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THE LOCATION AND TOPOGRAPHY OF OYSTER REEFS IN THE RAPPAHANNOCK RIVER ESTUARY, VIRGINIA

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ABSTRACT Public oyster grounds in the Rappahannock River, Virginia were charted in 1976 and 1977 using an electronic positioning system to locate oysters, shell, sand, or mud. Hydraulically operated patent tongs were used to sample the bottoms to validate the charts. During this study 17277.6 ha of public bottoms were surveyed; of this total, 3845.3 ha was oyster reef, sand-shell or mud-shell bottoms; the remainder, 13432.3 ha (78%) was sand, mud or buried shell. The location, extent, topography and environment of the oyster producing areas are discussed. Setting of oysters, physiography and productivity were analyzed.

KEY WORDS: substrates slopes physiography, settlement

INTRODUCTION

From 1975 to 1984 the Rappahannock River in Virginia has been the state's leading source of market oysters, producing an average of 146,999 bushels annually (Haven and Whitcomb 1986). Consequently, it is important to understand where oysters occur and the location and extent of bottom substrate types and levels of recruitment. This study utilizes data obtained during a bay-wide investigation of Virginia oyster grounds from 1976–1981 (Haven et al. 1981).[1] Portions of that investigation dealing with the James River and Pocomoke Sound have been published (Haven and Whitcomb 1983; Whitcomb and Haven 1987) and reference may be made to these reports for specific details.

The Rappahannock River starts in the Blue Ridge mountains and flows in a southeasterly direction for 126 km across the piedmont plateau to the "fall line" at Fredericksburg, then 174 km across the coastal plain to enter Chesapeake Bay. It follows a former river valley cut into coastal plain sediments and submergence of the valley during the post-glacial rise of sea level formed the sub-estuary. The 80 km long sub-estuary varies from 2.5 km wide at its mouth to 0.6 km near its saline head (Ellison and Nichols 1970).

A total of 17277.6 ha of river bottom have been included in the public (Baylor Survey) grounds in the Rappahannock River (Figs. 1, 2 and 3). This paper describes the location, extent, topography and environment of the oyster producing areas in the Rappahannock River sub-estuary. Reef geometry is discussed in the middle and lower estuary; oyster recruitment is reported and related to salinities and topography.

HYDROGRAPHY

Hydrographic observations by the Chesapeake Bay Institute show that water temperature varies seasonally with air temperature from a monthly mean of 4°C in winter to about 28°C in summer, with occasional extremes for short periods (Stroup and Lynn 1963). During late summer when the prevailing temperature is high, oxygen in deeper parts of the river basin is frequently depleted. This condition often kills fish and benthic fauna (McHugh 1967; Officer et al. 1984; and Tuttle et al. 1987). The salinity increases seaward from nearly 0‰ at the head of the sub-estuary to an annual average of 16.5‰ at the mouth. The increase is greatest in the middle (Towles Point to Jones Point) and upper estuary (Figs. 1 and 2); in this gradient zone stratification is most pronounced and salinity fluctuates up to 5‰ daily and 13‰ annually. With seasonal fluctuations of river inflow, the vertical haline stratification alternates from partially mixed to relatively well mixed (Ellison and Nichols 1970).

When river inflow is high, usually in late winter, freshening reduces surface salinity at the mouth to 14‰ and limits salty water to the lower 61 km of the estuary. As in other Chesapeake Bay sub-estuaries mean salinity is typically slightly higher on the north than on the south side of the estuary owning to the influence of the Coriolis force (Pritchard 1952; Ellison and Nichols 1970).

Silty clay is the most widespread type of substratum, but in the lower estuary sand is the principal sediment on the shoals. Also, scouring leaves some sand as lag deposits on bars and in deep holes of the channel floor (Ellison and Nichols 1970).

MATERIALS AND METHODS

This portion of the bay-wide study was completed in 1977. Equipment and survey methods have been reported previously (Haven and Whitcomb 1983; Whitcomb and Haven 1987). The Raydist® electronic positioning grid

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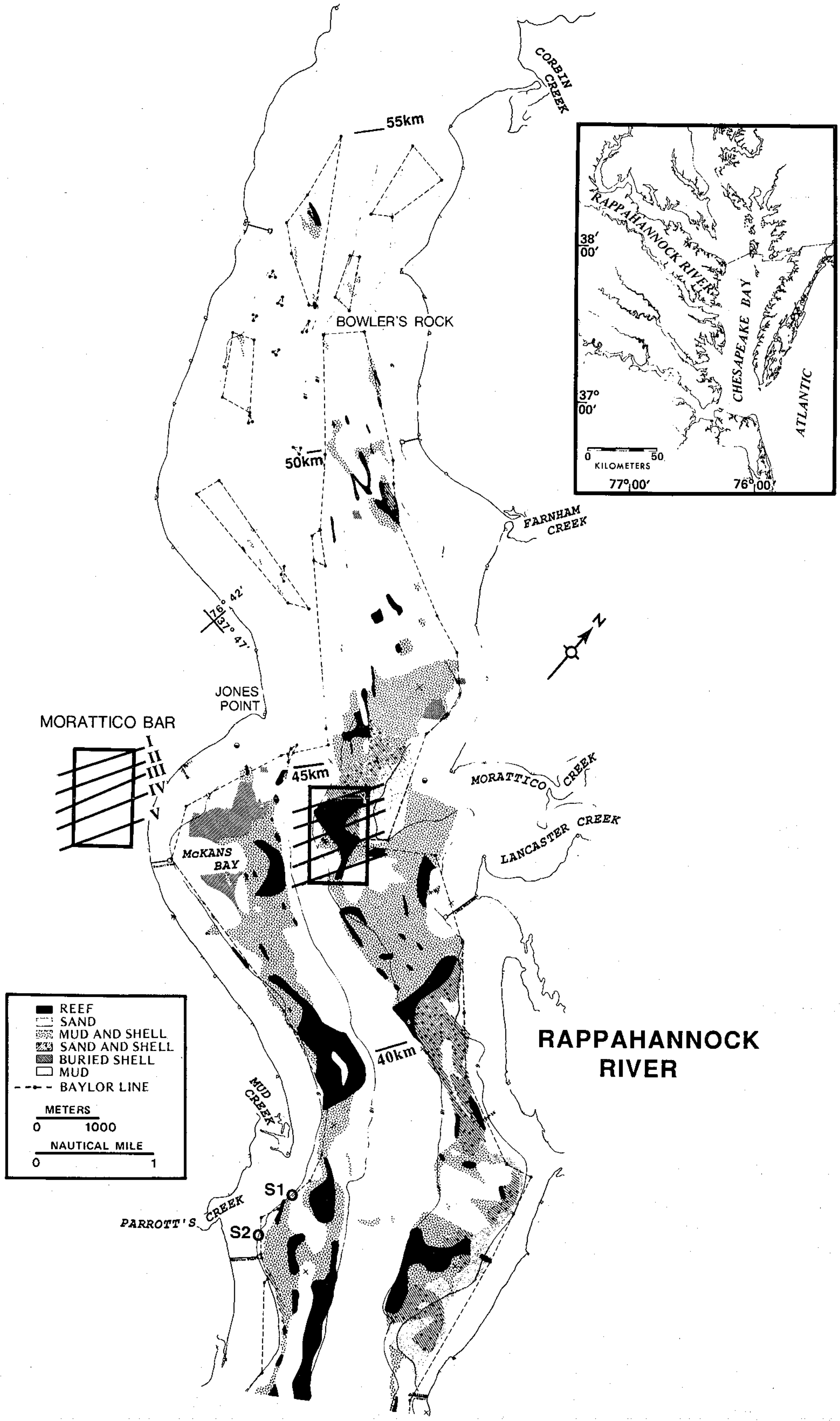

Figure 1. Location of the Rappahannock River (inset, upper right) transects in the Morattico area, oyster reefs and other substrate types. Mud bottoms within the bounds of the Baylor areas, outlined by dashed lines, are unstippled.

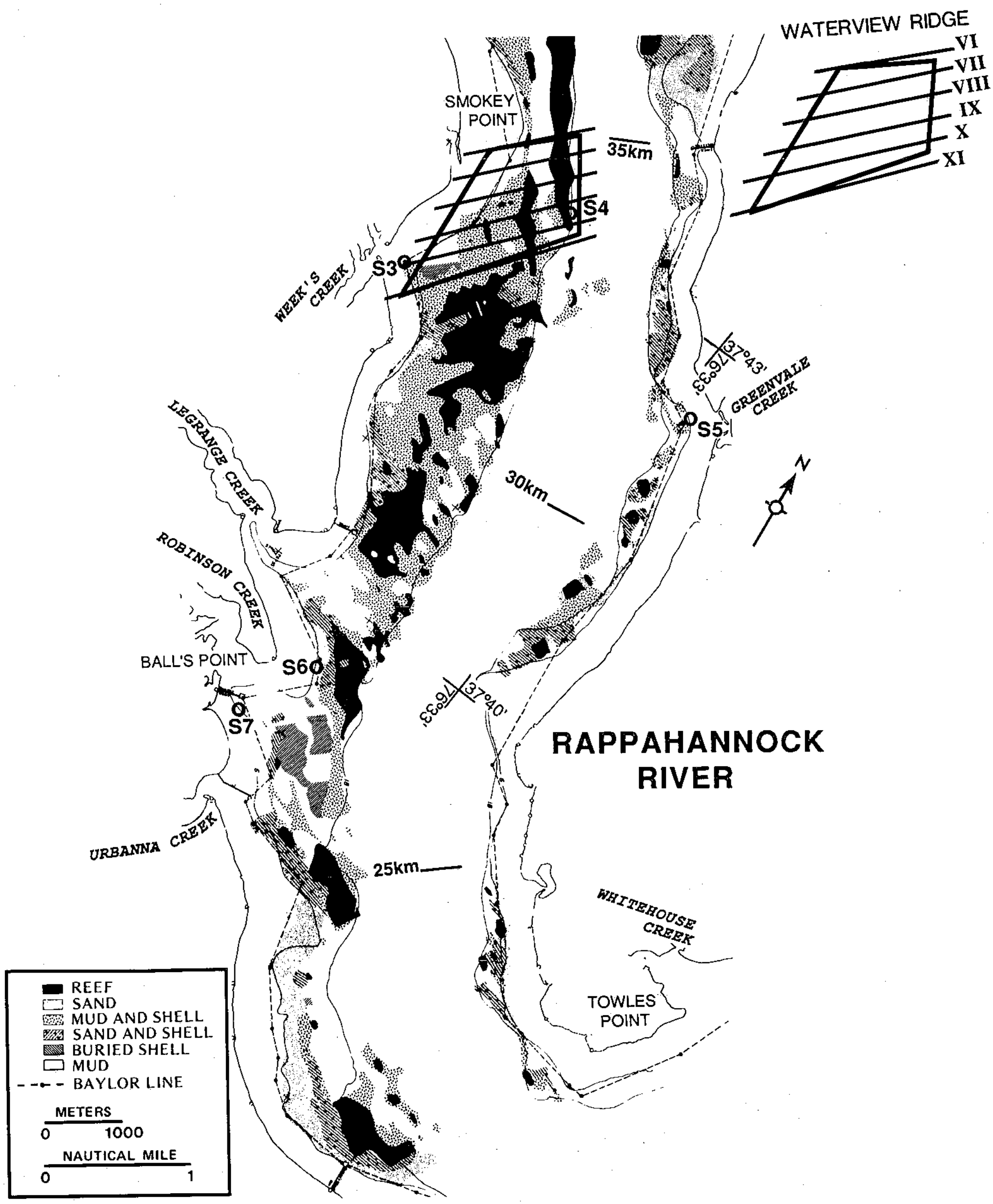

Figure 2. Location of transects in the Waterview Ridge area, oyster reefs and other substrate types. Mud bottoms within the bounds of the Baylor areas, outlined by dashed lines, are unstippled.

system (manufactured by Teledyne Hasting Corp., Hampton, VA) was augmented by an auxiliary system in the Rappahannock River erected by VIMS personnel. The transects were 183 m apart and the stations were 61 m apart where bottom showed little change. Bottom type was determined by probing the bottom with a long pole and this was supplemented by towing an acoustic underwater microphone over the bottom which detected shells. When our survey showed shells were not present the distance between transects was increased to 366 m; and, when substrates and slopes changed rapidly the distances between transects and stations was reduced. Subsequent to the survey, substrate charts of the bottom were constructed as previously described (Haven and Whitcomb 1983; Whitcomb and Haven 1987).

The five types of substrate are as follows:

1. *Oyster Reef:* Firm bottom, probe penetrated 0–5 cm. Shells and oysters were typically abundant. Shells were detected by microphone from 75 to 100% of the time between the probe stations.
2. *Sand-shell:* Firm bottom consisting largely of scattered shells and oysters; probe operator detected the gritty texture of sand. Shells or oysters were detected by the microphone from 25 to 75% of the time.
3. *Mud-Shell:* The probe operator detected a moderately firm crust over a soft bottom. The probe, after pene-

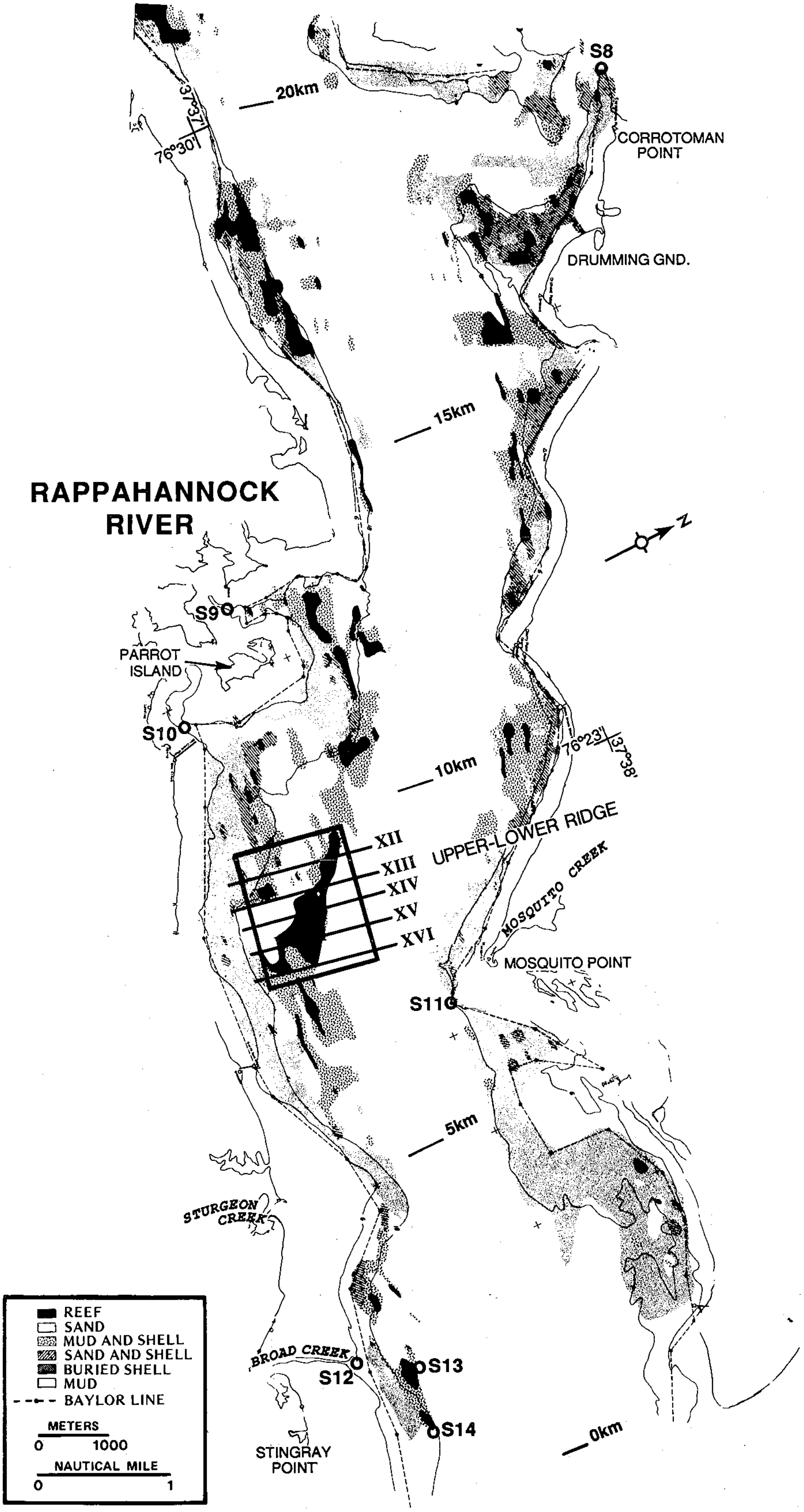

Figure 3. Location of transects in the Upper-Lower Ridge area, oyster reefs and other substrate types. Mud bottoms within the bounds of the Baylor areas, outlined by dashed lines, are unstippled.

trating the crust, could be thrust at least 0.2–0.6 m further into the bottom. Scattered shells and oysters were usually detected by the microphone from 25 to 75% of the time between stations.

4. *Mud:* On these soft bottoms the probe could often be pushed almost one meter into the bottom with little effort. The mud consisted largely of mixtures of silts and clays with some sand. Shells and oysters were usually absent, or very few as determined by microphone.
5. *Sand:* Firm bottoms into which the probe typically did not penetrate more than 2 cm. Few shells or oysters were detected by the probe or underwater microphone. Probe operator detected the gritty texture of sand.

The validity of these five substrate types has been substantiated previously for the James River and Pocomoke Sound areas (Haven and Whitcomb 1983; Whitcomb and Haven 1987). In this study, bottom supporting live oysters and shell was classified as productive; and, bottom supporting surface shell with few or no oysters was classified as potentially productive. Areas lacking shell were classified as barren or non-productive.

After the substrate types were outlined on a map, the area above Smokey Point Light (km 35) was verified by sampling with hydraulically operated patent tongs (Haven and Whitcomb 1983; Whitcomb and Haven 1987). A total of 127 sampling stations were randomly chosen along transects defined by the Raydist® system. Sampling intensity stipulated one sample for each 100 acres (40.5 ha) of oyster reef, 200 acres (80.9 ha) of shell and mud, 200 acres (80.9 ha) of shell and sand, 500 acres (202.4 ha) of mud and 500 acres (202.4 ha) of sand. Each tong grab sampled an area of 0.68 m^2 and penetrated the bottom about 10 cm on oyster reef and 30.5 cm on mud bottoms; each sample consisted of one-half of a Virginia bushel (one Virginia bushel = 0.05 m^3). Data from each grab were recorded as follows: numbers and volume (in U.S. quarts where 1 quart = 0.91 liter) of oysters exclusive of the current year's spat, volume in quarts of shells and fragments, and estimates of the percentage of unburied shell as identified by the presence of fouling organisms. Shell is defined as an entire oyster shell or shell fagments larger than 1 cm^2.

Oyster spatfall was monitored at 14 stations in the Rappahannock River from 1972 to 1980. Weighted strings of 12 oyster shells 5 to 7.5 cm long were suspended (smooth side down) 0.3 to 0.6 m above the bottom for one week periods during the setting season. At weekly intervals numbers of spat on the smooth surface of 10 shells were counted using a dissecting microscope at 15× magnification and the average spat/shell/week was calculated (Table 4). One bushel samples of cultch (bottom material) were dredged from five locations from 1947–1987 each fall after settlement ended and the numbers of spat per bushel were counted (Table 3).

The vertical profile of selected reefs is illustrated in three representative areas using data from transects, 183 m apart, across the reefs (Figs. 4, 5, and 6). The changes in substrate and slopes are shown by plotting type of substrate, depth and horizontal distance to scale. The distances shown in Figs. 1, 2 and 3 are measured from the mouth of the river in kilometers.

RESULTS

Reef Areas

Areas of oyster reef in the upper part of the survey area, as shown by Morattico Bar (km 44) occurred largely on sloping shelves adjacent to the main channel or on the upper portions of the slope leading to the channel. In outline they were often small, isolated, irregular areas, elongated areas parallel to the channel or, occasionally, at right angles to the main axis of the channel (Fig. 1). Depths of the reefs ranged from 1.8 to 5.5 m and, occasionally, as deep as 7.6 m.

Further downriver, from Weeks Creek (km 33) to Towles Point (km 21), oyster reefs have the same general configuration, but they were larger and often interconnected (Fig. 2). Here, because of bottom topography, the reefs largely occurred on the south side of the estuary on the crests of long ridges running parallel to the channel; they were separated by a trough with mud bottom. In general, most oyster reef bottoms occurred between 1.8 and 5.5 m but occasionally were found as deep as 8.8 m.

In the lower part of the estuary, from Towles Point (km 21) to the entrance of the river oyster reef areas were smaller and were more widely separated (Fig. 3); most were on the south side of the estuary. In outline they were similar to those observed elsewhere. A major difference in this section of the estuary is that reefs and areas of mud-shell or sand-shell occurred to depths of 9.1 m. Reefs as deep as these were not observed upriver.

Areas of mud-shell and sand-shell were observed in an irregular pattern throughout the survey area. In general, they surrounded oyster reef areas with mud-shell areas predominating in the deeper waters and sand-shell areas being located in shallower water. Their depth range was the same as the reefs discussed above.

Size of Substrate Types

The surface area of each substrate type in each of the sections of the river presents gradients or trends (Table 1). Mud bottoms comprised the largest component (11,586 ha), or 67.1% of the total area, and the relative size of this bottom type is about the same in each section. In contrast, sand bottoms (1702 ha) constitute only 9.9% of the total area and showed an increasing trend in a downriver direction (1.1 to 21.6%). Most of this increase was in the area below Towles Point (km 21). Mud-shell bottoms totalled 1981 ha, or 11.5% of the total area, and there was a pro-

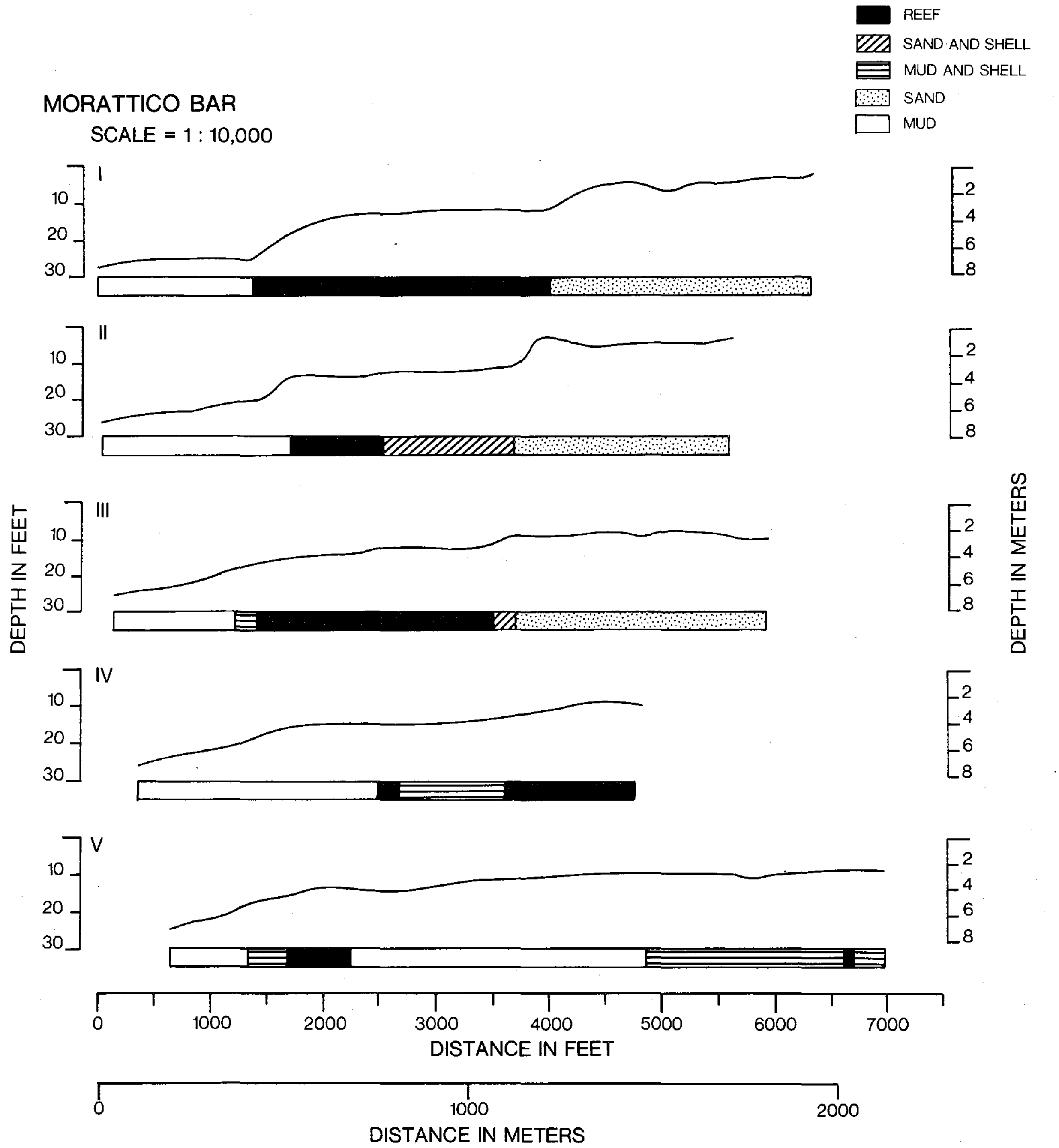

Figure 4. Longitudinal profile of the bottom on Morattico Bar in the Rappahannock River, Virginia, showing substrate, depth and horizontal distances.

gressive decline in relative abundance in the downriver direction (16.9 to 4.9%). Oyster reef areas totalled only 1116 ha, or 6.5% of the total area, and reef areas constituted relatively more of the bottom area in the Morattico Bar (km 44) to Towels Point (km 21) section. Sand-shell areas totalled 748 ha, or 4.3% of the total area, and there was no definite trend or difference in relative abundance in the different sections of the river.

In summary, the public grounds located in the 55 km upriver from the mouth of the river totalled 42,693.2 acres (17,277.6 ha). Of this, the productive, or potentially productive areas (oyster reef, mud-shell or sand-shell bottoms), totalled 9,501.8 acres (3845.3 ha). Approximately 78% of the public grounds were classified as not productive, or potentially productive.

Oyster and Shell Densities

Sampling with patent tongs to verify substrate types showed a wide variation in number of oysters and amount of shell among the samples in the Rappahannock River (Table 2) similar to the observations in the James River and

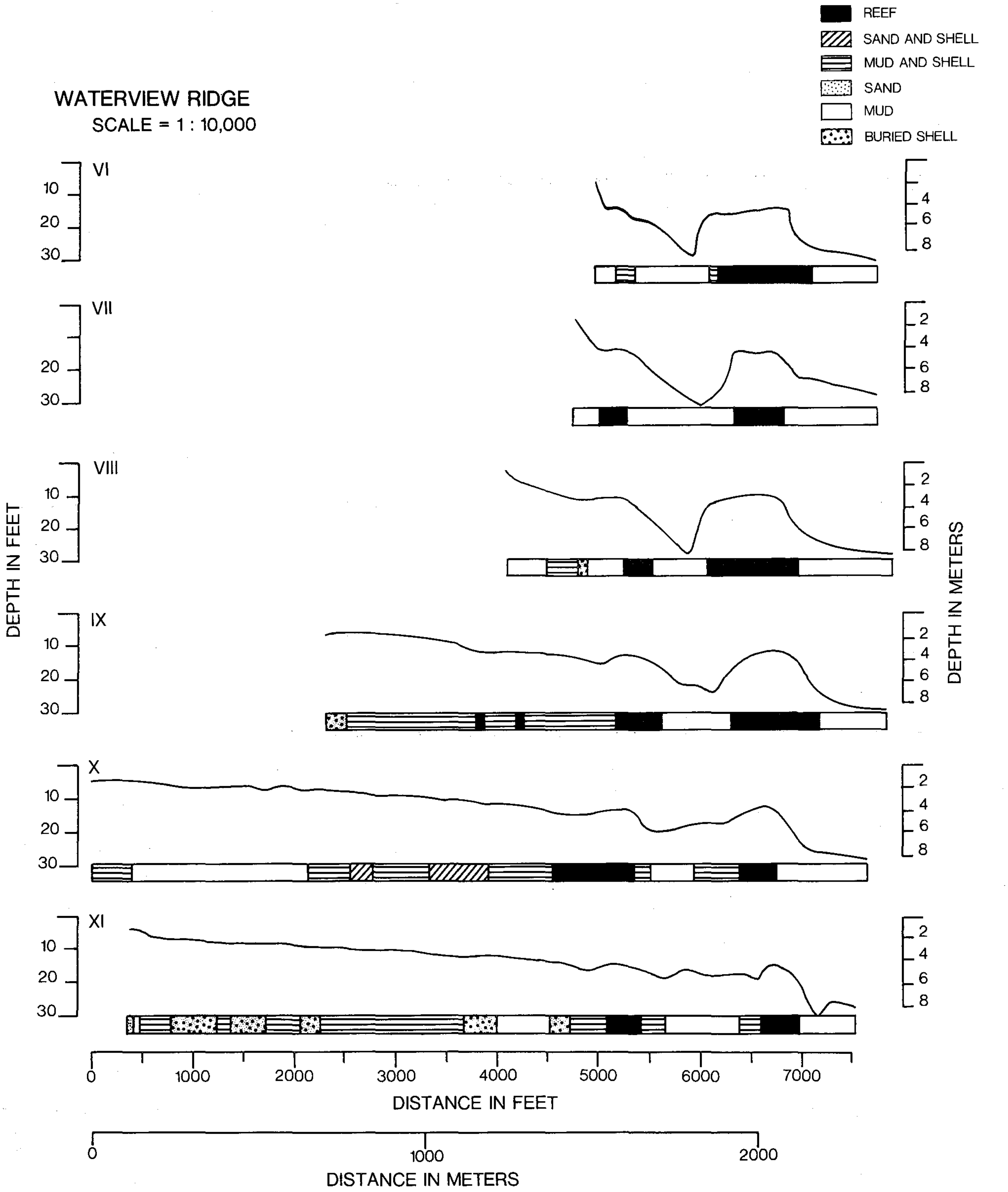

Figure 5. Longitudinal profile of the bottom on Waterview Ridge in the Rappahannock River, Virginia, showing substrate, depth, and horizontal distance.

Pocomoke Sound (Haven and Whitcomb 1983; Whitcomb and Haven 1987). These samples confirmed our observations with the bottom probe and sonic gear as to our classification of bottom types. Bottoms classed as oyster reefs had the highest oyster and shell densities; mud-shell and sand-shell bottoms had lower quantities of oysters and shells. Mud and sand bottoms had few oysters and little shell (Table 2).

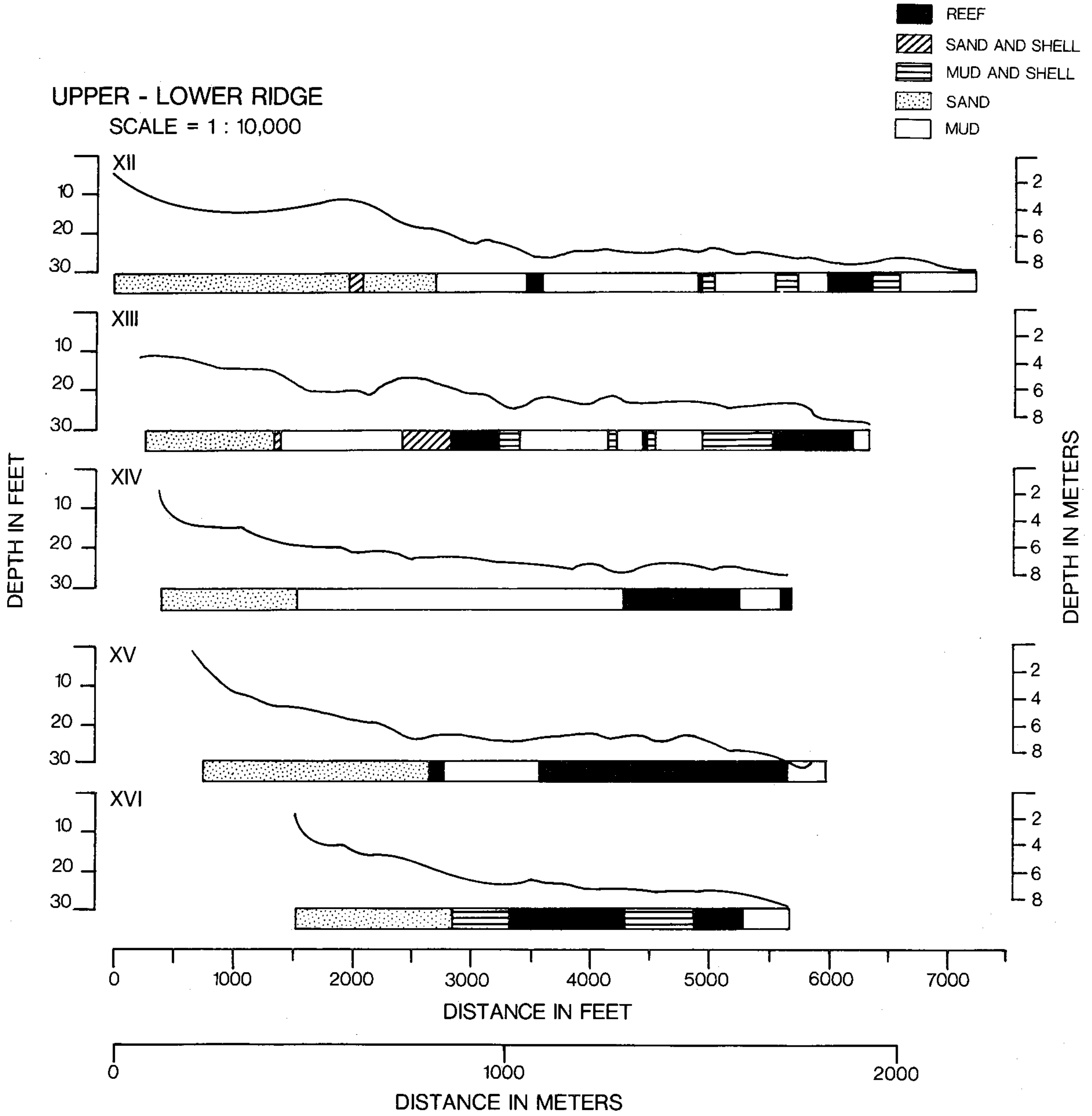

Figure 6. Longitudinal profile of the bottom on Upper-Lower Ridge in the Rappahanock River, Virginia, showing substrate, depth and horizontal distance.

TABLE 1.

Areas of bottom types in hectares and percent of total in each sub-area in the Rappahannock River.

Bottom Type	Total Area (ha)	% of Total Area	Km. From Mouth of River 53–46	46–33	33–20	20–7	7–0
Oyster Reef	1116.5	6.5	3.7	12.3	8.8	4.3	1.7
Sand-shell	747.6	4.3	3.0	5.8	5.2	4.9	1.0
Mud-shell	1981.2	11.5	16.9	19.6	11.9	8.6	4.9
Sand	1702.0	9.9	1.1	5.4	4.7	12.0	21.6
Mud	11586.0	67.1	74.4	54.4	68.4	70.1	70.7
Buried Shell	144.3	0.8	0.9	2.4	1.1	<0.1	0
Total Hectares	17277.6 (42692.3 acres)						

TABLE 2.

Number of oysters per m², exclusive of 1977 set, and average percent of sample containing single shells and cinder on five bottom types in the Rappahannock River, Va. (July 1977).

Area[1]	No. Samples	Mean Oyster Number · m^{-2}	Average % *Shell-Cinder*
		Oyster Reef	
Km53–Km46	4	3.0	51.0
Km46–Km33	29	3.14	49.6
Km33–Km0	32	4.29	47.0
		Sand-Shell	
Km53–Km46	1	13.43	50.0
Km46–Km33	11	2.31	15.4
Km33–Km0	0	—	—
		Mud-Shell	
Km53–Km46	7	0.82	35.0
Km46–Km33	17	0.79	16.2
Km33–Km0	0	—	—
		Mud	
Km53–Km46	6	0.0	<1.0
Km46–Km33	12	0.0	<1.0
Km33–Km0	0	—	—
		Gravel or Sand	
Km53–Km46	1	0.0	0.0
Km46–Km33	7	0.0	0.0
Km33–Km0	0		—

[1] Distances measured from mouth of river.

Transects

Distribution of substrate types with depth at the Moratico Bar area is shown in Fig. 4 by five transects illustrated on Fig. 1. The profiles show that the oyster reef bottoms generally occurred between 1.8 and 5.5 m and usually form a shelf. Adjacent to the reef on either the offshore or inshore margin was sand-shell or mud-shell substrate. The overall slope of the bottom from the offshore edge of the oyster reef bottom to the inshore end of the transect was 0.05 to 0.13 m (0.18 to 0.44 ft) vertically for each 30.5 m (100 ft) horizontal distance (slopes: 1:556 to 1:227, respectively). However, the reef may be level with adjacent substrate or rise as much as 3.7 m (12 ft) vertically, as on transect I (Fig. 4).

Downriver at Waterview Ridge (km 35) the distribution of bottom types with depth is shown in Fig. 5 by six transects illustrated on Fig. 2. Here, parallel reefs were separated by a muddy slough 4.0–5.5 m (13–18 ft) in depth and there was a deep mud basin 16.7 m (55 ft) in depth offshore. Inshore of the parallel reefs and bottom substrate graded into mud-shell or mud. The overall slope from the offshore edge of the reefs to the inshore end of the transect was 0.04 m to 0.29 m (0.13 to 0.95 ft) vertically for each 30.5 m (100 ft) horizontal distance (slopes: 1:769 to 1:105, respectively). On transect VI the offshore reef was very steep rising 3.4 m (11 ft) in 59.1 m (194 ft) above the mud substrate (slope: 1 to 17.6).

The five transects across Upper-Lower Ridge (km 9) near the mouth of the estuary (Fig. 3) showed a nearly flat oyster reef inshore of a deep basin with depths up to 21.6 m (71 ft) (Fig. 6). The reef was 593 meters in length, varying from 7.0 to 9.1 m in depth, and surrounded by mud or mud-shell substrate. The overall slope of the transects from the offshore edge of the reef to the shore was 0.11 to 0.18 m (0.37 to 0.59 ft) vertically for each 30.5 m (100 ft) horizontal distance (slopes: 1:270 to 1:169, respectively).

Spatfall

The seasonal settlement on dredged bottom shell at five representative locations from 1947 to 1987 showed that annual settlement was very low in the upper river, as confirmed by the shorter term shellstring data. During many years annual settlement was zero, and there were only four periods of exceptional setting intensity; 1949–50, 1953–54, 1962–66 and 1981–83 (Table 3).

The seasonal totals of spat per shell on shellstrings from 1972–80 (Table 4) showed a much higher settlement on shellstrings below Towles Point than in the area upriver. Three of the nine years (1975, 1977 and 1980) were clearly years with above-average potential for settlement on the bottom substrate, as shown by the settlement on shellstrings.

DISCUSSION

The surface configuration of oyster reef, mud-shell and sand-shell areas, and their location in respect to depth and their proximity to channel areas in the Rappahannock River, was similar to that observed in the James River and Pocomoke Sound (Haven and Whitcomb, 1983; Whitcomb and Haven 1987). In outline, the oyster reef areas may be classed as longitudinal, transverse, and irregular (Price 1954; Scott 1968; Bouma 1976; Haven and Whitcomb 1983; Whitcomb and Haven 1987). The distribution of substrate types with depth was also similar to that shown in the James River and Pocomoke Sound. In the Rappahannock River, James River and Pocomoke Sound areas of oyster reef, mud-shell and sand-shell, with one outstanding exception, occurred between 1.8 and 5.5 m contours. The exception was a large reef, 593 m in length, below Parrott Island that extended to 9.1 m in depth called Upper-Lower Ridge (Fig. 3). Bottom samples were not taken from this large reef in this study; however, exploitation by commercial tongers was observed during the 1980–85 period.

Typically, reef areas were located offshore or at the edge of the main channel. Mud-shell bottom often surrounded oyster reefs and they usually terminated the reefs offshore. When present, the mud-shell usually terminated the reefs offshore. When present, the mud-shell usually extends further inshore, as far as the 1.8 m contour. Sand-shell substrates were not as extensive as mud-shell sub-

TABLE 3.

Total seasonal set of *C. virginica* at five representative oyster reefs in the Rappahannock River, Va. 1947–1987. Data show spat/bu of bottom cultch for one Va. bushel.[1]

Year	Bowler's Rock	Morattico Bar	Smokey Point	Hogg House Bar	Drumming Ground
1947	16	0	—	140	166
1948	8	8	0	8	132
1949	12	24	10	12	346
1950	8	24	48	—	184
1951	0	3	2	5	173
1952	—	—	—	—	183
1953	5	8	5	4	90
1954	0	49	216	94	284
1955	—	0	0	18	22
1956	—	4	2	4	8
1957	2	9	53	27	21
1958	0	0	2	0	3
1959	—	0	—	3	118
1960	0	0	0	6	17
1961	0	4	0	0	12
1962	—	2	28	35	156
1963	—	4	29	89	85
1964	15	53	254	82	125
1965	—	52	112	60	227
1966	—	28	42	21	68
1967	—	0	0	0	5
1968	5	4	0	5	29
1969	8	6	8	9	5
1970	0	0	0	0	26
1971	4	2	22	8	142
1972	0	0	0	0	2
1973	1	2	0	2	0
1974	—	0	0	—	—
1975	4	0	0	20	34
1976	2	2	2	0	2
1977	0	0	12	40	270
1978	4	6	4	4	6
1979	0	0	2	4	4
1980	0	0	0	2	16
1981	21	186	202	152	892
1982	0	0	14	6	118
1983	0	0	40	106	24
1984	0	0	0	0	20
1985	22	2	4	4	64
1986	33	72	63	61	7
1987	35	16	11	11	131
$\bar{x}$ Spat/bu.	7	15	31	24	104

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[1] Data 1947 to 1966, Andrews, J. D. (Haven et al. 1981).

strates. Occasionally they extended offshore to the 5.5 m contour, but more frequently they were observed in shallower water inshore of the reefs and the mud-shell substrate.

It is obvious that natural recruitment (Table 3) has been typically low, sometimes zero above Towles Point, and low, but occasionally, moderate below Towles Point. This difference in recruitment is not explained by the study. Data on currents, circulation and salinity were not recorded, and concurrent data was not obtained on predators, diseases, etc. It is likely that these factors were involved since other studies show how several variables may interact to bring about differences in settlement in other estuaries (Pritchard 1953; Manning and Whaley 1954; Nelson 1954; Kennedy 1980; Andrews 1982; Krantz and Meritt 1977; and Haven and Fritz 1985). There is a suggestion; however, that water carrying oyster larvae is retained longer below Towles Point. The result of this water retention is a higher potential for settlement below Towles Point (Table 4).

TABLE 4.

Spatfall in the Rappahannock River—1972 thru 1980[1].

Location	Seasonal Total of Weekly Spat/Shell								
	1972	1973	1974	1975	1976	1977	1978	1979	1980
Above Towles Point									
S1—Punch Bowl					0.1	7.7	0	0.9	
S2—Waterview						1.0	0		
S3—Weeks Ck.					0.1	1.7	0		
S4—Smokey Pt.						2.3	0	2.2	0.4
S5—Greenvale Ck.	0	0	1.3	24.9	0.9	1.3	0.2	0.7	9.2
S6—Goose Pt.					0.2	2.9	0.1		
S7—Ball's Pt.					0	1.5	0.4		
Below Towles Point									
S8—Corrotoman Pt.	0	0.4	1.3	15.4	2.7	41.0	1.9	1.9	30.5
S9—Parrott's Rk.							5.6	4.2	1.7
S10—Cedar Bar							0.2		21.0
S11—Mosquito Pt.				18.2	1.5	8.7	8.5	15.6	50.1
S12—Broad Ck. In.		0	0	1.4	11.1				
S13—Broad Ck. Off		0	2.0						
S14—Spike's Rk.					0.8				

[1] VIMS (unpublished).

One aspect of the hydrography that does merit attention is that the deeper waters of the lower Rappahannock often become deficient in DO (dissolved oxygen) during the warmer months (McHugh 1967; Officer et al. 1984; and Tuttle et al. 1987). In spite of the deficiencies of DO in the lower river the Upper-Lower Ridge reefs extends to 9.1 m.

The Chesapeake Bay and its tributaries, including the Rappahannock basin, were flooded with sea water as sea level rose during the Holocene (Nichols 1972). We have speculated that many of the present day oyster reefs in the James River and Pocomoke Sound are the result of the upward growth of these reefs which accompanied that slow rise in sea level (Bouma 1976; Haven and Whitcomb 1983; Whitcomb and Haven 1987). It is probable that the oyster reef areas in the Rappahannock River evolved in the same manner.

In view of their origin, it is evident that the existence or permanence of an oyster reef in the Rappahannock River must depend on the accumulation of oysters and shells to balance the removal by exploitation or natural processes. The fact that recruitment is low or, at times, non-existent in the estuary above Towles Point indicates that this area is susceptible to over fishing.

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