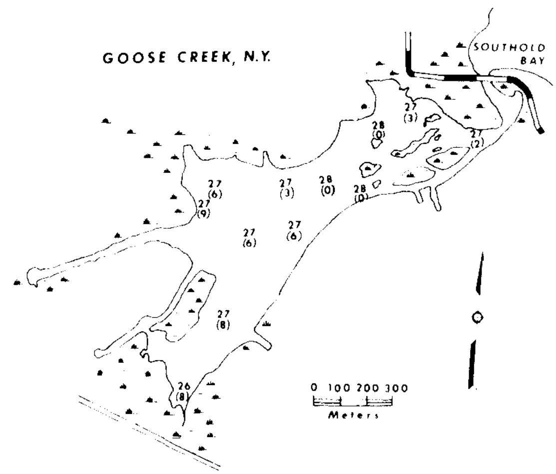

FIGURE 5.—Rhodamine B residues in ppm on day of administration and after 6 weeks. Figures in parentheses represent the later readings. (Drawn from data from Black, pers. comm.)

January 1968. This corresponds with a second dredging which occurred from 22 December 1967 to 12 April 1968 in the western quarter of the bay. The picture is very much like that of the first dredging. A similar peak chlorophyll *a* reading occurred at the onset of dredging followed by a sustained high yield throughout the late winter and early spring. Mean chlorophyll *a* readings for the months of December 1967 to June 1968 are consistently two to five times those of the comparable 1966-1967 period. Resolution of the problem of whether the chlorophyll readings represent an increase in phytoplankton or are artifacts resulting from runoff will be decided when Cassin publishes his analysis of the phytoplankton cycle 1967-1968.

TABLE 3.—The fluctuations in certain dissolved and particulate nutrients in Goose Creek, 1966-1968.

Nutrients	Mean concentration 1966 (Hair)	Mean concentration 1967 (Fazio)
Dissolved inorganic phosphorus	0.81 μg at. P/liter	0.86 μg at. P/liter
Nitrates	2.8 μg at. NO_3-N/liter	3.5 μg at. NO_3-N/liter
Silicates	July-Aug. values between 8 and 16 μg at. Si/liter	July-Aug. dredging period values between 30 and 35 μg at. Si/liter. Variable from station to station according to proximity to dredge.
Particulate phosphorus	Mean of 8 readings 6/16-7/18, 1966 4.94 μg at. P/liter	Mean of 8 readings 7/5-8/7, 1967 18.30 μg at. P/liter

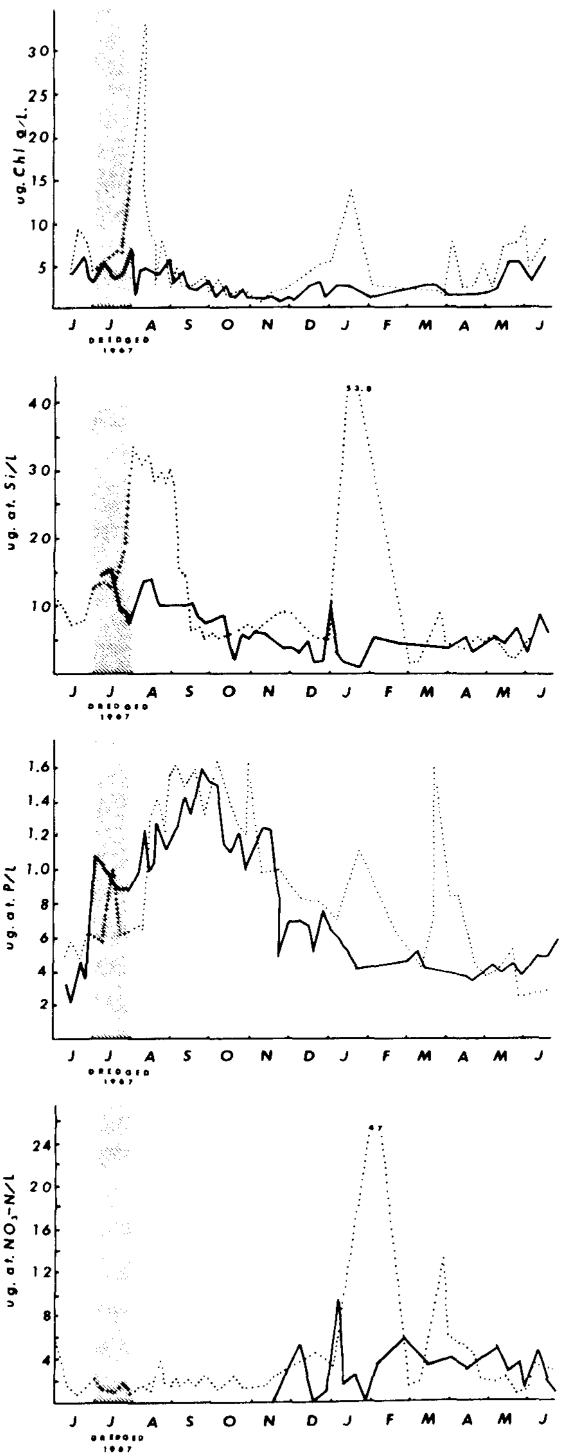

FIGURE 6.—Fluctuations of (from top to bottom) chlorophyll *a*, silicates, dissolved inorganic phosphates, and nitrites in Goose Creek, 1966-1968. (Redrawn from Hair, 1968; Fazio 1969.) Solid line represents 1966-1967 data; dotted line represents 1967-1968 data.

In general, the results of the Goose Creek nutrient studies are similar to those carried on in Chesapeake Bay by Flemer (1970) and Biggs (1968). Particulate phosphates, silicates, and chlorophyll *a* increased significantly. Concentrations of nitrates, nitrites, and dissolved organic and inorganic phosphates were not appreciably different before and after dredging.

Copeland and Dickens (1969) report that in Maryland, Texas, and South Carolina there was an initial diminution of phytoplankton productivity due to shading and a later enhancement due to resuspension of nutrients from dredge spoil. Flemer (1970) indicates that he found no demonstrable effect of the deposition of fine sediments from dredging on the production of phytoplankton in Chesapeake Bay.

There is no evidence that the release of nutrients from dredging produces an effect similar to that described by Raymont (1947, 1949) where the addition of fertilizer to small, enclosed embayments raised the level of benthic productivity up to 300% by stimulating production of phytoplankton.

Mechanical Analysis of the Sediment

Sanders (1956) points out the great variability in establishing criteria for the differentiation of particles constituting the sediment. He expressed the composition of the sediment in terms of the proportion of the particular component which was either most predominant or most relevant to the point he was making (e.g., *Mulinia lateralis* is either absent or present in low numbers when the proportion of silt-clay in the sample is greater than 40%). In the present study the samples were sieved and the lighter fractions analyzed by pipetting. Phi values were calculated and eight fractions recorded, one for sand (up to a maximum phi coefficient of 4.0), six for the various fractions of silt (phi = 4.5-8.0) and one for clay (phi = 9.0 and beyond). Data are recorded in percent sand, silt, and clay to conform with common practice.

Three sets of sediment samples were obtained during the course of the study. A preliminary survey was performed in September 1966, using a 1 m Phleger corer at each of the permanent sampling stations. Figure 7 delineates the sediment facies distribution compiled during this survey. Also found on this map are the stations for the second survey (triangles) taken just before the dredging in June 1967, and the post-dredging survey (circles) in July 1968, 1 yr after dredging.

Table 4 reveals that 1 yr after dredging, sediments in those stations in the path of the dredge (3, 10b, 11, and 11a) contained less sand after dredging in the previously sandy, high current velocity stations (3, 10b) and more sand in the previously silty, low current velocity stations (11, 11a).

Station 10a, in channel A, experienced a reduction in its sand proportion and an increase in silt. This conforms to the hypothesis that the lowered current velocity in channel A, resulting from a shift in the main volume of water transport to channel B, would favor the settling of lighter particles in the post-dredging period. Similarly, station 5 in channel C increased in its silt and clay components.

Stations 16 and 17 were located in the west-central portion of the bay, south of the channel. Both stations maintained a constant proportion of sand. Station 17 exhibited a marked increase in silt and a decrease in the clay facies.

Stations 14 and 24 exhibited an increase in sand and a decrease in silt and clay. Since these stations were near the western shore in an area of negligible current flow, it is difficult to envision pronounced sediment transport brought about by normal tidal flow, even with the slightly enhanced exchange rate brought about by the deepening of channel B. It is possible that spring tides and strong easterly winds could have acted synergistically with the deepened channel to bring about this effect.

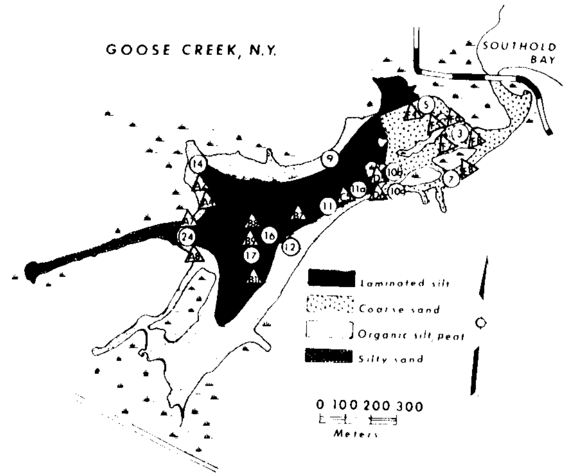

FIGURE 7.—Sediment facies and station locations, Goose Creek. Triangles represent pre-dredging stations, circles represent post-dredging stations.

The foregoing data must be viewed in conjunction with data on current velocities, wind-driven currents, etc., as further presumptive evidence of what appear to be permanent changes in the sediment transport patterns of Goose Creek brought about by current velocity modifications in the tidal channels.

The Effects of Wind-Driven Currents on Sediment Deposition

The importance of wind-driven water currents on the deposition of sediment in shallow-water estuarine situations has been emphasized by

TABLE 4.—Comparison of pre- and post-dredging sediment composition at selected stations, Goose Creek.

Pre-dredging				Post-dredging				
Station	%Sand	%Silt	%Clay	Station	%Sand	%Silt	%Clay	Comparison
F6	97	3% silt, clay						
F7	97	3% silt, clay		3	78	14	8	Less sand
F8	97	3% silt, clay						
F4	97	3% silt, clay						
F5	65	18	17	5	30	41	29	Less sand
E8	97	3% silt, clay		7	70	20	10	Less sand
D5	97	3% silt, clay		10b	91	8	1	Less sand
D6	97	3% silt, clay		10a	72	24	4	Less sand
C5	40	26	34	11a	75	17	8	More sand
B7	44	26	30	11	74	13	13	More sand
B8	48	28	24					
B9	49	18	33	16	49	29	22	No change
B11	34	34	32	17	35	64	1	More silt
A2	24	24	52					
A4	21	39	40	14	80	17	3	More sand
A7	37	44	19					
A8	55	12	33	24	62	28	10	More sand

TABLE 5.—Wind velocity recordings at or above 15 mph on days when there were two or more such recordings, 1967.[1]

Wind direction	Number of 3-hourly recordings
NE (10°-80°)	76
E (90°)	2
SE (100°-170°)	23
S (180°)	2
SW (190°-260°)	77
W (270°)	10
NW (280°-350°)	224
N (360°)	29

[1]Source: Local Climatological Data, 1967, John F. Kennedy Airport. U.S. Dep. Commer., Environ. Sci. Serv. Adm.-Environ. Data Serv. U.S. Gov. Print. Off., Wash., D.C.

Biggs (1968), Häntzschel (1939), Hellier and Kornicker (1962), and others.

In a shallow, almost completely enclosed embayment like Goose Creek, with a relatively broad exposure to prevailing winds, the effect of wind on the distribution of fine sediments becomes accentuated. Biggs (1968:481) states that "strong and persistent winds may cause high suspended sediment loads . . ."

The wind velocity data for Kennedy airport on Long Island were tabulated, and those days with two or more recordings of winds at 15 mph or above were compared. As can be seen from Table 5, the prevailing winds 15 mph and above come from the northwest on Long Island. Individual recordings from the northwest were more than ten times as common as those coming from the opposite direction, and at least three times more common than winds coming from any other quarter.

All other factors being equal, one would expect that the difference in mean wind velocity favoring the northwesterly prevailing winds would result in a net deposition of sediment in the southeastern region of the bay. Examination of Figure 1 reveals that this is the region where the channel opens to Southold Bay, the area of maximum tidal current velocity. This complex interaction of factors would probably result in an unusually high suspended sediment load in the incoming and outgoing tidal currents and the deposition of light particles carried by incoming tides in the southwestern margins of the bay.

This hypothesis is given substance by three sets of data: Hair (1968) and Fazio (1969) demonstrate that the transport of nutrients in Goose Creek was strongly influenced by wind-induced currents both before and after dredging. By drawing isopleths of NO_3 concentrations and relating them to wind direction and velocity, they were able to show that nitrate concentrations were responsive to both factors, with progressive diminutions of concentration across the bay in the direction of the wind source (see Figures 8 and 9).

Minimum wind velocity required to induce clear-cut distribution of particulate constituents was 5 mph according to Fazio. He also showed that a wind increase from 13 to 20 mph caused a resuspension of bottom material affecting concentrations of particulate phosphorus, chlorophyll *a*, dissolved inorganic phosphate, and nitrate.

Nuzzi (1969) shows a correlation between bacterial count and wind velocity in Goose Creek. He suggests that a critical wind velocity is

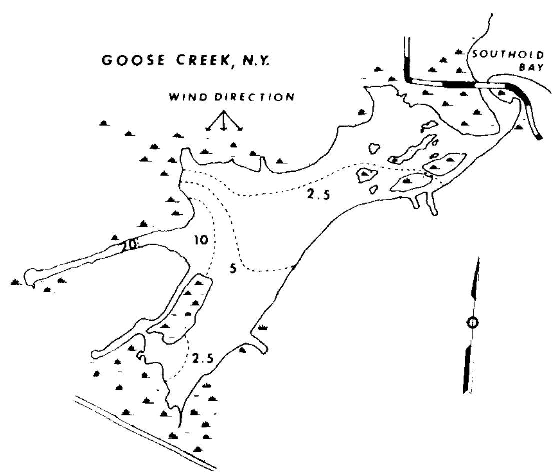

FIGURE 8.—Isopleths of NO_3 concentration in μg at. NO_3-N/liter, wind coming from the northern quarter. (Redrawn from Hair, 1968).

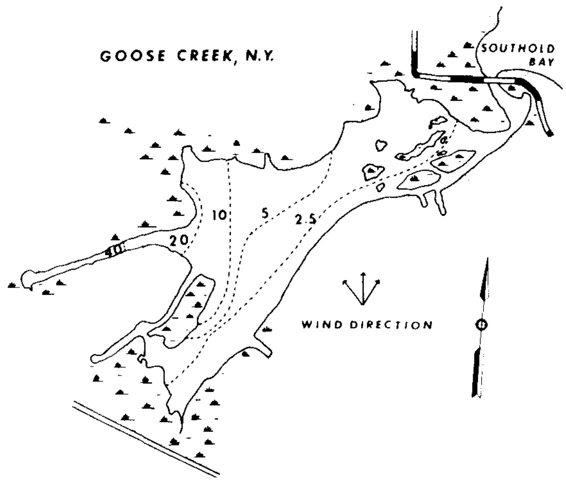

FIGURE 9.—Isopleths of NO_3 concentration in μg at. NO_3-N/liter, wind coming from the southern quarter. (Redrawn from Hair, 1968).

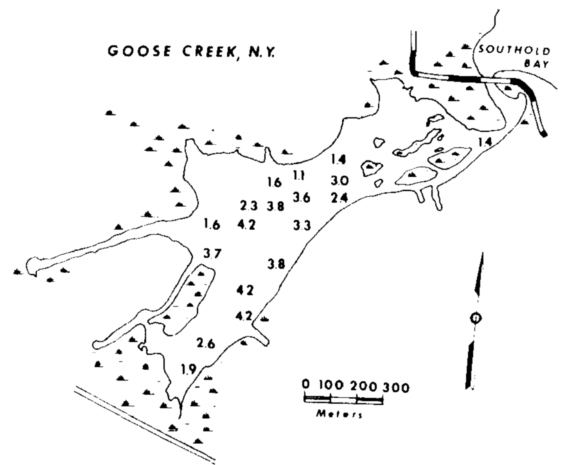

FIGURE 10.—Depths of sediment below mean low water in meters. Data taken from Suffolk County map dated 4/5/67.

necessary to overcome the inertia of the sediment particles as well as associated bacteria.

Further substantiation of the hypothesis that sediment distribution in Goose Creek was affected by wind-driven currents can be obtained from an examination of Figure 10. Depth of the sediment increases in a north-south direction, irrespective of the probable contour of the basin.

Table 6 tabulates the number of 3-hourly records of winds at or above 15 mph for 1967.

Suspension of fine sediments during dredging occurred during the months of least occurrence of high winds (July-August). The absence of strong winds would tend to minimize the distribution of suspended sediment but it also prevents the removal of the canopy of flocculent material observed covering the *Enteromorpha* and *Ruppia* stipes and leaves during and after dredging.

Flemer et al. (1968) suggest that late fall is the season which would be most desirable for dredging, since benthic animal populations are lowest then. On the other hand, the months of November and December are characterized by frequent windy days and any disturbance of the sediment would be accentuated by wind-driven currents. Saila, Polgar, and Rogers (1968) describe summer surface and bottom current patterns which caused maximum harmful effects of dumped dredged sediment. Such factors as water depth, contour of basin, and wind- and water-driven currents must be studied further to determine the optimal season for dredging.

Mercenaria Survey

Mercenaria mercenaria is exploited commercially in Goose Creek and it supports a substantial sport fishery. Both before and after dredging, from two to four commercial clammers regularly visited the creek. In 1968, less than a year after the dredging, two clammers were interviewed regarding changes in the productivity of clams over the interval of the dredging operation. They reported that there was no substantial difference in the size of their catch which, according to the local conservation officer, was 4-5 bushels of clams per day.

Apparently there was no mass mortality of clams resulting from the release of flocculent and suspended material into the water as a result of dredging.

Four major clam producing areas of the bay were sampled before and after dredging, on 8 July 1967 and 4 July 1968 (dredging was completed on 2 August 1967 (see Figure 11)).

TABLE 6.—Number of days of at least two recordings of winds over 15 mph by months (recordings taken at 3 h intervals), 1967.

Month	Number of days	Month	Number of days
January	7	July	1
February	13	August	1
March	9	September	13
April	17	October	5
May	18	November	13
June	10	December	11

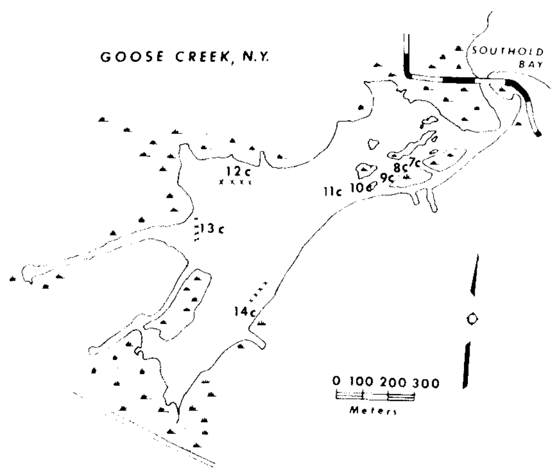

FIGURE 11.—Map of stations, *Mercenaria* study.

A 3.35 m² square frame was placed on the substratum and a skin diver sampled the area by hand, removing all clams. These were sorted as to size in the following categories: up to 1.90 cm; 1.90-3.80 cm; 3.81-5.70 cm; 5.71-8.90 +cm.

The areas sampled were channel B (destined to be the region of the newly dredged channel) and the three major clamming areas used by local residents. Stations 7c to 11c were 30 m apart running east to west down channel B. Stations 12c, 13c, and 14c were located on the north, west, and south shores of the bay respectively.

Each station in channel B comprised two sampling areas, one 1.5 m from shore and the other in midchannel or about 9 m from shore.

Each station in the clam beds used by local residents (stations 12c, 13c, 14c) comprised four sampling areas beginning 6 m from the shoreline at the east end of the bed and progressing westerly at 6-m intervals. The total area sampled was 33.5 m² in the channel and 39.25 m² on the clam beds (total 72.75 m²).

The data obtained on the pre- and post-dredging surveys are compared in Table 7.

Clams in Goose Creek not directly exposed to mechanical disturbance by the dredge (such as clam beds at stations 12c and 13c) were able to survive the dredging process itself, even though they were located within 400 m of the channel (see Table 7). The considerable reduction in the size of the clam populations at stations 12c and 13c suggests that some mortality-inducing factor was at work.

The effects of the mechanical removal of the clams by the dredge are obvious. Whether or not finding a few clams in the post-dredging survey at stations 10c and 11c means that there are signs of recovery in the population remains to be seen.

No evaluation of the long-term effects of changes in the environment has been attempted. These include processes such as the gradual incursion of silt towards the mouth of the bay due to lowered current velocity, factors affecting productivity such as a reduction of the quantity of organic materials introduced into the water as the *Spartina* marshes were covered with spoil, and an increase in pollutants as the population density of humans along the periphery of the bay increased.

Changes in Land Usage Patterns

At the inception of the study (1966) most of the periphery of Goose Creek was composed of *Spartina* and *Phragmites* marshes, except for the south shore and a neck of land on the southeastern corner which were developed with summer homes.

On a map of the area drawn in 1954, 41 homes are recorded bordering the bay. The total number of houses within 300 m of the bay was 114. At the present writing most of the previously undeveloped north shore of the bay is undergoing intensive development of houses used year round.

An aerial photograph taken in 1972 (Figure 2) revealed 223 houses within 300 m of the bay, an increase of 94%. All of the houses along the shore of Goose Creek were built on spoil taken from public or private dredging operations. All homes have cesspools.

Smith (pers. comm.) introduced Rhodamine B into a toilet in one of the homes bordering Goose Creek. In four weeks detectable quantities were found in the bay waters. Nuzzi (1969) speculates that human fecal coliform bacteria (as identified by elevated temperature incubation) were released into Goose Creek from the septic tanks of the surrounding homes. Maximum coliform counts in his 1966-1968 study were 918 MPN (most probable number)/100 ml.

The maximum federal permissible level for waters from which shellfish are taken is a median of 15 readings not exceeding 70 MPN/100 ml, or 10% of 15 readings above 230 MPN/100 ml (Houser, 1965). Individual readings above 230 MPN/100 ml were recorded throughout the period December-March 1967, at one station, and three

TABLE 7.—A comparison of *Mercenaria* populations in four selected areas of Goose Creek before and after dredging.

	Number of clams							
	Before dredging (7/8/67)				After dredging (7/4/68)			
Station	Inshore		Mid-Channel		Inshore		Mid-Channel	
7C	1.9 cm	5	1.9-3.80 cm	9				
	1.9-3.80 cm	8						
		13		9		0		0
8C	1.9 cm	4	3.8-5.7 cm	17				
	1.9-3.8 cm	18						
	3.8-5.7 cm	16						
		38		17		0		0
9C	1.9-3.8 cm	31	1.9-3.8 cm	14				
	3.8-5.7 cm	3						
		34		14		0		0
10C	1.9-3.8 cm	2	to 1.9 cm	2	1.9-3.8 cm	1		
	3.8-5.7 cm	5	3.8-5.7 cm	9				
		7	5.7-8.9 cm	2				
				13		1		0
11C	1.9-3.8 cm	2	0.75-1.50 cm	3	to 1.9 cm	3	to 1.9 cm	1
			1.50-2.25 cm	6				
		2		9		3		1
12C	Station A		Station B		Station A		Station B	
	1.9-3.8 cm	29	to 1.9 cm	12	to 1.9 cm	8	to 1.9 cm	8
			1.9-3.8 cm	11	1.9-3.8 cm	7	1.9-3.8 cm	3
		29		23		15		11
	Station C		Station D		Station C		Station D	
	to 1.9 cm	16	to 1.9 cm	7	to 1.9 cm	5	to 1.9 cm	3
	1.9-3.8 cm	14	1.9-3.8 cm	12	1.9-3.8 cm	1	1.9-3.8 cm	3
	3.8-5.7 cm				3.8-5.7 cm	1		
		30		19		7		6
	Average number of clams per m² = 7.5				**Average number of clams per m² = 2.9**			
13C	Station A		Station B		Station A		Station B	
	5.71-8.9 cm	27	3.8-5.7 cm	18		0		0
			5.7-8.9 cm	10				
		27		28		0		0
	Station C		Station D		Station C		Station D	
	1.9-3.8 cm	22	3.8-5.7 cm	8	1.9-3.8 cm	3		0
	5.7-8.9 cm	9	5.7-8.9 cm	11	3.8-5.7 cm	1		
		31		19		4		0
	Average number of clams per m² = 7.8				**Average number of clams per m² = 0.3**			
14C	Station A		Station B		Station A		Station B	
	5.71-8.9 cm	44	3.8-5.7 cm	17	na.		na.	
			5.7-8.9 cm	20				
		44		37				
	Station C		Station D		Station C		Station D	
	1.9-3.8 cm	24	5.7-8.9 cm	47	na.		na.	
	3.8-5.7 cm	6						
	5.71-8.9 cm	17						
		47		47				
	Average number of clams per m² = 12.1				**Average number of clams per m² = na.**			

times at another, with levels of 542, 918, and 348 MPN/100 ml. These readings appear to exceed the 10% limit mentioned above and may be sufficient grounds for closing the bay to clamming. The densities of presumptive human fecal coliforms found by Nuzzi correlated with increases in human population size, suggesting that the increase in number of homes around the periphery of the bay during the 1968-1972 will further increase the contamination of clams beyond acceptable sanitary standards.

ANALYSIS OF THE EFFECTS OF DREDGING ON MACROBENTHIC ANIMAL POPULATIONS

Dry weights from 263, 0.1 m^2 samples collected from the bottom of Goose Creek over 22 mo were compared by means of analysis of variance. In addition, chi-square analyses were performed to determine whether or not significant differences existed between pre- and post-dredging populations in number of individuals and species. All

TABLE 8.—Analyses of variance of pre- and post-dredging dry weights and between stations, in the bay and dredged channel.

Source	Sum of squares	Degrees of freedom	Mean squares (variance)	*F* test	Probability
Stations before and after dredging	158.387	1	158.387	10.623	0.005
Variation between stations	492.212	22	22.373	1.501	Less than 0.05
Interaction of pre- and post-dredging and stations	311.698	22	14.168	0.950	Less than 0.05
STATIONS 2-25 PLUS A-J, M (CHANNEL)					
Stations before and after dredging	491.813	1	491.813	37.211	0.001
Variation between stations	691.024	33	20.940	1.584	Less than 0.05
Interaction of pre- and post-dredging and stations	635.301	33	19.252	1.457	Less than 0.05
STATIONS A-J, M (CHANNEL)					
Stations before and after dredging	341.885	1	341.885	127.426	0.001
Variation between stations	163.579	10	16.358	6.097	0.001
Interaction of pre- and post-dredging and stations	133.872	10	13.387	4.990	0.001

computations were performed on an RCA SPECTRA 70/46 computer.[5]

Two-way analyses of variance were performed on dry weights of the samples drawn from stations 2-25; 2-25 plus channel stations A-J, M; and channel stations A-J, M alone.

Table 8 reveals that pre- and post-dredging biomass varied significantly among stations 2-25, among all stations, and between each channel station. The variances in biomass between stations were not significant in the bay and combination of bay and channel, even though they represented a substantial spectrum of substrata and current velocities. Biomass variances were, however, significant in the channel alone. There was also no significance in the variances of the interaction between stations and dredging, except in the channel.

The macrobenthic biomass in Goose Creek had not returned to its pre-dredged level 11 mo after dredging.

In the channel substratum, which had a virtually linear reduction in particle size and current velocity progressing from east to west, there was significance in both station to station variance and in the interaction between stations and pre- and post-dredging variances. This demonstrates a systematic difference between stations, as well as a significant difference from station to station in the manner in which the animal populations responded to the dredging process.

A second two-way analysis of variance was performed on all three sets of data in an attempt to determine whether or not the variance in biomass was a function of sediment type. The sampling stations were classified according to the sediment map (Figure 7), with verification provided by visual analysis of samples from the suction corer. Table 9 lists the stations according to their sediment classification.

TABLE 9.—Classification of the Goose Creek sampling stations according to sediment type.

Sediment type	Stations
Sand	2, 3, 4, 9, 10 A, B, C, D
Muddy sand	6, 7, 8, 24 E, F, G
Sandy mud	11, 12, 18 H, I, J
Mud-silt	14, 15, 16, 17 22, 23, 25, K
Intertidal	9A, 13, 20, 21

[5]The authors are grateful for the assistance rendered by the Hofstra University academic computing facility, Eugene Ingoglia, Director; John Pizzeriella, Programmer; Claire Gittelman, Statistician.

Table 10 summarizes an analysis of variance of the biomass at the Goose Creek stations according to sediment type. Separate analyses were performed on the data for stations 2-25; 2-25 plus channel stations A-J, M; and channel stations A-J, M alone.

Significance was found in all three analyses only among dry weights before and after dredging. There was no significance in the variances among substratum types, nor among the interactions of substrata and pre- and post-dredging biomass. There was, then, no systematic effect of particular sediment types alone on the rate of recovery of the in- and epifauna, even in the channel.

A four-way analysis of variance was performed to examine the relationship between seasons and variances in biomass at each station, without considering pre- and post-dredging effects. Stations 2-18 were studied. The unrepresented stations are in the less saline western half of Goose Creek which was frozen over during January and February of both years. There were no significant differences in the seasonal variances among stations, indicating that seasonal fluctuations in biomass were not factors which accounted for the differences in biomass, heretofore attributed to the dredging operation. Table 11 summarizes the statistics for the analysis of variance according to seasons.

Another four-way analysis of variance was performed to examine the relationship between seasonal variances and substratum type for stations 2-25. Again, there was no significance in any of the interactions, indicating that variances in biomass are not a function of season, sediment type, or of an interaction between these factors. This analysis is summarized in Table 12.

It was expected that the channel would show substantial effects of the dredging process, since it was from the channel that massive quantities of substratum were removed. The sediment and its inhabitants were physically removed to a depth of 2 m. What is of greater importance is the evidence

TABLE 10.—Analyses of variance of pre- and post-dredging dry weights according to sediment type in the bay and channel.

Source	Sum of squares	Degrees of freedom	Mean squares (variance)	F test	Probability
STATIONS 2-25					
Stations before and after dredging	107.634	1	107.634	6.584	0.025
Sediment types	32.746	4	8.187	0.501	Less than 0.05
Interaction of stations and sediment types	62.912	4	15.728	0.962	
STATIONS 2-25 PLUS A-J, M (CHANNEL)					
Stations before and after dredging	206.841	1	206.841	13.899	0.001
Sediment types	42.489	4	10.622	0.714	Less than 0.05
Interaction of stations and sediment types	81.747	4	20.437	1.373	Less than 0.05
STATIONS A-J, M (CHANNEL)					
Stations before and after dredging	160.146	1	160.146	22.043	0.001
Sediment types	17.083	3	5.694	0.784	Less than 0.05
Interaction of stations and sediment types	22.863	3	7.621	1.049	Less than 0.05

TABLE 11.—Four-way analysis of variance of dry weights according to season, stations 2-18.

Source	Sum of squares	Degrees of freedom	Mean squares (variance)	F test	Probability
Seasonal variations	10.653	3	3.551	0.250	Less than 0.05
Stations	224.442	16	14.028	0.988	Less than 0.05
Interaction between seasons and stations	566.497	48	11.802	0.831	Less than 0.05

TABLE 12.—Four-way analysis of variance of dry weights according to season and sediment type.

Source	Sum of squares	Degrees of freedom	Mean squares (variance)	*F* test	Probability
Seasons	17.307	3	5.769	0.332	Less than 0.05
Sediments	18.002	4	4.500	0.259	Less than 0.05
Interaction between seasons and sediments	119.121	12	9.927	0.572	Less than 0.05

that the rest of Goose Creek, as represented by stations 2-25, also suffered a reduction in biomass from which recovery was not evident 11 mo after dredging.

Further evidence of the reduction in biomass after dredging can be found in Table 13, which is a comparison of dry weights at stations 2-25 in June 1967 and 1968, 1 mo before and 11 mo after dredging. Only one station of the 13 (station 11) for which comparative data exist had biomass in excess of the 1967 levels. The significance of any individual datum is not great, since the presence of an adult clam or sea cucumber could inordinately affect a particular station. The general trend, however, is clear; 12 out of 13 stations have substantial reductions in biomass. This reduction cannot be attributed to mechanical removal of sediment or specimens, and is attributed to the dredging process itself.

Chi-Square Analysis of Number of Species and Specimens

Chi-square analyses were performed to determine whether or not the number of species and individuals in the post-dredging series differed significantly from the pre-dredging population. Data were further analyzed to determine if substratum and seasonal variations affected species diversity and numbers of individuals. Table 14 represents the chi-square analysis of the number of species before and after dredging for the whole bay (minus the intertidal stations), the bay stations plus the channel stations, and the channel stations alone. In all cases the chi-square was significant, indicating that species number was affected by dredging. Since chi-square analysis is limited by its inability to discriminate between sign (+ or −), Table 15 tabulates the number of species found at stations 2-25 in June 1967, 1 mo before dredging, and in June 1968. A reduction in species number occurred at 75% of the stations after dredging, with three stations or 18.7% exhibiting small increases in species number.

A chi-square analysis was performed on the number of species according to sediment type (e.g., sand, muddy sand, mud-silt). The number of species altered significantly according to substratum after dredging, both in the bay as a whole and in the channel (see Table 16).

TABLE 13.—A comparison of dry weights from stations 2-25, June 1967 and June 1968 (in g).

Station	June 1967	June 1968
2	1.37	0.92
3	1.80	0.31
4	—	—
5	1.92	1.04
6	0.63	—
7	9.44	—
8	4.81	0.15
9	18.25	0.83
9A	0.55	—
10	1.07	0.07
11	0.30	1.64
12	5.86	1.82
13	—	—
14	0.00	—
15	7.68	0.00
16	8.77	0.71
17	2.70	0.41
18	1.41	1.08
20	—	—
21	—	—
22	9.47	0.01
23	—	0.005
24	16.13	—
25	0.00	—

TABLE 14.—Chi-square analyses of the number of species before and after dredging for stations 2-12, 14-19, 22, 23; stations 2-12, 14-19, 22, 23 plus channel stations A-J, M, and stations A-J, M alone.

Stations	Chi-square	Degrees of freedom	Level of significance
2-23	32.763	18	0.025
2-23, plus A-J, M	55.366	26	0.005
A-J, M	21.557	7	0.005

TABLE 15.—Number of species found at stations 2-12, 14-19, 22, 23 on June 1967 and June 1968.

Station	June 1967	June 1968
2	22	5
3	16	5
5	19	17
6	11	3 (4/68)
7	25	—
8	19	13
9	21	13
10	26	5
11	9	5
12	3	6
14	0	4 (4/68)
15	11	0
16	10	3
17	5	1
18	5	7
22	9	3
23	1	1

TABLE 16.—Chi-square analysis of the number of species before and after dredging, as a function of sediment type. Stations 2-25; 2-25 and A-J, M; channel stations A-J, M.

Stations	Chi-square	Degrees of freedom	Level of significance
2-25	8.43	3	0.05
2-25; A-J, M	21.41	3	0.005
A-J, M	38.24	3	0.005

TABLE 17.—Chi-square analyses of number of organisms before and after dredging, stations 2-21, 23; 2-21, 23 plus A-J, M; stations A-J, M only.

Stations	Chi-square	Degrees of freedom	Level of significance
2-25	6,075.22	20	0.005
2-25, A-J, M	6,364.59	29	0.005
A-J, M	152.84	8	0.005

TABLE 18.—Chi-square analysis of the number of organisms before and after dredging as a function of sediment type, stations 2-25; 2-25 plus A-J, M; stations A-J, M.

Stations	Chi-square	Degree of freedom	Level of significance
2-25	2,051.59	3	0.005
2-25, A-J, M	1,679.51	3	0.005
A-J, M	21.57	3	0.005

Similar chi-square analyses were performed using number of individuals at all stations. Here results were even more positive. For example, the pre-dredging number of specimens at station 2 was 6,682; the post-dredging number was 27. Five out of 30 stations, or 16.6%, showed post-dredging increases in population; the others experienced drastic decreases.

Table 17 is a summary of the chi-square analysis of the number of individuals before and after dredging. The difference in specimen numbers was highly significant in both the bay as a whole and in the channel.

Chi-square analyses were made on the number of specimens before and after dredging as a function of sediment type. In both the bay as a whole and the channel the number of specimens was significantly different (0.005) in the post-dredging samples, according to sediment types (Table 18).

In summary, the numbers of species and organisms differed significantly before and after dredging, in the bay as a whole, as well as in the channel. Additional data show that this difference was in the direction of a post-dredging reduction in both species diversity and number of individuals found at each station. A few stations showed apparent recovery by June 1968, 11 mo after dredging. These were invariably low-population stations in the mud-silt region of the bay, where a few influents could appreciably change the population size. Stations 2-11, the sand, muddy sand, sandy mud stations, had drastic reductions in both parameters. Table 19 provides further substantiation for this conclusion.

Standing Crop Estimates

A total of 137 species was taken from the sediment of Goose Creek during the 22 mo of the study. Maximum wet weight at any one station was 2,581.4 g/m^2, with a corresponding dry weight of 355.6 g/m^2. Mean dry weight before dredging (excluding the channel) was 36.8 g/m^2 (49.6 g/m^2 including the channel) while the corresponding weight after dredging was 12.7 g/m^2 (10.1 g/m^2 including the channel), a loss of 63% of dry weight. The loss, including the channel, was 79%. (Pfitzenmeyer, 1970, reported a loss of 64% in his spoil deposition area and 72% in the channel.)

The mean number of species per station (stations 2-24 minus the four intertidal stations) was 5.47 (54.7/m^2) before dredging and 4.02 (40.20/m^2) after dredging, a reduction of 26%.

The maximum number of specimens found at any one station was 3,521, of which 3,470 were the gastropod, *Crepidula fornicata* (station 2, October 1966). The mean number of specimens before dredging for stations 2-24 (minus the intertidal stations) was 120.14 (1201.4/m^2), while the after-dredging mean was 25.63 (256.3/m^2). This constitutes a 79% reduction in the number of specimens found at the post-dredging stations.[6]

Comparison With Other Areas

Direct comparisons between the standing crop estimates at Goose Creek and other areas is complicated by the diverse methods of obtaining these estimates used by workers in the field. As previously indicated, Holme (1953) and Sanders (1956, 1958) used HCl to remove the carbonates from the carapaces of crustaceans and both removed all specimens greater than 0.2 g dry weight from their samples. For reasons previously mentioned, it is important in this investigation to obtain data on the populations of the larger forms which dominate the communities of the shallow, estuarine study area being investigated. Variation in sieve mesh size between studies is also an important factor accounting for differences in infaunal biomass estimates, but Sanders (1956) attempted to compare numerical results of several investigations by plotting mesh size against the log of the number of animals per square meter. The lowest estimates were those obtained by Holme (1953) from the English Channel (160/m^2) and Miyadi (1940, 1941a, 1941b) from Japanese bays (266-1,290/m^2). Sanders' mean number of animals for Long Island Sound was 16,443/m^2, although 63% of his stations had fewer than 8,500 animals/m^2. The mean number of animals at Goose Creek (1,201.4/m^2) is considerably lower than that obtained by Sanders, but it is unlikely that this parameter is the most useful in comparing areas since his *Ampelisca* and *Nepthys incisa-Yoldia limatula* communities contained relatively dense populations of small organisms, while at Goose Creek amphipods and protobranch pelecypods made up a very small proportion of the biomass.

[6]The data for the means of the stations (per 0.1 m^2 samples) were provided as a more accurate estimate of such quantities as species number, because extrapolations from 0.1 m^2 to 1.0 m^2 in the case of small numbers like 5.47 specimens/0.1 m^2 seem to introduce an inordinate amount of potential error.

TABLE 19.—The number of organisms found at each station before and after dredging, stations 2-25, A-J, M.

Station number	Before dredging	After dredging
2	6,682	27
3	1,499	188
5	466	330
6	266	41
7	566	266
8	342	95
9	153	56
9A	92	80
10	505	239
11	144	49
12	47	117
13	6	5
14	73	92
15	125	100
16	192	121
17	270	79
18	66	241
20	129	809
21	124	21
22	271	38
23	102	1
24	300	325
25	65	4
A	74	35
B	708	43
C	612	208
D	262	33
E	53	23
F	54	11
G	95	26
H	64	5
I	49	1
J	51	7
M	46	0

In a comparison of the dry weights of Long Island Sound with other areas, Sanders gives a figure for the mean total dry weight (including "large animals") of 54.627 g/m^2. This corresponds to a dry weight of only "small animals" of 15.88 g/m^2, a figure which is roughly twice as great as the highest mean value for the other areas discussed. Pfitzenmeyer (1970) performed a study closer in purpose to the present investigation than those described by Sanders. His pre-dredging mean dry weight (including large forms) was 0.90 g/m^2, while the immediate post-dredging mean was 0.67 g/m^2.

Holme's (1953) mean dry weight was 11.2 g/m^2, including "large" animals.

The figure obtained by Sanders for total dry weight are in good agreement with those computed for the present study, since the pre-dredging dry weight for Goose Creek was 36.83 g/m^2, while the Long Island Sound figure was 54.627 g/m^2. The substantial variance of these data from those of Holme (11.2 g/m^2) and Pfitzenmeyer (0.90 g/m^2) has been accounted for, in principle, by Sanders in his 1956 paper.

For data reported on the basis of the 0.2 g dry weight cut-off point, it is sufficient, in many cases, to add the factor suggested by Holme when he points out that 64.4% of the dry weight of his samples was excluded by the 0.2 g point, in order to bring the data to comparable levels.

Factors relevant in an explanation of the relatively high standing crop in Goose Creek are:

1. None of the studies referred to sampled to a depth beyond 22 cm, and most examined only the top 6-10 cm of sediment. Deeper-dwelling, large forms were excluded.

2. Virtually all of the investigations previously referred to examined relatively large, slow current velocity, deep bodies of water with relatively unvarying bottom sediments, such as Chesapeake Bay. Often the populations described comprise mud-silt or silt-clay communities, such as the *Ampelisca* community described by Stickney and Stringer (1957). It is well known that this sediment is not highly productive of biomass since most organisms are relegated to the upper few centimeters where gaseous exchange is most rapid (cf. Raymont, 1950; Sanders, 1956; Holme, 1953; Pfitzenmeyer, 1970). In Goose Creek the high current velocity over a substantial portion of the bay and the diversity of sediment types supported sizeable populations of large organisms, such as the 3,470 *C. fornicata* found in one dredge haul at station 2.

3. Phytoplankton production is high. Cassin (1968) studied the phytoplankton cycle in Goose Creek during the year before dredging, and found a mean standing crop of 1.64×10^6 cells/liter. This was lower than that for Long Island Sound (2.38×10^6 cells/liter; Conover, 1952), but considerably higher than those for Block Island Sound and Vineyard Sound. According to Riley (1955), the mean standing crop of phytoplankton in the English Channel is one-quarter that of Long Island Sound; while Flemer (1970) makes a primary production estimate for Upper Chesapeake Bay at one-fifth of that estimated by Riley for Long Island Sound. Phytoplankton population size appears to vary with benthic standing crop in the studies mentioned above.

Population Dynamics and Distribution of Organisms

Most of the dominant and subdominant organisms found in the channel before dredging were present in greatly reduced numbers after dredging (Kaplan, Welker, and Kraus, in press-b). Three species of mollusc increased in numbers after dredging. *Tellina agilis* and *Lyonsia hyalina* increased in sandy sediments while *Mulinia lateralis* became more abundant in the finer substrata. Two polychaetes, *Notomastus latericeus* and *Clymenella torquata*, abundant before dredging, virtually disappeared afterwards. O'Connor (1972) noted an increase in populations of *Mulinia lateralis* and *Tellina agilis* in his study of Moriches Bay. He suggests that *M. lateralis* is a fast-growing, short-lived species that is more successful in silt. If this is so, it may be suited as an indicator organism which would rapidly increase in numbers in areas where dredged channels cause decreased current velocity and, consequently, invasion of sandy areas by softer sediments.

The channel data were not duplicated in the bay as a whole. The most fundamental difference between the two areas was the fact that the substratum and all its infauna were removed in the channel study, while only stations 2 and 3 in the bay study were directly in the path of the dredge. Consequently, the drastic effects of the removal of the habitat were limited, and the reduced population size throughout the bay must be a concomitant of other long-term variables, such as changes in current velocity and anoxia resulting from siltation. Stations 22, 23, and 5 were particularly susceptible to this latter influence, being near spoil areas. Portions of Thyone Cove were inundated when the spoil gate broke during the dredging operation. In addition, station 23 was in the path of the 1968 dredging of an extension of the navigation channel through Thyone Cove.

Most stations, even those in the farthest reaches of the bay, showed reductions in benthic populations; however, no station was farther than 500 m from the dredge at some time during the operation, except for station 25. Figure 12 depicts the changes in population densities of 13 dominant and subdominant benthic organisms before and after dredging. In addition, the abscissa of each histogram represents the sediment type, from the gravel of station 2 to the silt of station 23.

Clymenella torquata, the nearly ubiquitous bamboo worm, was the numerical dominant in the sandy substrata, forming dense colonies. *Notomastus latericeus* shared this habitat, though in reduced numbers. Both species of worm

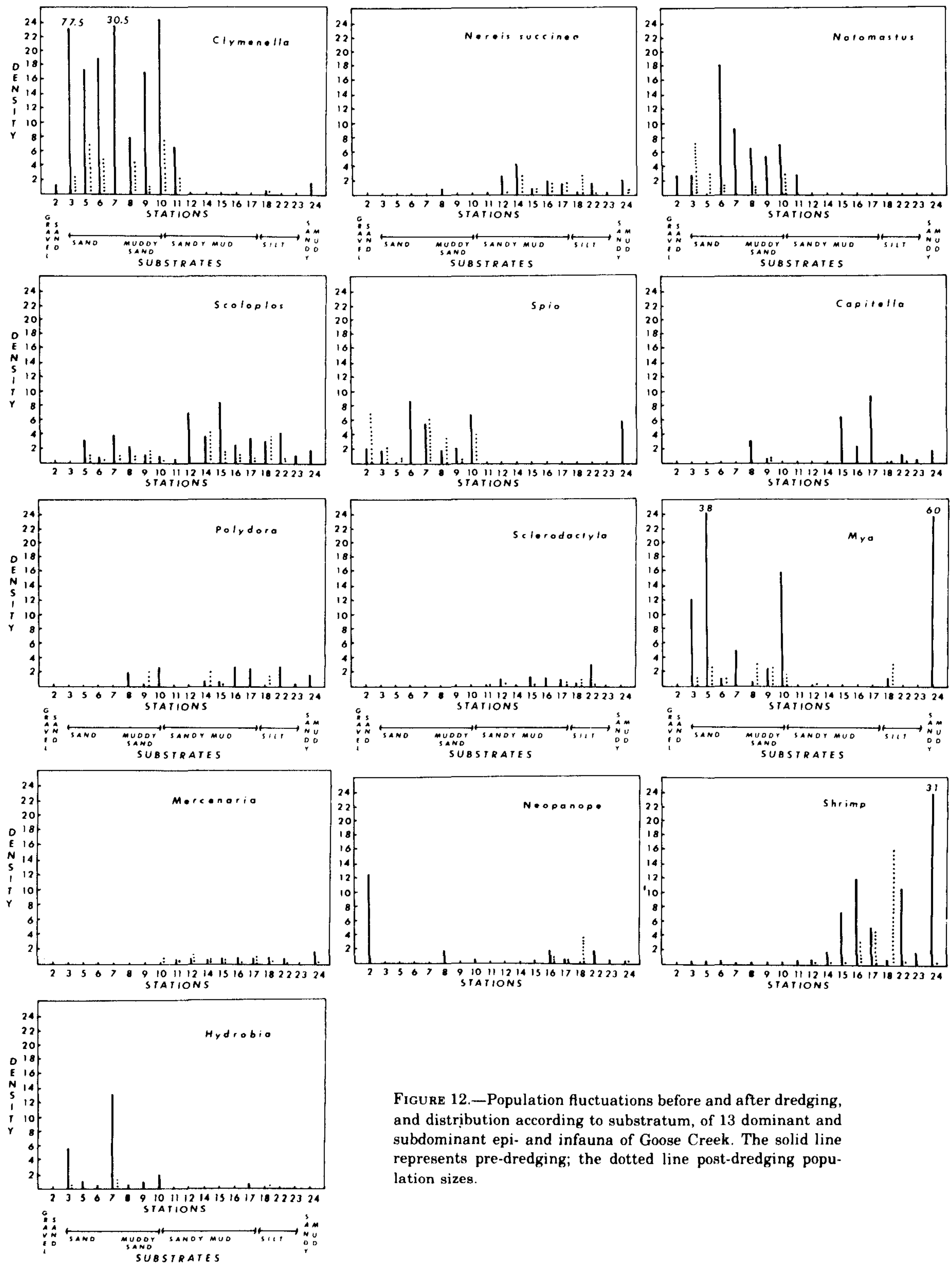

FIGURE 12.—Population fluctuations before and after dredging, and distribution according to substratum, of 13 dominant and subdominant epi- and infauna of Goose Creek. The solid line represents pre-dredging; the dotted line post-dredging population sizes.

showed substantial reductions in density in the post-dredging samples. *Spio setosa*, another inhabitant of sandy substrata, seems to have maintained its population size, with 50% of the stations recording increases in the number of specimens.[7]

Capitella capitata and *Polydora ligni*, inhabitants of sandy mud, also decreased in number. *Nereis areonodacea* was found in muddy sand in small numbers, while *Nereis succinea* was present in densities up to 42/m^2 in the sandy mud and silt stations, which were also frequented by *Mercenaria mercenaria*. Modest reductions in the *Nereis* and *Mercenaria* populations occurred after dredging.

Mya arenaria was found in sand and muddy sand. Certain areas experienced drastic reductions in the densities of these organisms, but since most of the *Mya* recorded were juveniles, population fluctuations independent of dredging may have been an important factor. Factors favorable to larval settling and the growth of juveniles may have been unsuited to their sustenance as adults, resulting in mass mortality of juveniles at critical points in their development.

Of the epifauna, *Neopanope texana sayi* was found in greatest abundance in the high current velocity, stony gravel of station 2. It was also abundant in the muddy sand of station 8 and the silt of stations 16, 18 and 22. It was recovered in five of the samples at station 16 and four at station 18, so it is unlikely that the presence of this crab in the silt regions was accidental. *Neopanope texana sayi* experienced a reduction in population density after dredging.

Crepidula fornicata was found in large numbers (3,470 in one haul) at station 2 before dredging, but since this station was in the channel, it was decimated by the dredge and no recovery was noted in the 11 mo period after dredging. *Crepidula* broods its young; recovery would be expected to be relatively slow in a decimated area as dispersal is not accomplished by free-swimming larvae.

Four species of Caridean shrimp were abundant on the silt substratum of Goose Creek. These were *Hippolyte pleurancanthus, Crangon septimspinosus, Palaemonetes vulgaris*, and *P. pugio*. Their numbers fluctuated seasonally and from station to station, possibly reflecting sampling error inherent in using the cumbersome corers to capture these relatively rapidly moving organisms. There were population decreases at most stations.

The snail, *Hydrobia totteni*, was most common in the sandier sediments, especially at stations 3 and 7 which had substantial current velocities. Its post-dredging density was considerably reduced from pre-dredging levels.

Mulinia lateralis was found to be more abundant in the channel after dredging than before. Too few were encountered in the bay study to corroborate this finding.

The polychaete *Maldanopsis elongata* was found only at station 11 in virtually all samples, reaching a density of 60/m^2. Its population size was maintained after dredging.

The holothurian *Sclerodactyla (=Thyone) briaerius* was common in the silt stations 12-22, reaching a density of 60/m^2 in the deep silt of station 22. The mean numbers at station 22 were 33/m^2 before dredging and 2/m^2 after dredging, reflecting, perhaps, the close proximity of this station to the spoil gate of spoil area C. *Sclerodactyla briaerius* experienced declines at five of the six stations at which it was recorded in substantial numbers.

The tunicate, *Molgula manhattanensis*, was common on the *Enteromorpha* which covered the silt at stations 22, 23, and 24, reaching a concentration of 590/m^2 in December 1966 at station 23 and declining in numbers after dredging at all three stations.

An amphipod community, similar to those described by Stickney and Stringer (1957) and Rhoades and Young (1970), occurred in the silt west of station 12. The most abundant species were identified as *Ampelisca macrocephala* and *A. spinipes*. Maximum abundance recorded for stations 16, 17, and 18 was 310, 490, and 190/m^2, considerably lower than the level of 10,000 m^2 mentioned by Stickney and Stringer for Greenwich Bay. The 1.4 mm sieve size used in this study contrasts with the practice used by Stickney and Stringer of examining the fine sediments completely, using no sieve. However, it seems unlikely that population densities would be comparable, since there was no massive concentration of amphipod tubes in the Goose Creek

[7]The reader should be cautioned in interpreting the fluctuations in population densities on these graphs. Although each column represents six pre-dredging or six post-dredging samples, the distribution of organisms was so patchy that accumulating the data and recording means still does not compensate for possible sampling error as the corer penetrated a worm colony one month and sampled a relatively sterile area 1 m away from it the next. Trends, however, are apparent.

samples. The amphipods found in Goose Creek were limited to the soft sediments, in contrast to Long Island Sound and Buzzards Bay, as reported by Sanders (1956, 1958), making it likely that they are detritus feeders. No pattern was evident between pre- and post-dredging population densities of amphipods.

The *Nepthys incisa-Nucula proxima* community of Sanders was not found in Goose Creek since both species were not abundant enough at any one station to be considered dominant. Instead, a *Nereis succinea-Mercenaria mercenaria-Sclerodactyla briaerius* community was found, with subdominants including *Capitella capitata* and the caridean shrimp previously mentioned as epifaunal subdominants.

Clymenella torquata and *Mya arenaria* can be considered the dominant sandy sediment assemblage, with *Notomastus latericeus* and *Hydrobia totteni* comprising important subdominant populations.

Scoloplos robustus, S. fragilis, and *Neopanope texana sayi* were distributed throughout the sediment types in Goose Creek, apparently without specificity.

There was no evidence that the dredging process eradicated any species. There was, however, evidence of two cyclical fluctuations in population density which occurred naturally and were superimposed on the dredging data. Individual *Aequipecten irradians* were found in only four sampler hauls. Much of the shell in the substratum was contributed to by this species, testifying to its former abundance. In fact, it was commercially harvested from Goose Creek in previous years. Its absence coincided with a cyclical low in its density and had nothing to do with the dredging. Similarly, not one specimen of *Callinectes sapidus* was recorded for the 22 mo of the study, yet in July 1970 large numbers of these crabs were observed in Goose Creek.

Productivity

The mean pre-dredging dry weight for Goose Creek was 36.83 g/m^2 before dredging and 12.78 g/m^2 after dredging, a decrease of 63%. Sanders (1956) suggests that standing crop figures for infauna are a function of productivity by a ratio of 2.1-5.0:1. Taylor and Saloman (1968) used a factor of 4 in their calculations of infaunal productivity in highly productive turtle grass beds.

Sanders' mean ratio for all stations in his Long Island Sound survey was 2.44. He estimated the total productivity of "small infauna" in the sediment of Long Island Sound at 21.49 g/m^2. In computing his estimate he did not consider epifauna and "large" forms. He also makes the assumption that the substratum of Long Island Sound is comprised of 80% fine sediments and 20% coarse. Goose Creek has a distribution closer to 50% of each type of sediment. Correcting for these factors would tend to raise the total value of the estimate, even though the biomass of "short-lived" species is a practically negligible component of the Goose Creek samples, a factor which could lower the figure to 2.1. Because of these considerations, and because of the contiguity of the two study areas, Sanders' figure of 2.44 was adopted for Goose Creek.

Macrobenthic animal production in Goose Creek before dredging is estimated at 89.87 g/m^2/yr, using the factor of 2.44. If Sanders had used his standing crop figure for all epi- and infauna from Long Island Sound (54.627 g/m^2) in a similar calculation, his estimate would be $54.63 \times 2.44 = 133.30$ g/m^2/yr, a figure in essential agreement with the ratios of the standing crop estimates in the two areas.

The after-dredging productivity figure is 31.18 g/m^2/yr for a loss of 58.69 g/m^2/yr. This means that 18,780 kg of animal production were lost from the 0.32 km^2 of bottom in Goose Creek during the post-dredging year. This corresponds to approximately 58,700 kg/km^2/yr reduction in the productivity of the bay, out of a total productivity of 89,870 kg/km^2/yr.

Primary productivity of the extensive *Ruppia* and *Enteromorpha* beds was not estimated.

An Estimate of the Productivity of the Marsh

The islands in Goose Creek are represented on a 1904 map with virtually unaltered boundaries. Their natural isolation makes it unlikely that they have ever been exploited by man. The relative abundance of "bank" or "mud" oysters and extensive colonies of *Modiolus* and *Uca* give further evidence of their pristine state.

The islands evidently have been created by the deposition of materials at the confluence of channels A, B, and C. They are covered with a uniform growth of *Spartina alterniflora*, with

Salsola kali and other plants growing on patches of slightly higher ground. The dominant animal is *Modiolus demissus* which was abundant on all four major islands, averaging 19.58 specimens per m². Colonies of fiddler crabs, predominantly *Uca pugnax*, were found on islands I and II.

The islands are little more than hassocks of *Spartina*. At low tide they project 0.7 m to 1 m above the water surface; at high tide they are virtually inundated. The largest of the islands, island II, was 115.59 m × 42.39 m.

The islands represent the most unspoiled aspect of the Goose Creek marsh. For that reason, they were chosen as the site for estimating the productivity of the *Spartina alterniflora* marsh along the periphery of Goose Creek. The resulting figure will be higher than other productivity estimates because it does not represent the *Spartina patens* and *Phragmites communis* marshes which are both transitory and strongly affected by man in the Goose Creek area.

Island II, the most southeasterly of the islands, was sampled by means of seven stations arranged at 15 m intervals and staggered so that both edges and the center of the islands were sampled at least twice (Figure 13).

A 1.83 m × 1.83 m frame was placed on the area to be sampled so that 3.34 m² were delimited. A team of four collectors was stationed, one collector on each of the sides of the sample area, to prevent motile forms from escaping. All surface-dwelling animals were removed by hand. The area was then spaded to a depth of 20 cm to remove burrowing forms. The total area sampled was 23.4 m².

Table 20 represents the animal biomass of the stations on island II. Animals making up the species mix were: 104 *Uca pugnax*, 6 *Uca pugilator*, 442 *Modiolus demissus*, 28 *Sesarma reticulatum*, 1 *Carcinus maenus*, 3 *Littorina littorea*, and one unidentified Nereid.

The total wet weight of the macrofauna taken from the seven stations is 2,327.01 g, or 90.94 g/m². The corresponding calculation for dry weight is 20.21 g/m². The ratio of dry weight to wet weight is 1:4.9.

The computations for estimating primary productivity of the marsh were taken from Udell et al. (1969) from their study of the Hempstead, Long Island, salt marsh. They calculated a total minimal estimate (harvest method) of annual production of 3.68 tons per acre of tall *Spartina*

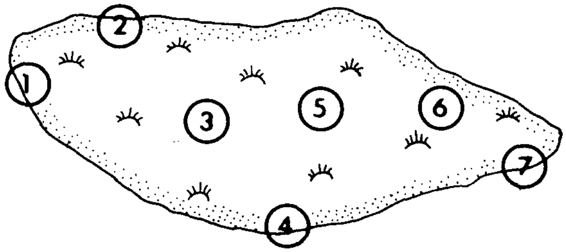

FIGURE 13.—The distribution of stations on island II.

TABLE 20.—Biomass of animals found on island II, Goose Creek.

Station	Animals				
	Wet wt. (g)	Dry wt. (g)	Dry-wet ratio	No. specimens	No. species
1	397.32	78.52	1/5	62	2
2	595.55	108.90	1/5	109	4
3	155.76	28.47	1/6	39	4
4	175.46	34.19	1/5	47	4
5	705.24	156.86	1/5	157	3
6	213.97	41.90	1/4	96	4
7	83.71	16.43	1/5	29	3
Total	2,327.01	475.27			

alterniflora and 2.55 tons per acre of the mixed species comprising the typical Long Island marsh (tall and short *S. alterniflora*, *S. patens*, *Distichlis spicata*, etc.). These weights corresponded to a mean dry weight of 827.2 g/m² for tall *S. alterniflora* and (by extrapolation) 578 g/m² for the mixed species. Animal production taken from our mid-August study is 20.21 g/m², dry weight. Sanders (1956) suggests that standing crop figures for infauna are a function of productivity by a ratio of 2.1-5:1. Since the organisms predominating in our samples are predominantly "long-lived," Sanders' factor of 2.1 was applied. Animal productivity of the marsh comes to 42.4 g/m²/yr, by this calculation. This is roughly 5% of the tall *S. alterniflora* productivity figure or 7% of the overall estimate. The total animal and plant productivity of the tall *S. alterniflora* marsh as represented by island II, is 869.64 g/m²/yr. Thus, if the dredged channel had passed through island II instead of skirting it, its 4,900 m² of marsh or 4,261.2 kg (dry weight) of animal and plant productivity would have been permanently obliterated.

The portion of the Goose Creek marsh inundated as spoil areas has been estimated at 108,712 m². Using Udell's estimate of 2.55 tons/acre (4,553.57 kg/ha), the total primary productivity of the marsh which became the spoil areas would be 4,553.57 kg/ha × 10.87 ha or 49,497.31 kg/yr.

Animal production of tall *S. alterniflora* marsh has been estimated to be 5-7% of primary productivity. Since mixed marsh is not as productive of animals as tall *S. alterniflora* marsh, a figure of 4% of the *mixed marsh* primary production seems to be a reasonable estimate. Annual animal production on the 10.87 ha of inundated mixed marsh would then be 4% of 49,497.31 kg or 1,979.89 kg.

Virtually the entire spoil areas have been turned into homesites. If they had been left to produce a *Phragmites communis* community, only a relatively small proportion of the original productivity would have been locally available on a trophic level (Johnson, pers. comm.).

Since approximately 45% of the net production of a salt marsh (Teal, 1962) is exported outside the area of its source, the loss of this productivity will have repercussions beyond Goose Creek.

The estimates given herein should be considered conservative, as E. P. Odum (1959) estimated the primary productivity of tall *S. alterniflora* in Georgia salt marshes at a high of 14 tons/acre and Ryther (1959) gives a figure for net organic production of *Spartina* marsh of 9.0 g/m²/day.

H. T. Odum (1963) indicates that *Thalassia* beds in Redfish Bay, Tex., recovered in the areas not directly in the path of the dredge after one year, but his data indicate that the dredged area and an area 0.25 mile east of the channel had no productivity due to removal of the substratum to bedrock in one case and "beds covered with 30 cm of soft silt" in the other. Virtually all of Goose Creek was within 0.25 mile of the dredge. Studies of large embayments tend to deemphasize dredging effects because of the dissipation of the products of the dredging process and dilution factors. Similarly, regions like Chesapeake and Redfish Bays have relatively extensive bottom areas and circumferences and dredge spoil is either deposited back in the basin where it spreads to form a relatively shallow homogeneous layer often virtually indistinguishable from the bottom (Biggs, 1968, 1970), or covers a relatively small portion of the bay edge.

The effects of dredging appear to be accentuated as the size of the embayment decreases.

DISCUSSION

The Relationship of the Substratum to the Distribution of Organisms

Wilson (1938, 1953), Morgans (1956), Sanders (1958), and Sasaki (1967) related larval or adult infaunal population densities to sediment type. McNulty, Work, and Moore (1962) and Harrison, Lynch, and Altschaeffl (1964) fail to corroborate either degree of sorting or median grain size as definitive factors affecting the distribution of deposit or filter feeders. It appears that animal-sediment relationships are variable depending on such factors as sediment type, life cycles of related fauna, and location.

In the Goose Creek study the analysis of variance between biomass before and after dredging as a function of sediment type revealed no significant interaction between productivity of animal biomass and sediment type in the bay as a whole. In the channel, however, there was a positive correlation between biomass and stations. Since the stations were arranged in linear fashion virtually in descending order of particle size and in the direction of lowered current velocity, these factors appear to have had an influence on productivity.

The recovery rate of the macrobenthic populations varied in different substrata according to a chi-square of the number of species found at the stations representing different sediment types. Similarly, the number of species was significantly different before and after dredging, as a function of sediment type.

It appears, then, that productivity in terms of animal tissue was not independently influenced by substratum in the bay as a whole, but there was a response to the specific conditions in the channel. Recovery of species and specimen numbers appeared to be affected by sediment type in both channel and bay. These data tend to substantiate those of Sasaki (1967).

The Relationship of Current Velocity to the Characteristics of the Sediment and the Distribution of Organisms

In a shallow bay with a narrow mouth like Goose Creek, wind-driven currents probably have a disproportionately large effect on the characteristics of the sediment. Prevailing winds can cause a net transport of materials towards the lee shore. Wind storms can so pile up water at the mouth of the bay that flood tide current velocities would be considerably above the normal range, causing erosion of the banks of tidal channels and exaggerated depositional patterns, or winds can depress the natural flushing action of the ebb tide, increasing the deposition of light particles. A number of the aforementioned factors have not been considered in the literature in detail, perhaps because most investigations are concerned with relatively large and deep bodies of water. However, Biggs (1968) concludes that most of the suspended material in Upper Chesapeake Bay came from the bottom and had been stirred by wind-waves and currents.

Inman (1949) refers to three basic factors in the transportation and deposition of sediments: degree of bottom roughness, settling velocity, and threshold velocity. He shows that as current velocity drops in a downstream direction, particle size also decreases. The degree of sorting, however, is at a maximum in sediments with a median diameter near the grade of fine sand (0.18 mm). Threshold velocity for grain diameters less than 0.18 mm increases with decreasing grain size. Since the threshold velocity is much greater than the setting velocity for smaller particles, suspended particles entering a bay will, when deposited, have a tendency to remain a part of the substratum rather than move about by surface creep or resuspension. On the basis of these characteristics of fine sands, Sanders (1958) deduces that they must represent a very stable environment. He also emphasizes the role of clay as an efficient binding agent for organic matter, thus influencing the number of deposit feeders present. The simple clay-silt proportion governing the population size of Sanders' deposit feeders is not apparent in the distribution of filter feeders, where more complex factors are at work.

McNulty et al. (1962) related low current velocity to the accumulation of a detritus layer on the sediment surface capable of supporting large populations of detritus feeders.

Rhoads and Young (1970) suggest that biogenic reworking lowers critical erosion velocity and increases the instability of the substratum as manifested by a high resuspension rate and increased turbidity close to the silt-water interface, placing selective pressure on suspension feeders.

In the present investigation, maxima in biomass production occurred in areas of coarse and fine sand in the channel (stations B, C, and H) with current velocities of the order of 56 cm/sec and 17 cm/sec, before dredging.

In the bay as a whole 14 of 113 individual dredge hauls yielded dry weights above 80 g/m². Since the distribution of organisms was so patchy, these extraordinarily large standing crop measures are perhaps the best index of the productivity of the various substrata. The highest biomass was recorded for station 2. However, this consisted almost exclusively of *Crepidula fornicata*, an epibenthic gastropod which requires the scouring action of a rapid current to establish a substratum of stones upon which it clings with a broad foot. Stations 7 and 9 had high and medium current velocities (41.5 and 12 cm/sec) and supported extensive colonies of the polychaetes *Clymenella torquata* and *Notomastus latericeus*, as well as large pelecypods (*Mya, Ensis, Mercenaria*) in the case of station 9. Both *C. torquata* and *N. latericeus* are deposit feeders inhabiting sandy sediments.

Stations 16, 17, and 22 were in regions of almost negligible current velocity which were characterized by a substratum of silt over fine gray sand. The major weight contributors at stations 16 and 17 were *Sclerodactyla (Thyone)* and large *Mercenaria*, with the polychaetes, *Capitella capitata, Polydora ligni, Scoloplos robustus*, and *S. fragilis* making important contributions. *Polydora* is almost exclusively an inhabitant of mud, while the other worms are found in sandy mud.

All of the above-mentioned worms are deposit feeders whereas Sanders groups *Mercenaria* and *Sclerodactyla* together as suspension feeders.

Deposit-detritus feeders were important contributors to the biomass in Goose Creek, in both the sandy and muddy habitats. These animals are more or less substratum-specific, as can be seen on their distribution graphs (Figure 12) and in Sanders' data. Changes in current velocity have a profound influence on the nature of the substratum and, consequently, on animal distribution. This is especially true in the regions of the sandier sediments. Stations 2, 7, and 9 had reductions from 50 to 75% of pre-dredging velocities. In the western portion of the bay, wind-driven currents are the predominant means of sediment transport, and, although some changes in the mid-bay region could be expected due to increased current velocities, these would not have a substantial influence on the soft sediment of the western half of the bay.

The most numerous instances of high infaunal standing-crop production were in areas which correspond to the general classification proposed by Sanders (1956), of a relatively high silt-clay composition, although the stations with the highest animal biomass were either somewhat above the 13-25% silt-clay level reported as most highly productive, or toward the lower end of the spectrum. Suspension feeders, with the exception of station 2, were not the dominant forms in the sandy sediments of Goose Creek, except in the littoral. Instead, deposit feeding polychaetes were numerically dominant and often constituted the major weight factor in the biomass. Furthermore, if *Mercenaria* and *Sclerodactyla* are grouped together (Sanders, 1956), the biomass of suspension feeders predominates in high silt-clay regions. An important *Ampelisca* community was not found.

The Effects of Dredging on the Substratum and Its Fauna

Three major categories of environmental disturbance brought about by dredging are:

1. *Immediate effects*, during and directly after the dredging, including suffocation of benthic animals by siltation; flocculation and removal from the water column of planktonic organisms (which affects benthic filter feeders by removing their source of food); and changes in water chemistry, as substances are released from the substratum and dissolved. Large quantities of bottom materials placed in suspension by the dredging process decrease light penetration, change the proportion of wavelengths of light reaching the plants and interfere with the food-getting processes of filter feeders by inundating them with wrong size or nonnutritive particles.

On the other hand, the release of nutrients into the water profoundly affects the composition of the plankton by favoring the growth of some species. This effect could be beneficial or harmful depending on whether or not the plankton bloom is utilized by the filter feeders. If nannoplankton like *Nannochloris* and *Stichococcus*, which have been incriminated in mass mortalities of *Mercenaria*, are the dominant forms in the bloom, selective removal of certain species of filter-feeders could be expected.

2. *Transitory or semipermanent effects* such as the mechanical removal of the benthos from the dredged area and a change in the nature of the substratum by the deposition of spoil. These changes may be temporary, as the dredged area is recolonized or tidal currents reestablish the original substratum composition by scouring away fine particles and reestablishing old channels, or depositing fine sediment over exposed, sandy areas.

Recolonization of areas denuded of organisms has been studied under either artificially induced conditions or as the result of major disturbances such as oil spillage. Reestablishment of the original fauna is estimated to take at least 8 yr in the intertidal zone, as reported by Castenholz (1967) and by North (1967). Clarke and Neushul (1967:47) give some insight into the complexity of the recolonization process when they report: "Apparently a barnacle stage had to be established before the surface of the rock was suitable for the larval stages of *Mytilus* to become established." In their study it took 4 yr for the reestablishment of small *Mytilus californianus* colonies.

In the aforementioned works the environment was not fundamentally changed by the conditions leading to defaunation, namely, storms, oil spillage, or artificial removal of the organisms from the substratum.

If a rock has been manually denuded of organisms, natural succession can begin immediately. In the case of dredging, however, the substratum may remain unstable for a considerable time and final recolonization cannot begin until the climax substratum is reestablished.

3. *Permanent changes* in the ecology brought about by dredging occur if the ambient flow of water and current distribution patterns are disrupted. One of the results of dredging was the reapportionment of maximum water transport into Goose Creek from channel A to channel B. Furthermore, the current velocity in all three channels dropped because of the enlarged capacity of the dredged channel for containing water, since it was approximately three times deeper than the channel it replaced. A different distribution pattern of silt and other fine particles occurred as the result of lowered current velocities which resulted in sediment changes in a substantial portion of the bay.

Spoil deposition on the surrounding marshes has a profound effect on the species composition and productivity of an estuarine area. Raising the level of the marsh above the inundation zone will replace the highly productive *Spartina* community with the less biologically useful *Phragmites communis*. Much of the food of detritus feeders comes from the disintegrating plant material of the *Spartina* marsh and, in the absence or depletion of this food source, the species mix and/or proportion of detritus to deposit on filter feeders may be permanently changed.

Even the removal of shell from a mud bottom has been suggested as a reason for the exclusion of certain species from a dredged bay. Barnard and Reish (1959) suggest that the amphipod, *Metaceradocus occidentalis* and the polychaete *Scyphoproctus oculatus* were in danger of losing their habitat as the upper shell and rock laden layers of the mud substratum were removed by a dredging operation.

The distribution or removal of materials during dredging in a body of water with even minimal flushing action results in immediate, temporary, and long-term changes in its ecology. The interaction of organisms with this rapidly changing environment is poorly understood. Estuarine organisms are noted for their ability to withstand environmental vicissitudes, yet this adaptability may be overstressed by one or another aspect of the dredging process. For example, Postma (1967:226) refers to the difference in the distribution patterns of dissolved and suspended materials. He points out that dissolved materials have a net transport from regions of high concentration to regions of low concentration, causing a rapid dispersal of the dissolved matter and its consequent removal from the source area: "In the case of suspended matter the reverse often occurs. This material may be trapped and accumulated in the nearshore environment." Thus, a benthic organism in the vicinity of a dredging operation can be subjected to a short-term rapid surge of dissolved nutrients in its environment, with all of the concomitant interactions this represents. Superimposed on this relatively fleeting enrichment of the water would be the longer-term deposition of suspended sediments. The interaction between the two, such as the adsorption of organic compounds on suspended clay particles (e.g. amino acid complexes binding strongly to clays) (Siegel, 1966), the effects of flocculation, etc., is poorly understood. The presence of the dissolved organic compounds liberated by the dredging process also can have beneficial effects on the benthic organisms. Siegel quotes Stephens and Schinske (1961) who found that glucose, glycine, and aspartic acid can serve as energy sources for marine invertebrates. Organic matter may also supply a growth factor such as vitamin B_{12} or may inhibit the growth of bacteria by its antibiotic effect (Saz et al., 1963). It may promote growth by solubilizing trace metals, thus making them available (Johnston, 1964). Udell et al. (1969) analyzed marsh grasses and found a number of vitamins, including vitamin B_{12}. The destruction of peripheral marsh by spoil deposition may eliminate a constant source of vitamins and other nutrients made available by the disintegration of the *Spartina*.

The effects of the dispersion of light rays in the turbid water of a dredged bay is also incompletely understood. It is unlikely that increased turbidity can destroy benthic flora through light deprivation in shallow waters. Clendenning (1958) studied the relationship between photosynthesis and light intensities for *Macrocystis pyrifera* laminae. Compensation (light intensity where photosynthesis balanced respiration) occurred at 15 foot candles using white light. First evidences of saturation occurred at about 400 foot candles and maximum photosynthetic rates occurred at 1,600 foot candles. Since the intensity of daylight delivered to the water surface is about 10,000 foot candles, it is unlikely that the light values would so depreciate in shallow water as to seriously impair photosynthesis. On the other hand, the authors observed a colony of *Ruppia* after dredging and the leaves were covered by a light brown flocculent material which had been deposited from the water. Large areas of *Enteromorpha* and *Aghardiella* showed a similar canopy of fine sediment. It is possible that the deposition of opaque material from the water onto leaves and stipes in areas of negligible current velocity might pose a threat to the plants by inhibiting photosynthetic activity even though the turbidity of the overlying water is not high enough to reduce adequate light penetration.

The estuarine environment is particularly susceptible to particle deposition. Although it shares the factor of close proximity to the source of the particulate matter with open beaches, the beaches have a longshore drift factor which tends to distribute particulate matter. It is well known that beach sands are well sorted. Estuarine areas, on the other hand, have a circulation cycle which favors deposition. Postma (1967:229) states: "The estuarine circulation therefore acts as a 'sediment trap' in which water flows freely seaward, but particles heavier than the water are retained."

Flemer et al. (1968) list a number of factors associated with the effects of dredging on animal survival and suggest that suspended sediments probably affect many sites in the energy flow sequence of the benthic community.

Several studies have been made on the effects of siltation on the survival of pelecypods.

Loosanoff and Tommers (1948), Davis (1960), Davis and Hidu (1969), and Loosanoff (1962) described harmful effects of heavy sediment loads on eggs, larval development, and adult pelecypods, while Lunz (1938), Wilson (1950), Mackin (1956), and Dunnington (1968) showed that adult oysters do not suffer appreciable physiological damage unless subjected to very heavy siltation or buried.

Pfitzenmeyer (1970) described the effects of dredging and spoil deposition in Upper Chesapeake Bay. The dredging process did not cause major topographical or stratigraphical changes since the spoil was fundamentally identical with the substratum upon which it was deposited and it spread out to form a thin layer over the bottom, undisturbed by strong currents. Species mix and biomass were markedly reduced immediately after dredging, but recovered to original levels after 18 mo.

Of interest in Pfitzenmeyer's study is the superimposition of the natural cycles of certain molluscs on the data related to dredging. The pelecypods *Macoma phenax* and *M. balthica* were in a period of natural decline during the period of the study, while *Rangia cuneata* experienced a short-lived population explosion, reaching a density of 10,000 clams per m^2. One year after the study, the *Rangia* population had disappeared. These rapid and extreme fluctuations in the population densities of organisms profoundly affected biomass calculations because of the relatively large size of the pelecypods, compared with, for example, the three permanent dominants, two of which were an isopod and an amphipod. If the *Rangia* population increase had not compensated for decreases in the *Macoma* populations during the study, it is possible that there might have been significant differences in the results. If the dredging had substantially altered the substratum, e.g., by removing the silt to a depth sufficient to expose the sand underneath, the recovery of the populations might have required a period of substratum stabilization before achievement of normal populations.

Pearce (1970) studied a spoil deposition area of the New York Bight known as the "dead sea." He describes the benthic environment as severely affected by the deposition of large quantities of spoil. He found contamination by heavy metals, pesticides, and petroleum derivatives. The central portion of the spoil area contained no living macrofauna; peripheral areas were frequently barren or impoverished; interstitial waters of spoil sediments had extremely high coliform counts.

In laboratory experiments where the crustaceans *Homarus americanus* and *Cancer irroratus* and the xiphosuran *Limulus polyphemus* were exposed to sludge and spoil sediments, high mortalities, and pathological conditions were described.

Pearce concluded, "... sewage sludge and dredge spoil deposits are incompatible with most normal biological phenomena," (p. 66). He blames this condition on:

1) adults being killed by toxins, anoxia, or inundation by solid wastes;

2) interference with or destruction of eggs and larvae; and,

3) active avoidance by adult and larval organisms.

A number of reasons suggest themselves to explain why the results of Pfitzenmeyer's and Pearce's studies are so diametrically opposed. For one, Pearce's study area was one of constant spoil deposition; Pfitzenmeyer's had only one inundation. Secondly, Pfitzenmeyer records relatively normal concentrations of oxygen while Pearce indicates that oxygen concentrations were frequently 2-3 ppm lower in the water above the spoil.

Finally, there seems to be a very high degree of contamination of the dredged sediments with heavy metals, insecticides, and petroleum fractions in Pearce's study, which is absent in Pfitzenmeyer's.

A number of studies was performed on the effects of dredging on oyster production. Breuer (1962) reported major changes produced by dredging spoil deposition in South Bay, Tex. Water circulation was impaired by reducing the size of the entrance. Water depth decreased, much of the oyster population was silted over and destroyed, and high local turbidity was evident.

Mackin (1961) reviewed the literature on the biological effects of dredging, with special reference to oyster survival. Most of the authors he cited found that oyster mortality was caused by direct inundation with spoil resulting in suffocation. Beyond the area of deposition, oysters and fishes were unaffected.

Mackin found that at low current velocities turbidity is not an important factor in oyster mortality at levels up to 700 ppm. Such levels were higher than those found beyond 250 ft from the outlets of the three types of dredges studied. He also argues that oxygen levels are not appreciably decreased under conditions normally found on oyster beds.

SUMMARY AND CONCLUSIONS

The results of the present study differ from those reported in most other investigations of the effects of dredging in that profound changes are reported in macrobenthic animal populations throughout the bay. Abundant evidence is available concerning long-term depreciation of standing crop in dredged channels (cf. Taylor and Saloman, 1968; Odum, 1963; Murawski, 1969; and O'Connor, 1972), but these reports show limited residual effects beyond the immediate region of the channel and/or spoil areas. This difference in results is attributed to the fact that most previous studies reported on the creation of channels through relatively large bodies of water such as Chesapeake or Boca Ciega Bays. Spoil distribution effects and changes wrought in current velocity and sediment deposition are minimized when the ratio of the dredged area to total bottom area and contained water volume is large. Long flushing time and reduced inlet size of small estuarine bays exaggerates the hydrodynamic effects of channel construction. Wind-induced sediment transport and the effects of spoil deposition on the surrounding peripheral marshes are factors which complicate the evaluation of the effects of dredging, especially in small bays.

In areas of high human population density, combined dredging-landfill operations have become common and their effects have been felt primarily in the small shallow bays which could provide (if dredged) good anchorages for pleasure boats and picturesque settings for homes. Yet these small bays, edged with *Spartina* marshes, are primary trophic energy sources in the economy of the sea. It appears that further long-term investigations of the effects of dredging on these bays is warranted.

A summary of the areas of investigation and conclusions follow:

1. The dredging process caused turbidity throughout the bay. Light penetration was reduced to 0.4 m during dredging, but the particulate matter released was rapidly dissipated. It is unlikely that turbidity affected light penetration enough to interfere with photosynthesis. However, a canopy of flocculent material deposited on the plants as the result of the deposition of suspended bottom material may have interfered with primary productivity in the low current velocity areas of the bay.

2. Water transport patterns were greatly modified as the result of dredging. Current velocity in the eastern half of the bay was reduced approximately 50%, while small increases were noted for the middle portion of the bay, which previously had negligible velocities.

The main mass movement of water shifted from channel A to channel B as the result of deepening the latter channel.

Dye studies revealed that flushing time of the bay as a whole was not appreciably changed.

3. Correlations between sediment particle size and changes in current velocity suggested that the distribution of sediment types in Goose Creek would be permanently changed as the result of modified current velocities.

4. Values of particulate phosphorus, silicates, and chlorophyll *a* increased substantially. Dissolved organic phosphorus and nitrates increased slightly during the post-dredging year.

A number of authors have reported increases in phytoplankton and/or benthic productivity as a result of increased nutrient levels, but no definitive correlation could be observed in the course of this study.

5. It was found that wind-driven currents affected the distribution of nutrients and bacteria in the bay. In view of the predominance of strong northwesterly winds over the year and the shallow, slowly moving water of the western half of Goose Creek, it was suggested that sediment deposition in this region was primarily a function of wind-driven currents. The assertion by Flemer (1968) that late fall is the best season for dredging is disputed on the basis of a high

level of wind-influenced sediment distribution at that season.

6. Standing crop figures for the commercially important clam, *Mercenaria mercenaria*, were reduced in the bay as a whole. Some areas, especially those in the path of the dredge, did not recover one year after dredging.

7. Land usage patterns were drastically altered during the study as well as in the previous 15 yr. Homes within 300 m of the bay increased by 94%.

Rhodamine B placed in a toilet in a house along the periphery of the bay was detected in the bay water, although all houses have septic tanks. Maximum coliform counts exceeded present legal standards in 1968.

8. Significant reductions in standing crop figures occurred in the channel and the bay as a whole. Recovery of biomass in the channel was also affected by sediment composition and an interaction between the sediment and the dredging process itself.

The effect of different sediment types and seasonal variances on the biomass is shown to be not significant, negating two of the most important variables which might confuse the interpretation of the pre-and post-dredging data.

Chi-square analyses were done on number of species and number of individuals in the bay and in the channel. There were significant reductions in both parameters. Recovery of species and specimen numbers appeared to be affected by sediment type.

Drastic reductions in biomass, species number, and population size occurred in the dredged channel as a function of the removal of the substratum and its in- and epifauna. Recovery had not occurred at the termination of this study, 11 mo after dredging.

Of perhaps greater significance are the substantial reductions in all parameters which occured in the bay as a whole, with only a few stations showing recovery to pre-dredging levels. Only one of the stations was more than 500 m from the dredged channel and spoil deposition areas.

9. Goose Creek had a relatively high in- and epifaunal standing crop estimated at 36.83 g/m^2 for the bay as a whole, including large forms. This compares to Sanders' (1956) estimate of 54.627 g/m^2 for Long Island Sound, but is much higher than the standing crop levels obtained for Upper Chesapeake Bay or the English Channel.

The number of organisms per m^2 is lower for Goose Creek than for the other areas reported on, indicating a preponderance of large forms.

10. Phytoplankton production in Goose Creek was lower than that of Long Island Sound, but far higher than that of the English Channel or Upper Chesapeake Bay. There were three maxima in phytoplankton production in Goose Creek in 1966-1967.

11. The removal of the substratum in the channel affected the population dynamics of the infauna. The molluscs *Tellina agilis*, *Lyonsia hyalina*, and *Mulinia lateralis*, while insignificant components of the standing crop both before and after dredging, increased in numbers in the post-dredging samples.

Two dominant forms, the polychaetes *Clymenella torquata* and *Notomastus latericeus*, virtually disappeared after dredging.

In the bay as a whole there appeared to be no substantial change in the species mix, except for the removal of the dense population of *Crepidula fornicata* (34,000/m^2) by the dredge near the confluence of the three channels. No recovery was noted for this species after 11 mo at that station.

In general, the bay sediments exhibited an overall reduction in epi- and infaunal populations, which did not approach recovery levels 11 mo after dredging.

The *Ampelisca spinipes* and *Nepthys incisa-Nucula proxima* communities described by Stickney and Stringer (1957) and Sanders (1956, 1958) were not found in Goose Creek, being replaced by a *Clymenella torquata-Mya arenaria* community in the sandy sediments, and a *Mercenaria mercenaria-Sclerodactyla briaerius-Nereis succinea* community in the softer substratum.

12. Animal productivity for Goose Creek was calculated at 89.87 g/m^2/yr before dredging and 31.18 g/m^2/yr after dredging. During the post-dredging year, 18,780 kg of animal production was lost from the 0.32 km^2 bottom of Goose Creek.

13. The productivity of island II was considered representative of unspoiled tall *Spartina alterniflora* marsh. Animal productivity was estimated at 42.44 g/m^2/yr, composed almost entirely of *Uca pugnax*, *Modiolus demissus*, and *Sesarma reticulatum*. This represented 5-7% of the total productivity figures of 869.64 g/m^2/yr. The gross estimate for mixed peripheral marsh came to 4,553.57 kg/ha. Using this figure to calculate the

loss of productivity represented by the spoil areas which had inundated 10.87 ha of marsh, 49,497.31 kg of plant matter were removed from the trophic cycle of Goose Creek in the post-dredging year.

Replacement by houses or *Phragmites* marsh would tend to fix this loss on a permanent basis.

In summary, reductions in the productivity of Goose Creek were induced by the dredging process. Recovery to pre-dredging levels had not occurred 11 mo after dredging. Arguments were proposed which suggested that changes in current velocity and the concomitant modifications in substratum type represented permanent changes which would affect the future productivity of the bay by changing the nature of the habitat.

Spoil disposal and land usage changes brought about an enhanced land value of the disposal areas, stimulating the development of the periphery of the bay, removing or depleting the marsh as an energy source available to the aquatic environment. These changes also were of a permanent nature.

ACKNOWLEDGMENTS

This study was supported in part by a grant from Suffolk County, N.Y. The authors are grateful to the following persons for assistance in obtaining samples: John Dinaro, Paul Laucher, Ed Wainwright, Pat Langstone, Paul Salomans, and Harry White. Edwin J. Sherrill, Jr., designed the vessel and saw to its construction. John Black supplied data on water chemistry. Walter Smith originated the project.

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Appendix Table I.—Faunal list for Goose Creek.

Total number of species = 138.

CNIDARIA—ANTHOZOA
- *Haloclava producta*[1]
- *Metridium senile*
- *Sagartia modesta*[1]

PLATYHELMINTHES—TURBELLARIA
- *Euplana gracilus*[1]

NEMERTINEA
- *Amphiporus caecus*[1]
- *Carinoma tremaphoros*[1]
- *Cerebratulus lacteus*
- *Zygeupolia rubens*[1]

ANNELIDA—POLYCHAETA
- *Amphitrite affinis*[1]
- *A. cirrata*[1]
- *A. ornata*[1]
- *Arabella iricolor*
- *Arenicola cristata*[1]
- *Capitella capitata*
- *Cirratulus grandis*
- *Clymenella mucosa*[1]
- *C. torquata*
- *Dispio uncinata*
- *Drilonereis longa*
- *Eteone heteropoda*[1]
- *E. lactea*[1]
- *E. longa*[1]
- *Eumida sanguinea*
- *Glycera americana*
- *G. dibranchiata*
- *Glycinde solitaria*[1]
- *Harmothoe imbricata*
- *Lepidametria commensalis*[1]
- *Lumbrineris tenuis*
- *Maldanopsis elongata*[1]
- *Melinna cristata*
- *Nephtys picta*
- *Nereis (Neanthes) arenaceondonta*[1]
- *N. (Hediste) diversicolor*[1]
- *N. (Neanthes) succinea*
- *N. (Neanthes) virens*[1]
- *Notomastus latericeus*[1]
- *Orbinia ornata*[1]
- *Pectinaria gouldii*
- *Phyllodoce arenae*[1]
- *P. groenlandica*[1]
- *Pista cristata*[1]
- *P. palmata*
- *Polydora ligni*[1]
- *Prionspio malmgreni*[1]
- *Sabella microphthalma*[1]
- *Scolecolepides viridis*[1]
- *Scoloplos fragilis*
- *S. robustus*
- *Spio setosa*
- *Sthenelais boa*[1]
- *Tharyx acutus*[1]

SIPUNCULOIDEA
- *Golfingia gouldi*

ARTHROPODA—CRUSTACEA
- **Cirripedia**
  - *Balanus amphritrite niveus*[1]
  - *B. balanoides*
- **Isopoda**
  - *Chiridotea almyra*[1]
  - *C. coeca*[1]
  - *Cyathura polita (=C. carinata)*[1]
- **Amphipoda**
  - *Ampelisca macrocephala*
  - *A. abdita (=Ampelisca B.)*
  - *A. spinipes*
  - *Gammarus (=Carinogammarus) mucronatus*
  - *Microdeutopus gryllotalpa*
- **Decapoda**
- **Caridea**
  - *Crangon septemspinosus*
  - *Hippolyte pleuracanthus*
  - *Palaemonetes intermedius*[1]
  - *P. pugio*
  - *P. vulgaris*
- **Thallassinidea**
  - *Callianassa atlantica*[1]
  - *Upogebia affinis*[1]
- **Brachyura**
  - *Neopanope texana sayi*
  - *Ovalipes ocellatus*
  - *Pinnixa chaetopterana*[1]
  - *P. cylindrica*[1]
  - *P. sayana*
  - *Sesarma reticulatum*[1]
  - *Uca pugilator*
  - *U. pugnax*
- **Anomura**
  - *Pagurus longicarpus*

MOLLUSCA
- **Gastropoda**
  - *Acteon punctostriatus*
  - *Alexia myosotis*[1]
  - *Bittium alternatum*
  - *Busycon carica*[2]
  - *B. canaliculatum*[2]
  - *Columbella lunata*[1, 2]
  - *C. translirata*[1, 2]
  - *Crepidula fornicata*
  - *Crepidula plana*[2]
  - *Eupleura caudata*
  - *Epitonium multistriatum*[2]
  - *Haminoea solitaria*
  - *Hydrobia totteni*[1]
  - *Littorina littorea*
  - *L. obtusata*
  - *L. saxatilis*
  - *Lunatia heros*
  - *Melampus bidentatus*[2]
  - *Melanella oleacea*[2]
  - *Nassarius obsoletus*
  - *N. vibex*[2]
  - *N. trivittatus*

Odostomia bisuturalis[2]
O. seminuda
Polinices duplicatus
Pyramidella fusca[1,2]
Tornatina canaliculatum[1]
Triphora nigrocincta[1,2]
Urosalpinx cinerea

Pelecypoda
Aequipecten irradians
Aligena elevata[1]
Anadara transversa[2]
Anomia simplex
Clinocardium ciliatum (=Cardium islandica)[1,2]
Crassostrea virginica[2]
Cuminga tellenoides[1]
Ensis directus
Gemma gemma
Laevicardium mortoni[1]
Lyonsia hyalina
Macoma balthica[1]
Mercenaria mercenaria
Modiolus demissus
Mulinia lateralis
Mya arenaria
Nucula proxima
Pandora gouldiana
Petricola pholadiformis
Solemya vellum[1]
Spisula solidissima[2]
Tagelus plebeius[1]
Tellina agilis
Yoldia limatula

ECHINODERMATA—HOLOTHUROIDEA
Leptosynapta roseola[1]
Sclerodactyla (=Thyone) briareus

CHORDATA-UROCHORDATA
ASCIDIACEA
Dendrodoa carnea[1]
Molgula manhattensis
Styela partita[1]

[1]Organisms not heretofore reported in the major faunal lists of Long Island (Sanders, 1956; Hechtel, 1968; Townes, 1938.

[2]Shells only; no living specimens found.