MOLLUSKS AND BENTHIC ENVIRONMENTS IN HILLSBOROUGH BAY, FLORIDA[1]

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ABSTRACT

Analysis of benthic mollusks and sediments at 45 stations showed that the diversity and abundance of mollusks was affected by bottom conditions which were influenced in varying degrees by domestic and industrial pollution and dredging. Nineteen stations had no living mollusks, 18 stations had one or more of the four mollusk species that were predominant, and 8 stations had mollusks well represented by numerous species and large numbers of individuals. Stations with no living mollusks were termed unhealthy, and others were designated marginal or healthy on the basis of the mollusks present. From station data, isopleths connecting similar areas indicated that 42 percent of the bay bottom was unhealthy, 36 percent marginal, and 22 percent healthy. Infrequent occurrence of the American oyster (*Crassostrea virginica*) further suggests that the major portion of Hillsborough Bay was seriously contaminated. An appendix has a checklist of the 64 species of mollusks collected in the bay.

This report treats the relation of diversity and abundance of mollusks to bottom conditions in Hillsborough Bay, Fla., where dredging and pollution from domestic and industrial sources now control the ecology. The data are from benthic and hydrological surveys by the Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla., during August and September 1963.

The problem of pollution in coastal waters has stimulated research to establish environmental quality criteria based on physical, chemical, and biological components of marine and brackish water communities. Mollusks are useful in such studies because the group is well described taxonomically and contains species that vary greatly in habitat selection, mode of feeding, and tolerance to environmental change. Furthermore, most mollusks are sedentary as adults and the remains of their shells provide a semipermanent record of their occupancy.

The ecology of mollusks in natural waters has been studied by a number of authors. Previous studies on the ecology of mollusks in natural and polluted waters of the southeastern United States provided a basis for the interpretation of collections from Hillsborough Bay. Reports on mollusk assemblages in unpolluted estuaries included work by Ladd (1953), Parker (1960), and Brett (1963). Within the same geographic area, studies of mollusks in polluted estuaries include work on the ecological effects of petroleum wastes (Mackin and Hopkins, 1961), pesticides (Butler, 1966), siltation and dredging (Mackin, 1961), channelization (Chambers and Sparks, 1959), and domestic sewage (McNulty, 1966). The work by McNulty, and an earlier series of studies with collaborators, represent a comprehensive study over a period of 11 years in Biscayne Bay, Fla., before and after pollution abatement.

ECOLOGICAL FEATURES OF HILLSBOROUGH BAY

Hillsborough Bay lies in the upper part of Tampa Bay, east of Interbay Peninsula and north of a line between Gadsden Point and Newman Branch (fig. 1). The 56-km. shoreline encompasses a water area of about 10,360 ha. Forty percent of this area is 1.8 m. or less, and except for dredged ship channels up to 10.5 m. deep, the greatest depth in the bay is about 5.4 m. Tidal range is normally 0.9 m. or less, and maximum tidal current is under 51 cm./second (1 knot)—see Olson and Morrill (1955) and Taylor and Saloman (1969). Portions of the bay around Davis Island, Seddon Island, McKay Bay, and Port Sutton have been dredged for fill material or deepened for shipping (fig. 1). Other dredging in the bay centers around oyster shell deposits which are used for the construction industry (Dawson, 1953). These deposits are extensive and show that the American oyster, *Crassostrea virginica*, once

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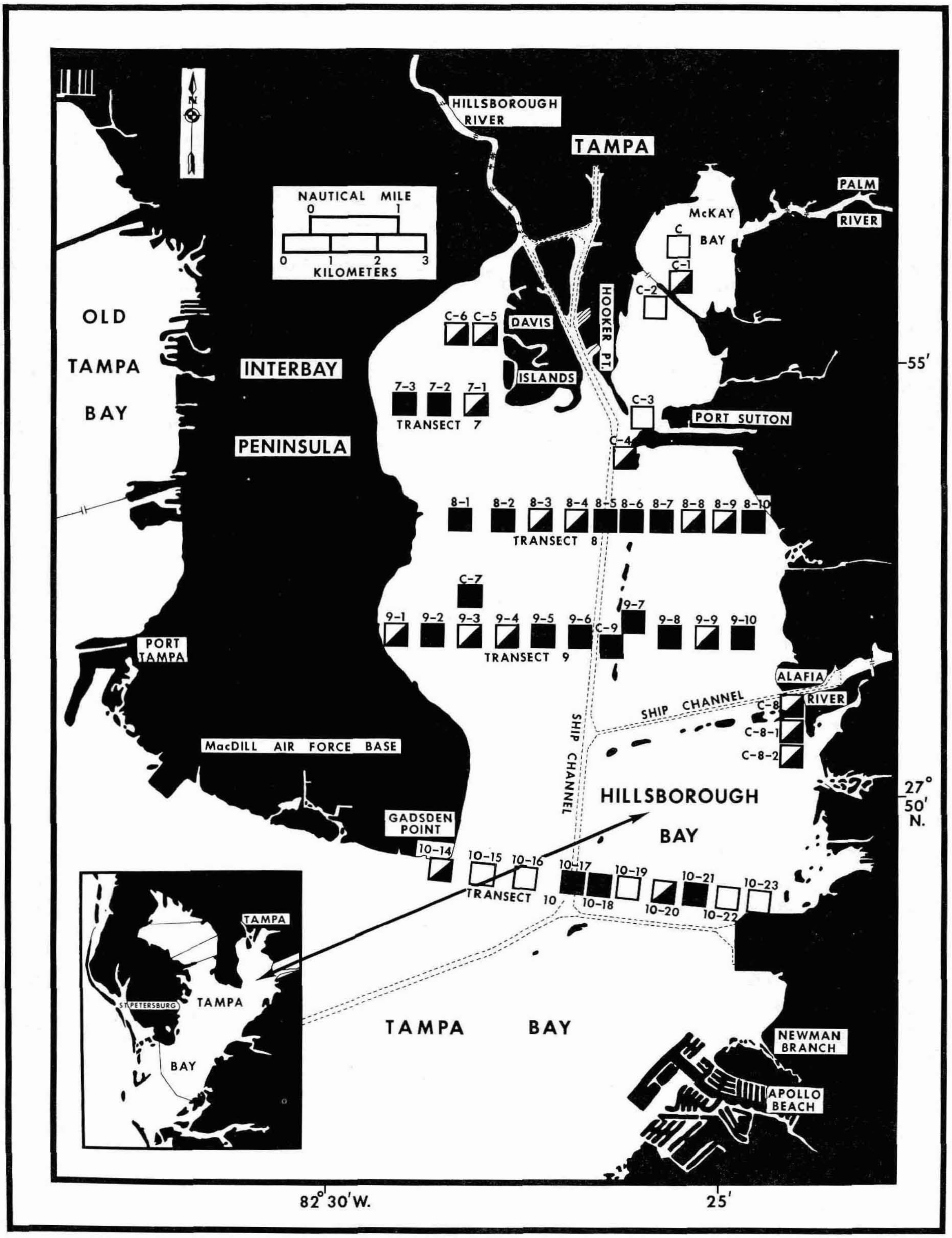

FIGURE 1.—Tampa Bay and Hillsborough Bay showing channels, survey transects, collecting stations, and environmental conditions at each station—healthy stations (unshaded); marginal stations (half-shaded); unhealthy stations (shaded)—August and September 1963.

flourished in Hillsborough Bay as it does today along most of the Gulf Coast between Cape Sable and the Rio Grande (Butler, 1954). The annual mean and range of salinity (22.20 and 12.65–27.84 p.p.t.), water temperature (24.96° and 11.65°–34.00° C.), and other hydrological features of the bay have been reported by Saloman and Taylor (1968).

In addition to considerable physical alteration of the bay, water chemistry and resident biota have changed decidedly as a result of domestic and industrial sewage. The principal identified pollutants are compounds of phosphorus and nitrogen, and highly organic suspended solids. Regional sanitation plants provide only primary sewage treatment for 120,000 $m.^3$/day (30 m.g.d.—million gallons per day) and serve a population of about 300,000. The treated effluent carries more than 50 percent of the suspended solids present before treatment and adds an enormous load of phosphorus and nitrogen.[2] The solids are deposited as sludge, and phosphorus and nitrogen are available as nutrients for plants and animals. The phosphate industry provides additional sediment and phosphorus, and natural land drainage provides substantial amounts of phosphorus, nitrogen, iron, copper, and organic compounds (Odum, 1953; Dragovich and May, 1962; Dragovich, Kelly, and Goodell, 1968). Dragovich et al. (1968) estimated that the Hillsborough and Alafia Rivers together add 557 metric tons of phosphorus to the bay each year. In the bay the annual mean concentration of total phosphorus is 19.38 μg.at./liter, and the total nitrogen (Kjeldahl) is 80.17 μg.at./liter. Comparative figures for Tampa Bay entrance ($P=14.39$; $N=45.08$ μg.at./liter) and the nearshore Gulf of Mexico ($P=3.6$; $N=23.4$ μg.at./liter) give some idea of the extraordinary mineral enrichment that exists in Hillsborough Bay (Saloman and Taylor, 1968). In Biscayne Bay, Fla., McNulty, Reynolds, and Miller (1959) and McNulty (1966) found that domestic sewage adversely affected the biotic environment. There, daily discharge of 120,000 to 200,000 $m.^3$/day (30-50 m.g.d.) of raw sewage raised the average concentration of total phosphorus to 3 μg.at./liter or about one-sixth of the concentration now in Hillsborough Bay.

Enrichment of Hillsborough Bay by phosphorus and nitrogen causes excessive growth of phytoplankton and filamentous algae (Dragovich, Kelly, and Kelly, 1965). The heavy growth of algae and the phytoplankton blooms cause marked fluctuations in dissolved oxygen. In periods of photosynthetic activity, oxygen concentrations have exceeded 8 ml./liter but at other times, BOD (biochemical oxygen demand) may reduce dissolved oxygen to 1 ml./liter or less at the bottom (Saloman, Finucane, and Kelly, 1964; Saloman and Taylor, 1968; FWPCA, personal communication[3]).

Other consequences of pollution in Hillsborough Bay include high water turbidity (annual average, 19.19 Jackson Turbidity Units), low light transmission (annual average, 30.3 percent of incident radiation at 60 cm. below the water surface), and very little growth of marine grasses (Taylor and Saloman, 1966; Saloman and Taylor, 1968; and Taylor and Saloman, 1969). In their comparative study of macrofauna in major geographic areas of Tampa Bay, Sykes and Finucane (1966) provided further biological evidence of pollution in the bay. From quantitative sampling, their work showed that catches of fish and crustaceans were lower in Hillsborough Bay than in any other region of the estuary. The greatest catches came from Old Tampa Bay where environmental conditions differ from those in Hillsborough Bay mainly in terms of fewer and smaller sources of pollution, lower turbidity, lower nitrogen concentration, higher dissolved oxygen at the bottom, more sandy sediments, a more natural shoreline, and extensive beds of sea grasses.

PROCEDURES

We sampled mollusks together with bottom vegetation and sediments with a bucket dredge and rigid-frame net at 45 stations between August 13 and September 5, 1963 (fig. 1). The dredge dug 5 cm. into the bottom and had a capacity of 15 liters. It filled with sediment after covering an area of about 30 by 100 cm. The net skimmed the bottom and had an opening of 30.5 by 91.4 cm. It was hung with square-mesh netting with openings of 3.2 mm. (Taylor, 1965). At intertidal stations, the bottom was sampled by shovel and the

[2] Hillsborough County Health Department, Tampa, Fla. 33601, personal communication, 1969.

[3] Federal Water Pollution Control Administration, Tampa-Hillsborough Bay Project, Tampa, Fla. 33605, 1968.

net was pulled by hand. One dredge haul, or a nearly equivalent volume of sediment collected by shovel, and one 2-minute net haul were taken at each station. We collected water samples at each station with a Van Dorn bottle for determination of temperature, salinity, and pH. Water depth was measured by handline.

We removed the mollusks from bottom samples by sieving sediment and bottom debris on a screen of 0.701-mm. mesh (Tyler #24 screen[4]). Before sieving, we removed a subsample of sediment (about 300 cc.) from each bottom sample for analysis at the Sedimentological Laboratory, Florida State University. Their analyses included measurements of grain size, calcium carbonate, organic nitrogen, and organic carbon as well as statistical characteristics of mean grain size, sorting (as standard deviation), skewness, and kurtosis (Taylor and Saloman, 1969).

[4] References to trade names in this publication do not imply endorsement of commercial products.

DIVERSITY AND ABUNDANCE OF MOLLUSKS

We collected and identified 64 species of mollusks from bottom samples taken in Hillsborough Bay (Appendix). Of these species only 36 were represented by living individuals; furthermore, live mollusks were collected at only 26 of the 45 stations sampled. Samples at all stations where live mollusks were collected always included one or more of four species, i.e.: dwarf surf clam (*Mulinia lateralis*), paper mussel (*Amygdalum papyria*), common eastern nassa (*Nassarius vibex*), and stout tagelus (*Tagelus plebeius*). On an individual basis, *M. lateralis* was present in 65 percent of the station samples that contained live mollusks; the incidences of *A. papyria*, *N. vibex*, and *T. plebeius* were 58, 54, and 35 percent, respectively (table 1). The next most numerous mollusks were the crown conch (*Melongena corona*) and the lunar dove-shell (*Mitrella lunata*) which occurred at 6 of the 26 stations where live mollusks were found.

TABLE 1.—*Numbers of living mollusks by species and station collected from Hillsborough Bay, Fla., August and September 1963*

[Number of times a station sampled in parentheses]

Species	Station numbers																	
	7-1 (2)	7-2 (2)	7-3 (2)	8-1 (2)	8-2 (2)	8-3 (2)	8-4 (2)	8-5 (2)	8-6 (1)	8-7 (2)	8-8 (2)	8-9 (2)	8-10 (2)	9-1 (1)	9-2 (2)	9-3 (2)	9-4 (2)	9-5 (2)
Mulinia lateralis						1	2				4	2				800	1	
Amygdalum papyria												40				1		
Nassarius vibex	4															122	4	
Tagelus plebeius												7		1				
Melongena corona						1												
Mitrella lunata																1		
Tellina versicolor																		
Ensis minor																		
Mercenaria campechiensis																	1	
Macoma tenta																		
Crepidula plana																		
Bittium varium																		
Thracia sp.																1		
Modiolus americanus												5						
Anadara transversa																		
Crassostrea virginica																		
Retusa canaliculata																		
Polinices duplicatus																		
Odostomia acutidens																		
Mystella planulata												5						
Epitonium humphreysi																		
Corbula caribaea																		
Anachis obesa																		
Tagelus divisus																		
Urosalpinx tampaensis																		
Nucula proxima																		
Natica pusilla																		
Laevicarium mortoni																		
Haminoea succinea																		
Epitonium angulatum																		
Crepidula fornicata																		
Corbula barrattiana																		
Brachidontes exustus																		
Polymesoda caroliniana																		
Acteon punctostriatus											4							
Ischnochiton papillosus						1												
Total number species	1	0	0	0	0	3	1	0	0	0	2	5	0	1	0	5	3	0
Total number individuals	4	0	0	0	0	3	2	0	0	0	8	59	0	1	0	925	6	0

TABLE 1.—*Numbers of living mollusks by species and station collected from Hillsborough Bay, Fla., August and September 1963*—Continued

[Number of times a station sampled in parentheses]

Species	Station numbers														
	9–6 (2)	9–7 (2)	9–8 (2)	9–9 (2)	9–10 (2)	10–14 (3)	10–15 (2)	10–16 (2)	10–17 (2)	10–18 (1)	10–19 (2)	10–20 (2)	10–21 (2)	10–22 (2)	10–23 (2)
Mulinia lateralis				4		21	63				10	1		35	
Amygdalum papyria						21	3				3	4		41	300
Nassarius vibex						9	10	3				1		4	5
Tagelus plebeius						12									
Melongena corona							1								
Mitrella lunata						203	359	1							30
Tellina versicolor							16	4			1			2	
Ensis minor						7								1	2
Mercenaria campechiensis								4			2			1	
Macoma tenta							7	4			2			1	
Crepidula plana						3		1							1
Bittium varium						10	1								10
Thracia sp.							2	1			1				
Modiolus americanus															
Anadara transversa							10				5				
Crassostrea virginica							3								
Retusa canaliculata							2								1
Polinices duplicatus														1	1
Odostomia acutidens							1								2
Mysella planulata															
Epitonium humphreysi							6							1	
Corbula caribaea								5			41				
Anachis obesa							22							1	
Tagelus divisus															
Urosalpinx tampaensis															
Nucula proxima											1				
Natica pusilla											2				
Laevicarium mortoni							3								
Haminoea succinea															
Epitonium angulatum							3								
Crepidula fornicata											1				
Corbula barrattiana											2				
Brachidontes exustus															1
Polymesoda caroliniana															
Acteon punctostriatus															
Ischnochiton papillosus															
Total number species	0	0	0	1	0	8	17	8	0	0	12	3	0	10	10
Total number individuals	0	0	0	4	0	286	512	23	0	0	71	6	0	88	353

Species	Station numbers												Stations where collected	
	C (2)	C–1 (1)	C–2 (2)	C–3 (2)	C–4 (1)	C–5 (2)	C–6 (2)	C–7 (1)	C–8 (1)	C–8–1 (1)	C–8–2 (1)	C–9 (1)	Stations	Percentage of stations
													Number	*Percent*
Mulinia lateralis	129		268	99		8	150						17	65
Amygdalum papyria	26	1	16	80	2	3	22						15	58
Nassarius vibex		22	2	2		1	15						14	54
Tagelus plebeius	1		16	2					71	142	89		9	35
Melongena corona	10	1	4	5									6	23
Mitrella lunata			8										6	23
Tellina versicolor			8										5	19
Ensis minor				5		1							5	19
Mercenaria campechiensis													4	15
Macoma tenta													4	15
Crepidula plana	6												4	15
Bittium varium	17												4	15
Thracia sp.													4	15
Modiolus americanus	1			17			15						4	15
Anadara transversa			3										3	12
Crassostrea virginica			2	2									3	12
Retusa canaliculata													2	8
Polinices duplicatus													2	8
Odostomia acutidens													2	8
Mysella planulata	1												2	8
Epitonium humphreysi													2	8
Corbula caribaea													2	8
Anachis obesa				1									2	8
Tagelus divisus													1	4
Urosalpinx tampaensis			1										1	4
Nucula proxima													1	4
Natica pusilla													1	4
Laevicardium mortoni													1	4
Haminoea succinea	1												1	4
Epitonium angulatum													1	4
Crepidula fornicata													1	4
Corbula barrattiana													1	4
Brachidontes exustus													1	4
Polymesoda caroliniana		1											1	4
Acteon punctostriatus													1	4
Ischnochiton papillosus													1	4
Total number species	9	4	10	9	1	4	4	0	1	1	1	0		
Total number individuals	192	25	328	159	2	13	202	0	71	142	89	0		

Live specimens of *M. lateralis*, *A. papyria*, *N. vibex*, and *T. plebeius* indicated bottom conditions by their presence or absence and by their abundance in relation to other live mollusks. On the basis of the occurrence and distribution of these four species, bottom environments were classified as healthy or marginal. Healthy stations were those where indicator species were less than 50 percent of all live mollusk species present; at marginal stations, the indicators represented 50 percent or more of all live species present. Unhealthy stations were those where no living mollusks were collected (fig. 1 and tables 2–4). The number of living mollusks was generally higher at healthy than at marginal stations except at marginal station 9–3 where *M. lateralis* and *N. vibex* were unusually abundant. Furthermore, on the basis of station classification the entire area of the bay was divisible into healthy, marginal, and unhealthy zones.

The four species selected as indicators for the bay, and perhaps the crown conch as well, may be useful for biological evaluation of the environment in estuarine water of the southeastern and Gulf States. Table 5 represents a summary of ecological literature and shows the extreme ranges of environmental conditions that these five mollusks can tolerate under natural conditions.

HEALTHY STATIONS

Eight stations, or about 18 percent of those having live mollusks, were classified as healthy. The average incidence of indicator species at these stations was 27 percent, and the average numbers per station were 11 species and 225 individuals (table 2).

TABLE 2.—*Biotic and physical characteristics of healthy benthic stations in Hillsborough Bay, Fla., August and September 1963*

Station	Species [1]	Individual [1]	Indicator species [1]	Depth	Mean sediment grain size	Sediment sorting	Sediment type	Bottom vegetation	Bottom salinity
	Number	*Number*	*Percent*	*M.*	ø	ø			*P.p.t.*
C	9	192	33	1.7	4.05	2.5	Coarse silt	*Gracilaria* sp	18.19
C–2	10	328	40	4.7	2.28	1.0	Fine sand	*Gracilaria* sp	18.56
C–3	9	213	44	2.0	2.78	1.6	Fine sand	*Gracilaria* sp	16.35
10–15	17	512	18	3.0	2.74	1.4	Fine sand	*Gracilaria* sp	21.82
10–16	8	23	13	6.0	3.15	1.5	Very fine sand	None	22.62
10–19	12	71	17	3.7	2.02	1.8	Fine sand	None	22.95
10–22	10	88	33	2.0	2.84	1.3	Fine sand	*Gracilaria* sp	22.43
10–23	10	353	20	1.0	2.59	.8	Fine sand	*Gracilaria* sp	21.26
Mean	11	225	27	3.0	2.80	1.5	Fine sand		20.52
Range			13–44	1.0–6.0	2.02–4.05	.8–2.5			18.19–22.95

[1] Collected alive.

TABLE 3.—*Biotic and physical characteristics of marginal benthic stations in Hillsborough Bay, Fla., August and September 1963*

Station	Species [1]	Individual [1]	Indicator species [1]	Depth	Mean sediment grain size	Sediment sorting	Sediment type	Bottom vegetation	Bottom salinity
	Number	*Number*	*Percent*	*M.*	ø	ø			*P.p.t.*
C–1	4	25	50	1.0	2.32	1.8	Fine sand	None	18.33
C–4	1	2	100	1.0	2.95	1.2	Fine sand	None	15.59
C–5	4	13	75	4.2	2.58	1.0	Fine sand	None	19.78
C–6	4	202	75	2.0	2.88	1.0	Fine sand	None	18.96
C–8	1	71	100	.7	2.51	1.1	Fine sand	None	.74
C–8–1	1	142	100	.7	2.95	1.6	Fine sand	None	1.15
C–8–2	1	89	100	.3	5.28	2.6	Medium silt	None	3.69
7–1	1	4	100	2.0	3.04	1.1	Very fine sand	None	17.79
8–3	3	13	50	3.6	4.09	2.2	Coarse silt	None	19.78
8–4	1	2	100	3.9	5.23	2.7	Medium silt	None	20.50
8–8	2	8	50	2.8	3.14	1.4	Very fine sand	None	16.56
8–9	5	57	60	1.0	2.51	.5	Fine sand	None	18.78
9–1	1	1	100	.3	2.53	.7	Fine sand	None	17.25
9–3	5	925	60	2.0	2.38	.8	Fine sand	None	18.37
9–4	3	6	67	2.4	2.25	.7	Fine sand	None	18.51
9–9	1	4	100	2.8	3.37	1.8	Very fine sand	None	17.70
10–14	8	267	50	1.0	2.68	.8	Fine sand	*Gracilaria* sp	20.61
10–20	3	6	100	3.9	2.88	1.6	Fine sand	None	22.92
Mean	3	102	80	1.9	3.09	1.4	Very fine sand		15.90
Range			50–100	.3–4.2	2.25–5.28	.5–2.7			.74–22.92

[1] Collected alive.

TABLE 4.—*Biotic and physical characteristics of unhealthy benthic stations in Hillsborough Bay, Fla., August and September 1963*

Station	Depth	Mean sediment grain size	Sediment sorting	Sediment type	Bottom vegetation	Bottom salinity
	M.	Ø	Ø			*P.p.t.*
C-7	0.7	−0.95	1.4	Very coarse sand	None	18.33
C-9	.7	−.77	2.1	Very coarse sand	None	16.22
7-2	4.2	5.76	2.3	Medium silt	*Gracilaria* sp.	17.79
7-3	2.7				None	17.61
8-1	3.9	5.65	2.5	Medium silt	None	18.78
8-2	3.3	2.93	1.3	Fine sand	None	19.04
8-5	10.3	7.40	2.0	Very fine silt	None	22.92
8-6	6.7	−1.90	2.0	Granule	None	18.60
8-7	3.3	4.77	2.8	Coarse silt	None	19.42
8-10	.7	3.31	1.4	Very fine sand	None	17.94
9-2	3.3	5.12	3.2	Medium silt	None	18.33
9-5	4.2	7.55	2.0	Very fine silt	None	19.74
9-6	12.1	6.91	2.2	Fine silt	None	22.38
9-7	3.6	7.84	1.8	Very fine silt	None	20.05
9-8	4.2	4.35	2.6	Coarse silt	None	19.42
9-10	1.0	2.88	1.2	Fine sand	None	18.75
10-17	10.9	4.46	2.3	Coarse silt	None	23.77
10-18	.7	−.96	2.7	Very coarse sand	None	22.11
10-21	3.6	3.62	1.5	Very fine sand	None	22.81
Mean	3.8	[1] 5.37	2.1	Medium silt		19.60
Range	.7-12.1	−1.90-7.84	1.2-3.2			16.22-23.77

[1] Negative grain sizes excluded.

TABLE 5.—*Range of tolerance in ecological factors and geographical distribution of the five most commonly collected mollusks in Hillsborough Bay, Fla., August and September 1963*

Species	Temperature	Salinity	pH	Turbidity	Depth	Current	Sediment type	Bottom type	Distribution
	° *C.*	*P.p.t.*			*M.*	*Cm./sec.*			
Mulinia lateralis	[1 2] 1-34	[3] 1.4-75	[2] 6.8-8.7	Tolerant [2 3]	[4 5] 1-4.7	[5] 9.4-90	Nonselective; fine sand and silt.[5 6 7 8]	Unvegetated [3]	Maine to Florida and Guf of Mexico.[9]
Amygdalum papyria	[1] 9-36	[10] 5-38	[2] 6.8-8.7	do [2 10]	[3 5] 1-4.7	[6] <90	Fine sand [5]	Unvegetated [5] Vegetated.	Maryland to Florida and Gulf of Mexico.[1 9]
Nassarius vibex	[1] 3-36	[1 11] 9-42	[2] 6.8-8.7	do [2 10]	[12] 1-15	[4 6] 8.6-90	Nonselective; sand and silt.[5 13]	Unvegetated [5 13] Vegetated.	Cape Cod to Florida and Gulf of Mexico.[9]
Tagelus plebeius	[1 2] 1-34	[1 7] 1-37	[2] 6.8-8.7	do [2]	[5 12] 1-4.7	[4 6] 30-90	Nonselective; sand and silt [5 14]	Unvegetated [5] Vegetated.	Cape Cod to Florida and Gulf of Mexico.[9]
Melongena corona	[2] 11-34	[15 16] 8-45	[2] 6.8-8.7	do [2 10]	[5 10] 1-4.7	[6] <90	Nonselective; shell, sand and silt [5 17]	Unvegetated [5 15 17]	Florida and Gulf of Mexico.[8 18]

[1] Parker, 1959.
[2] Saloman and Taylor, 1968.
[3] Breuer, 1962.
[4] Brett, 1963.
[5] This report.
[6] Taylor and Saloman, 1969.
[7] Hedgpeth, 1954.
[8] Marland, 1958.
[9] Abbott, 1954.
[10] Tabb, Dubrow, and Manning, 1962.
[11] Wells, 1961.
[12] Wass, 1965.
[13] Moore, Davies, Fraser, Gore, and Lopez, 1968.
[14] Allen, 1954.
[15] Tabb and Manning, 1961.
[16] Hathaway and Woodburn, 1961.
[17] Menzel, 1956.
[18] Hedgpeth, 1953.

Most of the healthy stations (60 percent) were at the mouth of Hillsborough Bay along transect 10. The most numerous and diverse mollusk assemblage was at station 10–15, where we collected 512 individuals and 17 species. At the upper end of the bay, conditions were healthy at stations C, C–2, and C–3 where more than average current (C–2 and C–3) and benthic algae (C, C–2, and C–3) maintain a favorable environment for many mollusks despite the proximity of effluent discharged from the Tampa Sewage Treatment plant at Hooker Point. Throughout the rest of the bay, all stations were either marginal or unhealthy (fig. 1).

The predominant sediment type at healthy stations was fine sand (2.80 Ø). Sediment sorting was poor (1.5 Ø), according to the classification of Folk (1964), and is a reflection of the weak current system in the bay (Taylor and Saloman, 1969). A number of authors have noted that fine sand is well suited for colonization by a variety of mollusks (Jones, 1950; Pratt, 1953; Thorson, 1956; Sanders, 1958; McNulty, 1961; Brett, 1963). Another feature of most healthy stations was the occurrence of a red alga, *Gracilaria* sp., which is a source of organic detritus and provides a base for attachment of epiphytic mollusks.

Salinity at healthy stations was between 18 p.p.t. (upper bay stations C, C–2, and C–3) and 23 p.p.t. (transect 10). The combination of relatively high mollusk diversity and reduced salinity at the upper bay stations indicated that a factor other than salinity prevented the establishment of an equivalent variety of mollusks at most marginal and unhealthy stations.

MARGINAL STATIONS

At the 18 stations classified as marginal at least 50 percent of the live mollusks were indicator species, and the average incidence of indicators at these stations was 80 percent. The average number of species per station represented by live animals was only 3; the mean number of individuals was 102 (table 3). In comparison with the healthy stations, marginal stations had about one-fourth as many species of mollusks and about one-half as many individuals.

Sediments at marginal stations ranged from fine sand to medium silt. The average sediment type was very fine sand (3.09ϕ)—a somewhat finer particle size than the average size at healthy stations. Sediment sorting was poor (1.4ϕ) and very close to the figure for healthy stations.

Bottom vegetation (*Gracilaria* sp.) was found at only one marginal station. That station had a substrate of fine sand and more species of mollusks than any other station.

Low salinity (less than 4 p.p.t.) near the mouth of the Alafia River was probably responsible for fewer species of mollusks at stations C–8, C–8–1, and C–8–2. The only species present in this area was *Tagelus plebeius*.

Data for DO (dissolved oxygen) indicated that from June through August bottom water in the bay between transect 10 and McKay Bay becomes anaerobic (FWPCA, personal communication; see footnote 3). At other times, however, DO values are generally above 3 ml./liter and would not prove limiting. Changes in the DO at stations regarded as marginal may create a more favorable environment for mollusks during other seasons.

UNHEALTHY STATIONS

No live mollusks were collected at 19 stations classified as unhealthy (fig. 1). Two of these stations were on the eastern shore of the bay (8–10 and 9–10) and adjacent to an extensive area of gypsum spoil—a byproduct of the phosphate industry. The gypsum forms a crust on the bottom that virtually eliminates macrobenthic organisms.

Sediments at other unhealthy stations had a mean grain size that varied from −1.90 ϕ (granule) to 7.84 ϕ (very fine silt)—see table 4. Sediments were coarse at stations near spoil islands left from channel construction and on a natural, shelly shoal (C–7). Absence of mollusks in coarse sediments probably resulted from the grinding action of large particles powered by wave action. Stations with fine sediments were in comparatively deep water. There the sediments had a high concentration of the toxic compound, hydrogen sulfide, and are probably anaerobic, or nearly so, at all times (Florida State Board of Health, 1965).

ECOLOGICAL ZONES

Isopleths were drawn between similar stations to represent approximate boundaries of healthy, marginal, and unhealthy zones in Hillsborough Bay (fig. 2). Calculation of the area within each zone showed that only 22 percent of the bay falls in the healthy category, 36 percent is marginal, and 42 percent is unhealthy. Most healthy zones were near the mouth of the bay where the solid and soluble products of pollution were least concentrated. Marginal zones were on the bottom slopes between the three unhealthy zones that were along the eastern and western shores and in midbay ship channels. Observations in Raritan Bay (Dean and Haskin, 1964) and Biscayne Bay (McNulty, 1966) suggest that pollution abatement in Hillsborough Bay would favor progressive repopulation of marginal zones by a more normal assemblage of benthic plants and animals. In heavily silted areas of the unhealthy zones, however, biological restoration would probably require a long period of time.

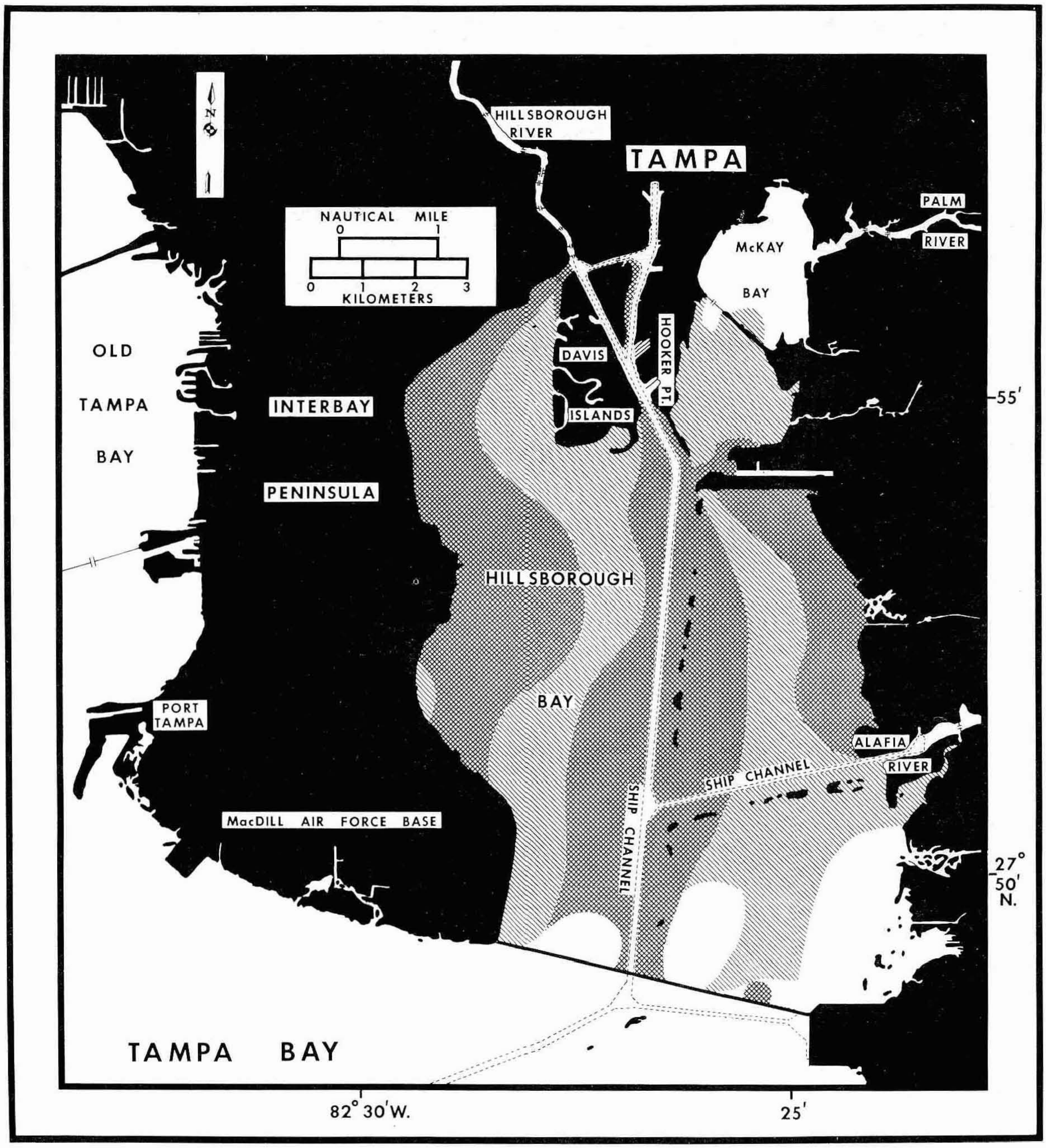

FIGURE 2.—Ecological zones in Hillsborough Bay, Fla., based on the comparative diversity of mollusks—healthy zone (unshaded); marginal zone (hatching); unhealthy zone (cross hatching)—August and September 1963.

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APPENDIX

A CHECKLIST OF MOLLUSKS FOUND IN HILLSBOROUGH BAY, FLORIDA, AUGUST AND SEPTEMBER 1963

We collected and identified 64 species of mollusks representing 43 families. Determinations were based on standard taxonomic works (Abbott, 1954; Perry and Schwengel, 1955; Warmke and Abbott, 1962; Keen, 1963; Abbott, 1968) and by comparison with specimens in the U.S. National Museum (+). An asterisk (*) indicates that the species was collected alive.

Class Gastropoda

Family Neritidae
  Neritina reclivata (Say)
Family Rissoidae
  Rissoina chesneli Michaud
Family Vitrinellidae
  Cyclostremiscus sp.
Family Cerithiidae
  **Bittium varium* (Pfeiffer)
  Seila adamsi (H. C. Lea)
Family Triphoridae
  Triphora nigrocincta (C. B. Adams)

Family Epitoniidae

**Epitonium angulatum* (Say)
**Epitonium humphreysi* (Kiener)
Epitonium rupicola (Kurtz)

Family Calyptraeidae

**Crepidula fornicata* (Linné)
**Crepidula plana* Say

Family Naticidae

**Natica pusilla* Say
**Polinices duplicatus* (Say)

Family Muricidae

**Urosalpinx tampaensis* (Conrad)

Family Columbellidae

**Anachis obesa* (C. B. Adams)
+*Anachis semiplicata* (Stearns)
**Mitrella lunata* (Say)

Family Melongenidae

**Melongena corona* (Gmelin)

Family Nassariidae

**Nassarius vibex* (Say)

Family Olividae

Olivella perplexa Olsson

Family Marginellidae

Prunum apicinum (Menke)

Family Atyidae

**Haminoea succinea* (Conrad)

Family Retusidae

**Retusa canaliculata* (Say)

Family Pyramidellidae

+**Odostomia acutidens* Dall
Odostomia impressa (Say)
+*Odostomia producta* (Dall)
+*Turbonilla conradi* Bush.

Family Acteocinidae

Cylichna bidentata (Orbigny)

Family Acteonidae

**Acteon punctostriatus* (C. B. Adams)

Family Ellobiidae

Melampus coffeus (Linné)

Class Amphineura

Family Ischnochitoniidae

**Ischnochiton papillosus* (C. B. Adams)

Class Pelecypoda

Family Nuculidae

**Nucula proxima* Say

Family Nuculanidae

Nuculana acuta Conrad

Family Arcidae

**Anadara transversa* (Say)

Family Mytilidae

**Amygdalum papyria* (Conrad)
**Brachidontes exustus* (Linné)
**Modiolus americanus* (Leach)
Modiolus demissus granosissima (Sowerby)

Family Pinnidae

Atrina rigida (Lightfoot)

Family Ostreidae

**Crassostrea virginica* (Gmelin)

Family Carditidae

Cardita floridana Conrad

Family Corbiculiidae

**Polymesoda caroliniana* (Bosc)

Family Leptonidae

**Mysella planulata* (Stimpson)

Family Cardiidae

**Laevicardium mortoni* (Conrad)

Family Veneridae

Chione cancellata (Linné)
**Mercenaria campechiensis* (Gmelin)
Parastarte triquetra (Conrad)

Family Petricolidae

Petricola pholadiformis Lamarck

Family Tellinidae

Macoma constricta (Bruguière)
**Macoma tenta* Say
Tellina alternata Say
Tellina lineata Turton
**Tellina versicolor* DeKay

Family Semelidae

Semele bellastriata (Conrad)
Semele proficua (Pulteney)

Family Donacidae

Donax variabilis Say

Family Sanguinolariidae

**Tagelus divisus* Spengler
**Tagelus plebeius* (Lightfoot)

Family Solenidae

**Ensis minor* Dall

Family Mactridae

Mactra fragilis Gmelin
**Mulinia lateralis* (Say)

Family Corbulidae

**Corbula barratiana* C. B. Adams
**Corbula caribaea* Orbigny

Family Pholadidae

Cyrtopleura costata (Linné)

Family Lyonsiidae

Lyonsia hyalina floridana Conrad

Family Thraciidae

**Thracia* sp.