The origin and extent of oyster reefs in the James River, Virginia

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THE ORIGIN AND EXTENT OF OYSTER REEFS IN THE JAMES RIVER, VIRGINIA[1]

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ABSTRACT The public oyster grounds (Baylor Survey Grounds) in the James River, VA, were studied with respect to bottom type and oyster density from 1978 to 1981. Approximately 10,118 ha (25,000 acres) were investigated using an electronic positioning system to establish station locations. Bottom types were determined using probing pipes, patent tongs, and an acoustical device. About 17.1% of the bottom was classified as consolidated oyster reef, and 47.5% was moderately productive mud-shell or sand-shell bottoms. The remaining 35.4% was rated as unsuitable for oyster culture. The surface configuration of oyster reef areas in the James River is similar to those in coastal lagoons along the Gulf of Mexico. They are thought to have developed in the James River as they did in the Gulf of Mexico area as sea level rose during the Holocene Period.

KEY WORDS

INTRODUCTION

The naturally productive oyster-growing areas in Virginia were surveyed and set aside for public use in 1894 by Lt. J. B. Baylor (Baylor 1894) and since then have been designated as Baylor Grounds. Statewide, they comprise about 98,324 ha (243,000 acres) with 10,118 ha (25,000 acres) located in the James River, VA (Haven et al. 1981a). The Baylor Survey outlined only broad areas of naturally productive bottoms and did not delineate nor quantify the size or shape of individual oyster reefs. Consequently, many unproductive areas (mud and sand bottoms) were included within the bounds of the survey (Moore 1911, Loosanoff 1931, Haven et al. 1981a).

This paper describes and quantifies the seed-oyster producing regions in James River, VA, within the bounds of the public (Baylor Survey) oyster grounds. It is a portion of a much larger investigation which evaluated the suitability for oyster culture of nearly all public oyster grounds in Virginia (Haven et al. 1981b). The area studied, divided into five zones, is shown in Figures 1 and 2.

Prior to this study there were only two attempts to quantify productive and nonproductive areas within the Baylor Grounds. The first was conducted in 1910 using a chain drag, hand tongs, and a lead line to outline bottom types and quantify oyster density (Moore 1911). Positions were established by sextant bearings and about 10,440 soundings were taken. A second study was conducted between 1973 and 1976 which demonstrated significant changes in oyster density along seven corridors in the James River, but the area of the various bottom types were not determined (Loesch et al. 1975).

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The James River has been and continues to be of major importance to the oyster industry in Virginia. Oysters set and survive well there but growth is slow and meat quality is typically poor (Loosanoff 1931, Haven et al. 1981b). Since the mid-1800's, small oysters of less than 7.6 cm (3 in.) in length (termed seed oysters) have been harvested from the river and transplanted to other areas where growth and meat quality improved. In the past 50 years, an estimated 75% or more of the seed oysters planted in Virginia by private interests on leased bottoms came from the James River (Haven et al. 1981b).

From about 1920 to 1945 annual seed-oyster production in the James River averaged about 1,675,000 Virginia bushels (82,346 m^3) (Marshall 1954), and from 1946 to 1961 it averaged between 1.5 to 2.5 million (73,800 to 123,000 m^3). Between 1961 and 1981, however, yearly production fell drastically and in that period it fluctuated between 250,000 and 550,000 bushels (12,300 and 27,075 m^3) (Haven et al. 1981b).

The decline in landings has been associated in part with a decline in demand for seed oysters because of the impact of the oyster pathogen *Haplosporidium nelsoni* (Haskin, Stauber and Makin), commonly called MSX, on adult populations growing in high salinity waters (Haskin et al. 1966, Andrews 1968). An additional cause of the decline in seed production was the low demand for seed resulting from unfavorable economic conditions such as high growing costs and an unstable market for the final product (Haven et al. 1981b). Accompanying the decline in landings was a decline in spatfall intensity which was most severe in the lower half of the seed area (Haven et al. 1981b, Andrews 1982) (Table 1). The cause of this latter decline has not yet been adequately explained. The James River, like most of Chesapeake Bay, has in the past three decades experienced

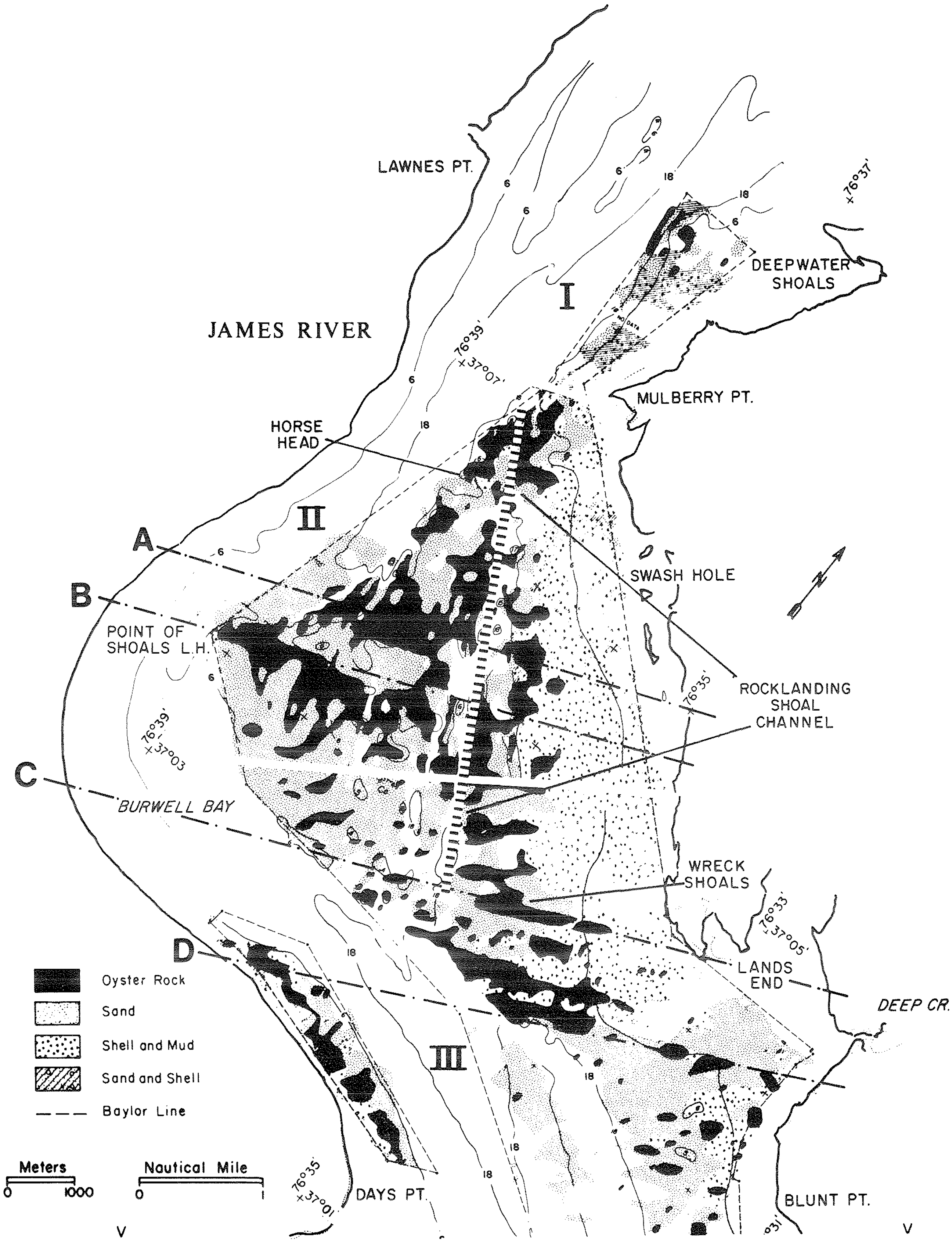

Figure 1. Oyster reefs and other bottom types in the James River, VA. Shown are areas I, II, and III separated by the clear lines and transects A, B, C, and D. Mud bottoms within the bounds of the Baylor areas are unstippled.

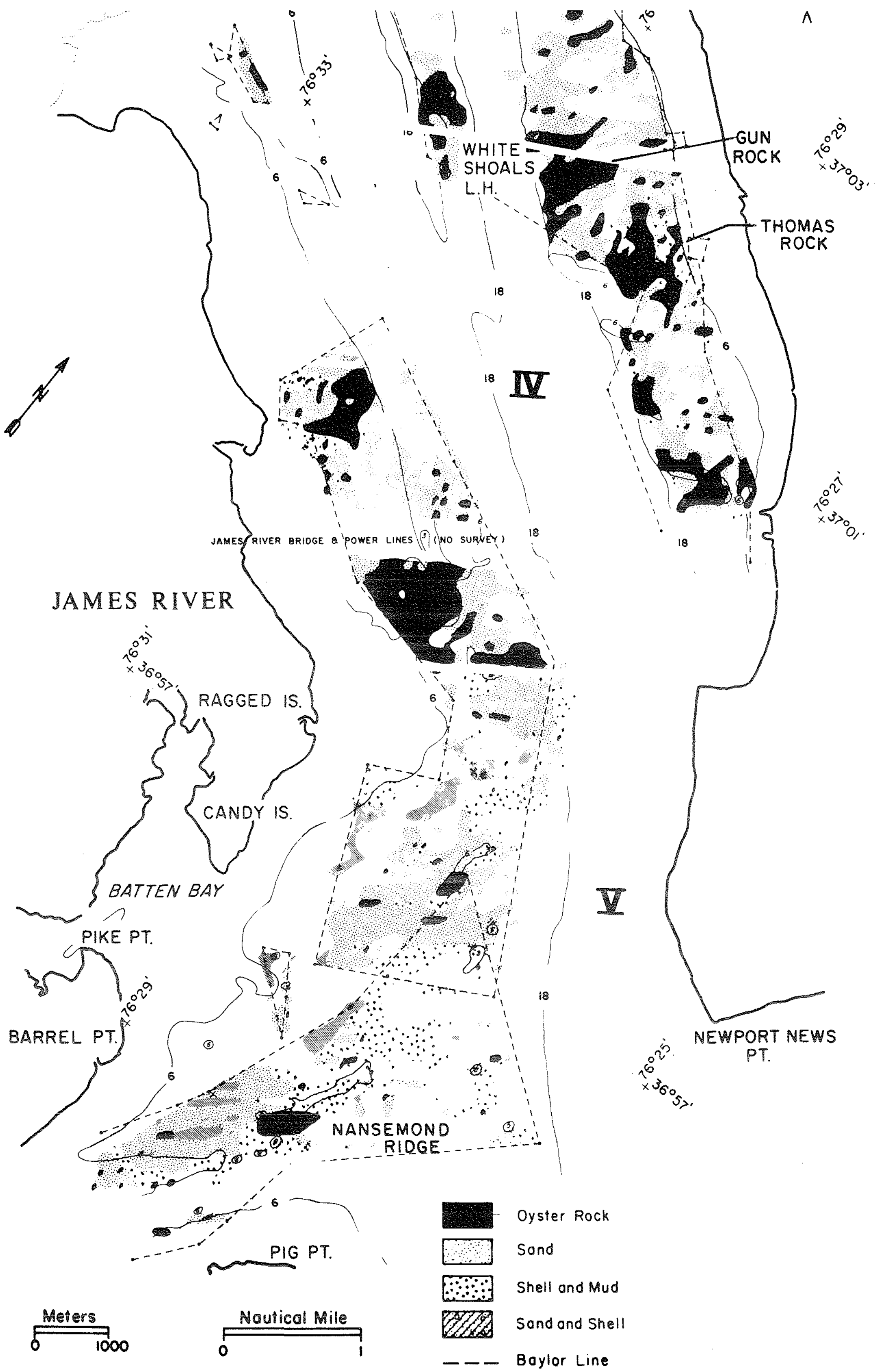

Figure 2. Oyster reefs and other bottom types in the James River, VA. Shown are areas IV and V separated by the clear lines. Mud bottoms within the bounds of the Baylor areas are unstippled.

increased levels of nutrient enrichment, toxic chemicals, sedimentation, and other human alterations (Haven et al. 1981b), all of which may have affected setting of spat.

TABLE 1.

Mean spatfall per Virginia bushel of bottom substrate at representative locations from 1947 to 1980.*

Period	Brown Shoals	Wreck Shoals	Point of Shoals	Deep Water Shoals
1947–1950	718	1901	385	1744
1951–1955	1030	1945	336	872
1956–1960	412	995	––	468
1961–1965	94	298	135	113
1966–1970	27	88	249	334
1971–1975	46	167	82	49
1976–1980	43	199	169	534

*1947–1965 data from Andrews (1982).

Hydrography of the James River

The hydrography of the James River has been the subject of several major studies but many details are still poorly understood. Basically, it is a partially mixed tidal estuary (Pritchard 1953, Nichols 1972b); recent studies suggest it may undergo a cyclic stratification-destratification process related to the neap and spring tidal cycles (Haas 1977).

Published information on salinity from 1949 to 1961 at Deep Water Shoals showed a range from about 2 to 10 ppt, at Wreck Shoals from 7 to 14.5 ppt, at Newport News Point from 12.5 to 18.5 ppt, and at Nansemond Ridge from 13.5 to 19.5 ppt (Table 2). Additional data for all stations from 1963 to 1981 showed a similar range (VIMS unpublished). Freshets occur at irregular intervals in this estuary and 0.0 ppt has been recorded as far downriver as Wreck Shoals (Andrews et al. 1959, Haven et al. 1976). Salinities of 0.0 ppt commonly occur at Deep Water Shoals where oysters are frequently killed by fresh water in the spring of the year (Andrews et al. 1959).

TABLE 2.

Mean salinities (in ppt) in the James River, VA, from 1949 to 1961.*

	Stations			
Season	Deep Water Shoals	Wreck Shoals	Newport News Point	Nansemond Ridge
Spring	2.0	7.0	12.5	13.5
Summer	10.0	14.0	17.5	18.5
Fall	5.0	14.5	18.5	19.5
Winter	––	13.0	16.0	16.5

*Adapted from Stroup and Lynn (1963).

The natural channel in the lower James River lies close to the north shore, near Newport News Point, and toward the south shore in the Burwell Bay area. In the upper estuary near Deep Water Shoals, it is near the center of the river. Rocklanding Shoals Channel was cut through the northern edge of the seed areas and its depth in 1976 was 7.6 m (25 ft) (Figure 1).

The names of individual seed areas in the James River have remained virtually unchanged for over 100 years. For example, the oyster reef known as Deep Water Shoal, marks the upriver limit of commercial production and Nansemond Ridge is the lower limit (Figures 1 and 2). These names can only be used to designate the general location of a seed-producing area because one area grades imperceptibly into another.

MATERIALS AND METHODS

The criterion for defining the naturally productive areas is based on one aspect that is considered of major importance. The naturally productive areas in the James River (those having oysters or shells) have existed in nearly the same location since 1854 (Moore 1911, Marshall 1954). Moreover, as will be discussed later, many probably existed in the same approximate location for much longer periods as was determined for Gulf of Mexico oyster beds (Bouma 1976). This study was designed to detect shells or living oysters in or on the bottom. Their presence was indicative of productive or previously productive bottoms.

The survey vessel was navigated at a speed of about 5.5 $km \cdot h^{-1}$ (3 knots) within the bounds of Baylor Grounds along a series of transects which were delineated using the Raydist® (manufactured by Teledyne Hastings Corp., Hampton, VA) electronic positioning grid system with a precision of ± 2 m. While traversing these transects, the bottom was probed with a 2.5-cm diameter copper pipe every 60 to 90 m to determine bottom type. The probing interval was decreased when the bottom type changed rapidly. Transects were usually about 183 m apart. Studies on bottom types were completed during 1979; sampling for oyster density was carried out in 1981.

The presence or absence of shells and/or oysters between probe stations was monitored continuously with an underwater microphone mounted in a steel frame and dragged on a cable about 37 m behind the vessel. The sounds made by the microphone bouncing over shells or oysters or sliding over sand or mud were amplified and broadcasted. The intensity and frequency of the sounds and the percentage of time the microphone was impacting on shells or oysters or other bottom types between stations were recorded by the operator (Haven et al. 1979). Depths were monitored continuously with a recording fathometer. These latter readings were used to reconstruct four longitudinal profiles across various bottom types.

For each station, Raydist® coordinates, coded information on bottom types obtained with the probe, acoustic information, and depths were recorded on tape using a Teledyne/Hastings printer. Later, the data on the printed tape were plotted on a series of 1:10,000 charts The charts showed latitude and longitude, 1.8- and 5.5-m (6- and 18-ft) depth contours, outlines of the shorelines, outlines of the Baylor Grounds, and information on bottom types. Subsequently, the boundaries of the various bottom types were outlined on the charts. Areas of various bottom types were determined with a digitizing planimeter.

The following bottom types were described:

Oyster reef: firm bottom, probe penetrated 0 to 5 cm. Shells and oysters were typically abundant. Shells or oysters were detected using the microphone from 75 to 100% of the time between the probe stations.

Sand-shell: The firm bottom consisted largely of unconsolidated shell; probe operator detected the gritty texture of sand. Shells or oysters were detected using the microphone from 25 to 75% of the time.

Mud-shell: The probe operator detected a moderately firm crust over a soft bottom. The probe, after penetrating the crust, could be thrust at least 0.2 to 0.6 m further into the bottom. Unconsolidated shells or live oysters were usually detected using the microphone from 25 to 75% of the time between stations.

Mud: On these soft bottoms the probe could often be pushed almost 1 m into the bottom with little effort. They consisted largely of mixtures of silts and clays with some sand (Nichols 1972a). Shells and oysters were usually absent, or very few as determined using the microphone.

Sand: These were firm bottoms, and the probe typically did not penetrate more than 2 cm. Few shells or oysters were detected using the probe or underwater microphone. Probe operator detected gritty texture of sand.

After the bottom types were outlined on charts, the bottoms in Areas II and III (Figure 1) were sampled with hydraulically operated patent tongs. Each tong grab sampled an area of 0.68 m^2 (7.29 ft^2) and penetrated the bottom about 10 cm on oyster reef and 30.5 cm on mud bottoms; each sample consisted of at least one-half of a Virginia bushel (one Virginia bushel = 0.05 m^3). A total of 476 sampling stations were randomly chosen along transects defined using the Raydist® system. Data from each grab were recorded as follows: numbers and volumes (in U.S. quarts where 1 quart = 0.91 liter) of oysters exclusive 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. These data were used to calculate oyster density (number · m^{-2}) and the percentage of each grab that was composed of shells and shell fragments.

A preliminary analysis of data on oyster density indicated a skewed distribution with a high percentage of zero values; therefore, densities were analyzed for possible significant differences in modal values using the Mann-Whitney test for nonparametric data (Sokal and Rohlf 1981). Oyster distribution obtained in this study was compared to distribution found in 1910 by Moore (1911).

National Oceanic and Atmospheric Administration (NOAA) charts 12248 and 12222 (1:40,000) were used in this study to outline depth contours and shorelines. Because these charts show depths in feet and distances in nautical miles, these same units are used to delineate depth contours and distances shown in the illustrations and in some of the tabular material. In the text the following conversions are used: the standard 6- and 18-ft contour depths are 1.8 and 5.5 m, respectively. One nautical mile (6,000 ft) is equal to 1.83 km.

RESULTS

Reef Areas

Areas classified as ***oyster reef*** show distinctive outlines in different parts of the estuary. In Area I six small reefs existing near the channel are generally elongate and parallel to the axis of the estuary and to the currents. They occur at depths ranging from 1.8 m to more than 5.5 m (Figure 1).

Area II is characterized by larger oyster reefs, most of which differ in shape from those in Area I (Figure 1). On the northeastern side of Rocklanding Channel, they begin about 1.4 km offshore (beyond the 1.8-m contour) and extend to Rocklanding Channel. Many are extensive and appear to be oriented parallel to the current and the axis of the river. Usually, however, there is an almost equal component oriented at right angles to the shore and the current. A similar type of orientation exists on the extensive reef area along the southwestern side of Rocklanding Channel. There the reefs extend to the south for a maximum distance of about 3.7 km, at depths ranging from 1.8 to 5.5 m (Figure 1).

The oyster reefs in Area III are among the most productive in James River, and Rocklanding Shoal Channel passes through the center of this area. On the northeastern side of the natural channel (off Lands End) between the 1.8- and 5.5-m contour intervals, the oyster reef areas form well defined and approximately parallel rows which are approximately at right angles to the axis of the river (and current). Frequently, a reef ends as an isolated series of small reefs still in line with the larger one. On the southwestern side of the estuary in Area III, the oyster reefs are irregular in outline but the trend appears to be parallel to the channel as in Area I. Many are located at depths of less than 1.8 m. This is in contrast to the distribution noted on the northeastern side where most occur between the 1.8- to 5.5-m contour lines (Figure 1).

In Area IV on the northeastern side of the natural channel, which varies in depth from about 7.3 to 15.8 m, irregularly shaped reefs occur between the 1.8- and 5.5-m contours (Figure 2). Here, in contrast to the upriver areas, there is no apparent orientation with respect to the axis of the river (Figure 2). On the southwestern side, the depths of the reef areas differ from those on the opposite side because they exist primarily in less than 1.8 m of water.

They are, however, similar in that they have no apparent orientation.

Oyster reefs in Area V (Figure 2) are usually small and scattered and are oriented at right angles to the axis of the river and are, therefore, similar in this respect to those in Areas I and II. Moreover, they are usually at depths less than 1.8 m as are most reefs on the southwestern side of this estuary.

Other Bottom Types

In Areas I through IV, ***sand-shell*** bottoms generally occur inshore of oyster reef areas and often extend into the inshore margin of Baylor Grounds; in Area V, where sand-shell bottoms are scarce, they occur largely between the reefs. Areas of ***mud-shell*** are the most extensive bottom type in Areas II, III and IV and they occur offshore of sand-shell bottoms. Oyster reefs in all zones are usually surrounded by this type of bottom.

Sand bottoms are not common in the James River Baylor Grounds; when they do occur, they are generally located inshore of sand-shell areas. ***Mud*** bottoms are extensive and occur in all five segments as large irregular zones between shelled areas and in the deeper channels (Figures 1 and 2).

Acreage of Subaqueous Bottom Types

Mud-shell bottoms were the most extensive and totaled 29.8% (3,030 ha) of the Baylor Grounds surveyed (10,178 ha). ***Oyster reefs*** and ***sand-shell*** are about equally abundant and comprise 17.1% and 17.7% (1, 744 and 1,800 ha), respectively, of the total area. Therefore, about 64.6% (or 6,574 ha) of the Baylor Grounds in the James River can be classified as productive or potentially productive (Table 3).

The nonproductive ***mud, sand,*** and ***buried-shell*** bottoms make up 35.4% (3,604 ha) of the total 10,178-ha area. These latter types have little, if any, potential for oyster culture.

Oyster and Shell Densities

Patent-tong sampling showed a wide variation in oyster density on the various types of bottom. This was expected because a previous study during 1973 and 1974 showed that oyster distribution in the James River was typically noncontiguous (Loesch et al. 1975). The present study showed that oyster densities on all bottom types ranged from 0 to 274 oysters$\cdot m^{-2}$ (Table 4). Oyster-reef bottoms had the highest mean density and ranged from a mean of $34.8 \cdot m^{-2}$ in Area II to $28.0 \cdot m^{-2}$ in Area III. Sand-shell and mud-shell bottoms supported about 50 to 75% fewer oysters. No oysters were recovered in eight samples taken in Area II on mud and sand bottoms. On similar substrates in Area III, oyster densities ranged from 2.2 to $10.7 \cdot m^{-2}$. This latter value, discussed later, seems atypical.

A statistical analysis using the Mann-Whitney test for nonparametric data (Sokal and Rohlf 1981) showed that the modal grouping for oyster density (Table 4) on oyster-reef areas was significantly higher than for mud-shell and sand-shell bottoms in Area II (Table 5). Mud-shell bottoms have a significantly higher modal grouping than sand-shell. No oysters were found on sand or mud bottoms (Table 4).

In Area III, oyster-reef bottoms have a modal grouping of oyster densities higher than all bottom types tested (Table 5). Sand-shell bottoms were significantly higher than mud-shell, and both have a modal grouping higher than sand. Mud bottoms seemed to show anomalous situations because oyster densities were higher than those found for sand-shell bottoms. A possible reason for this will be covered in the Discussion section.

Analysis of the patent-tong data showed that bottoms classified as oyster reef (on the basis of data obtained using a probe and sonic gear) also contained the highest content of shell material. In Areas II and III, shells and fragments averaged from 42.8 to 33.9%, by volume, respectively, of the grab's content. The high shell content and high values for oyster density are responsible for the firmness of bottoms classified as oyster reef. In addition, almost half of the shell material on oyster reef bottoms was surface shell which was exposed to the flow of the current (Table 6).

Bottoms that were classified as ***mud-shell*** or ***sand-shell*** in Areas II and III differed from ***oyster reef*** bottoms

TABLE 3.

Areas of various types of bottom in the James River, VA, expressed as hectares and as percent of total in each of the subareas (I–V).

Bottom Type	Total Area (ha) I to V	Size of Each Bottom Type (% Total) in Each Subarea I	II	III	IV	V	Percent Total All Areas	
Oyster Reef	1,744	5.1	28.0	14.1	28.5	2.8	17.1	64.6
Sand-Shell	1,800	35.8	22.6	16.5	5.5	19.9	17.7	
Mud-Shell	3,030	14.5	29.7	33.5	31.3	23.7	29.8	
Sand	623	11.6	4.6	6.2	1.5	10.5	6.1	35.4
Soft Mud	2,811	33.0	15.1	29.7	32.8	34.8	27.6	
Buried Shell	170	0	0	< 0.1	0.4	8.3	1.7	
Total hectares	10,178	298	2533	3903	1466	1978		

because they had smaller volumes of shell material and lower percentages of surface shell; they were less consolidated and more scattered.

TABLE 4.

Density of oysters collected with patent tongs in the James River seed area.*

Bottom Types	Area II N	Area II Mean	Area II Range	Area III N	Area III Mean	Area III Range
Oyster Reef	19	34.82	0 to 165.76	66	27.98	0 to 273.81
Sand-Shell	27	9.0	0 to 109.52	63	6.48	0 to 35.52
Mud-Shell	19	13.40	0 to 118.90	188	5.75	0 to 59.20
Sand	4	0		21	2.18	0 to 41.44
Mud	4	0		73	10.72	0 to 112.48

*From Statistical Summary of Means and Range (1981).

TABLE 5.

A statistical comparison using the Mann-Whitney test of modal grouping of oyster density (m^2) in Areas II and III in the James River, VA. (Mean values for numbers of oysters per m^2 are shown in Table 3.)

Bottom Type	Levels of Significance
	Area II
Oyster reef versus mud-shell	Difference significant at $0.25 > P > 0.01$
Oyster reef versus sand-shell	Difference significant at $0.01 > P > 0.001$
Mud-shell versus sand-shell	Difference significant at P = 0.01
	Area III
Oyster reef versus mud-shell	Difference significant at $P < 0.001$
Oyster reef versus sand-shell	Difference signfiicant at $P < 0.001$
Oyster reef versus sand	Difference significant at $P < 0.001$
Mud-shell versus sand-shell	Difference significant at $0.01 > P > 0.001$
Mud-shell versus sand	Difference significant at $0.05 > P > 0.02$
Sand-shell versus mud	Difference significant at $0.01 > P > 0.001$
Mud versus sand	Not significant at P = 0.10
Mud-shell versus mud	Not significant at P = 0.10

Transects

Elevations and slopes were studied across the oyster reefs, or shoals, on four transects in the area near Point of Shoals Light (Figures 1 and 3). Those transects crossed productive oyster reefs such as Wreck Shoal and Point of Shoals. The overall slope from the channel to the sandy margins along the shore ranges from about 0.04 to 0.11 m (0.13 to 0.35 ft) vertically for each 30.5 m (100 ft) horizontal distance (slopes: 1:769 to 1:286, respectively). Frequently, the elevation of the bottom from a nonproductive slough to a productive shelled area was less than 0.30 m (1 ft) vertically for every 30.5 m (100 ft) horizontally. Very steep slopes occur adjacent to the channel or mud sloughs where they join productive oyster-reef or mud-shell substrates. These sharp slopes may be as large as 4.6 m (15 ft) vertically in 30.5 m (100 ft) horizontally (a slope of 1:6.7). ***Sand-shell*** bottoms occur as flat areas and are usually near the shore.

DISCUSSION

Samples obtained with patent tongs in Areas II and III confirmed observations made using a bottom probe, acoustic gear, and fathometer. ***Oyster reef*** bottoms had higher densities of oysters and shell material. ***Sand-shell*** and ***mud-shell*** bottoms had lower densities of oysters and shells. ***Sand*** bottoms seldom contained shells or oysters. ***Mud*** bottoms, while definitely soft, sometimes contained significant numbers of oysters.

The surface outlines of oyster reefs in the James River may be separated into four types which closely resemble those that occur in lagoonal systems of the Gulf of Mexico (Graves 1905, Hedgpeth 1953, Price 1954, Scott 1968, Bouma 1976). The **longitudinal** type, for example, is represented in the James River by those shown on Area I where tidal currents are rapid over shoal bottoms. The **large irregular** type is common throughout the estuary and has two components; one is at a right angle to the axis of the river and a second is parallel to the axis (Area II). A third type, termed a **transverse** reef, is long and lies at right angles to the current as seen in Area II off Lands End (Figure 1). The last type, without any obvious shape, is termed a **pancake** reef (Scott 1968); these are common in Area V (Figure 2).

While those bottoms that were classified as ***sand-shell*** and ***mud-shell*** in the James River support live oysters and are moderately productive, we do not believe them to be long-term features of the estuary at specific locations as are oyster reef areas. This concept was originally discussed by Moore (1911) who stated that the boundaries of the highly productive areas in the James River seed area, which approximate our oyster reef classification, were originally sharply marked and separated from the barren (***mud*** or ***sand***) bottoms. Moore (1911) speculated that operations by man (harvesting activities and culling of the catch) over the years were responsible for scattering shells and oysters between the reefs and onto otherwise barren bottoms. The atypical value of 10.7 oysters$\cdot m^{-2}$ on ***mud*** bottoms shown for Area III (Table 4) probably resulted from this activity.

Oysters do not grow or survive well on ***sand*** and ***mud*** bottoms because of several physical factors. ***Mud*** bottoms in the James River are areas of active sedimentation (Nichols 1972a); in that environment, oysters may be covered with sediment faster than they can grow (MacKenzie 1983).

TABLE 6.

Number of oysters per m^2, exclusive of 1979 spat set, and amounts of surface and buried shells on five bottom types in the James River, VA (August 1979).

Bottom Type	Number Sampled	Mean Number • m^{-2}	Percent Shell	Percent Surface Shell	Percent of Sample with Surface Shell
			Area II		
Oyster reef	19	34.8	42.8	47.7	94.7
Sand-shell	27	9.0	23.1	16.1	48.1
Mud-shell	19	13.4	16.0	17.9	36.8
Sand	4	0.0	12.0	0.0	0.0
Mud	4	0.0	5.1	0.0	0.0
			Area III		
Oyster reef	66	27.98	33.9	41.8	90.1
Sand-shell	63	6.48	23.1	25.0	81.0
Mud-shell	188	5.75	11.8	13.2	41.0
Sand	21	2.18	9.9	8.1	9.0
Mud	73	10.72	6.8	8.5	8.0

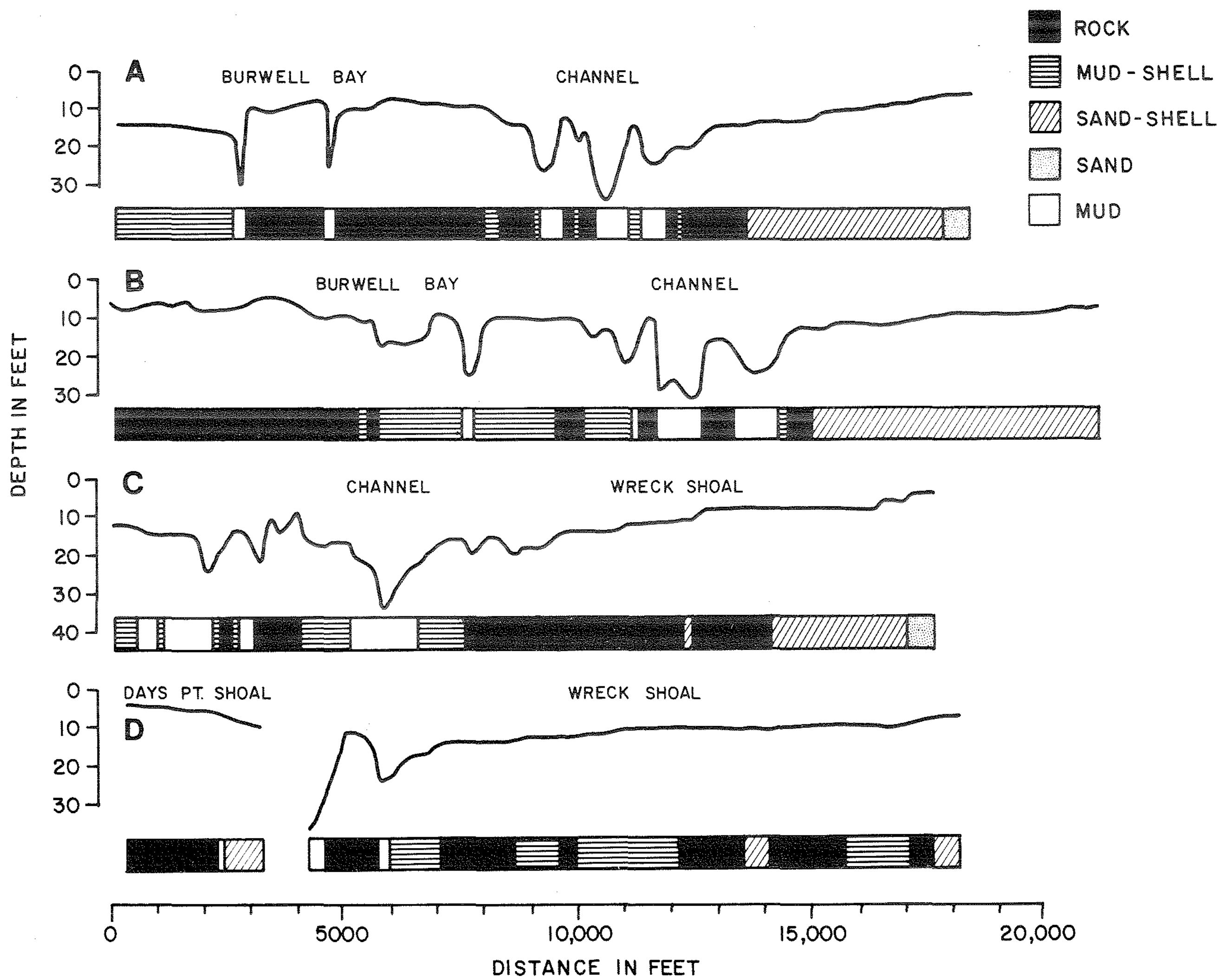

Figure 3. Longitudinal profile of various oyster bottom types along transects A, B, C and D (see Figures 1 and 2).

Sand bottoms, while firm, offer an unstable, shifting substrate and sand grains are abrasive and difficult to void from the mantle cavity when washed in by wave or current forces. We speculate that conditions for recruitment and growth on ***mud-shell*** or ***sand-shell*** areas may often be marginal or they may fluctuate to a greater degree than ***oyster reef*** areas.

The extent and depth of buried oyster shell deposits below the reefs in the James River are not known; however, about 2.0×10^6 m^3 of buried oyster shells were dredged commercially between 1963 and 1969 from the southern side of this estuary approximately 6 km southwest of Newport News Point (Figure 2) (Va. Comm. Fish. Rept. 1969, Haven et al. 1981b). An early study of lagoonal systems in the Gulf of Mexico showed that exposed oyster reefs often extended down into the sediments for at least 2.7 m (Norris 1953). Later Bouma (1976), working in the same area, related reef oyster formation to the world-wide rise in sea level during the Holocene Period (Emery and Uchupi 1972). He concluded that most of the present-day oyster reefs in San Antonio Bay exist on top of old reefs that started to grow about 9,000 years ago in the former river cuts incised in late Pleistocene deposits as the sea level began to rise. He demonstrated that shell deposits extended as deep as 21 m (69 ft) below the sediment surface and his ^{14}C data showed ages of buried shell from 1,500 to 9,000 years. Bouma (1976) also stated that many surface reefs were probably connected or adjacent to buried shell deposits.

The James River Basin and Gulf of Mexico areas experienced the same rise in sea level during the Holocene Period. In relation to this event, the James River Basin flooded with seawater between 9,000 and 6,500 years ago. The original flooding occurred along the axis of the river as defined by the deeper channels that today range in depth from 8 to 29 m (Nichols 1972a). The sea level has increased about 0.6 m in the James River between 1854 and 1954.

It has yet to be determined how far oyster reefs extend into bottom sediments in the study area; however, on the basis of similarity in shape of oyster reefs in the James River and Gulf of Mexico areas and the similar geological histories, we speculate that oyster reefs in the river are underlain with shell deposits of varying thickness and that the reefs evolved as they did in the Gulf areas from old shore or bottom features as sea level rose.

There have been slow changes in water depth over oyster reefs in the James River over the last century. Marshall (1954), using depth data from U.S. Hydrographic charts from 1854-55 to 1943-48, stated that considerable variations existed in the physiographic changes in the surfaces of the seed beds (tops of the oyster reefs) during that period. At most points depth comparisons over the 100-year period, after allowing for the increase in sea level, indicated a decline in elevation of about 0.18 m (0.6 ft). He speculated that this decline was the net effect of both natural phenomena and fishery activities.

Our data, when compared with those obtained by Moore in 1910 (Moore 1911), suggest no major differences in oyster density in 1911 and 1981. Moore reported oyster densities for about 590 locations in the seed area and used them to separate bottoms into five classes (Table 7). Those classifications were a combination of numerical data on oyster density coupled with Moore's concept of how many oysters a waterman needed to harvest during a 9-hr day at the former price of $0.20 to $0.30/bu for seed and $0.45/bu for market oysters. Certain of his categories are still valid. Moore's ***barren*** category is comparable to our mud or sand classifications; both have a very low potential for growing oysters. Moore's ***dense growth*** is equivalent to our oyster reef classification, and our definition of productive bottoms (oyster reefs and mud-shell or sand-shell bottoms) is comparable to Moore's ***dense, scattered, very scattered*** and ***depleted*** categories (Table 7).

TABLE 7.

Classification of oyster bottoms in the James River, VA.*

	Oyster Harvest in Virginia Bushels by a Tonger in a 9-hour Day	
Oyster Density	Seed Oysters	Market Oysters
Barren (no shell or oysters)	9	9
Depleted	4	3
Very scattering (scattered)	4 – 8	3 – 5
Scattering (scattered)	8 – 12	5 – 8
Dense	12	8

*Classification from Moore (1911).

Using the preceding categories, the following comparisons are made (Table 8). In 1910 (Moore 1911), mean oyster densities on ***dense*** bottoms ranged from 26.9 to 35.4 oysters$\cdot m^{-2}$ in Area II. In contrast, our randomly collected reef samples in 1981 showed a similar density of $34.8 \cdot m^{-2}$. Mean oyster densities on ***scattered*** to ***depleted*** bottoms in Moore's study (1911) ranged from nearly zero to a maximum of $20.2 \cdot m^{-2}$ while mean densities for comparable bottom types in 1981 ranged from 9.0 to $13.4 \cdot m^{-2}$. In Area III, three stations in Moore's study ranged in density from 32.9 to $57.0 \cdot m^{-2}$; our mean density for oyster reefs in the same general area was $28.0 \cdot m^{-2}$. Mean densities in areas of ***scattered*** to ***depleted*** bottoms ranged from zero to $33.1 \cdot m^{-2}$ in the early 1900's; our density data showed a mean range of 2.2 to $10.7 \cdot m^{-2}$ (Table 7). The overall similarities in density for ***dense*** and ***reef*** bottom types were unexpected because of the decline in setting intensity in the James River that began in 1960 (Haven et al. 1981b). We speculate that, in 1910, the intense harvest may have depleted the beds to low levels, even when oysters were setting at a much higher rate.

TABLE 8.

Mean densities of oysters on various bottom types in the James River, VA, 1910–1981. (Locations shown in Figure 1.)

1910 (Moore 1911)			1981 (Present Study)		
Oyster Reefs	Growth Type	Oysters/m^2	Location	Substrate	Oysters/m^2
		Area II			
Horse Head	Dense	35.4	Horse Head to Point of Shoals	Oyster reef	34.8
	Scattering	15.4		Sand-shell	9.0
	Very Scattering	20.2		Mud-shell	13.4
	Depleted	0.1		Sand	0
				Mud	0
Point of Shoals	Dense	26.9			
	Scattering	13.1			
	Very Scattering	5.5			
	Depleted	2.0			
		Area III			
Wreck Shoals	Dense	48.6	Wreck Shoals to Thomas Rock	Oyster reef	28.0
	Scattering	0		Sand-shell	6.5
	Very Scattering	0		Mud-shell	5.8
	Depleted	0		Sand	2.2
				Mud	10.7
White Shoal	Dense	57.0			
	Scattering	0			
	Very Scattering	10.3			
	Depleted	9.1			
Thomas Rock	Dense	32.9			
	Scattering	33.1			
	Very Scattering	22.4			
	Depleted	15.4			

Further inspection of Moore's data reveals that the present productive areas in the James River are in the same approximate area as they were in 1910; however, the areas of productive and potentially productive bottoms may have increased since 1910. To show this, we compared the geometric area of the top four categories shown by Moore (Table 7) with our ***mud-shell, sand-shell*** and ***oyster reef*** categories in Areas II and III. These data showed a total area of 2,722 ha (6,727 acres) in 1910 and 4,534 ha (11,204 acres) in 1980, a gain of about 60%. While this cannot be considered conclusive because of the nature of the original data set, the positive direction is suggestive. We attribute the probable increase to the effect of culling unwanted shells and small oysters onto unproductive sand and mud bottoms from 1910 to 1981.

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ERRATA-Vol. 3, No. 2, Haven and Whitcomb, 117-128. 1983. Origin and Extent of Oyster Reefs in Va. Page 149, Para. 3, Line 8, about 0.6 m should read "about 0.18 m". Page 149, Para. 5, Line 9, about 0.18 m (0.6 ft) should read "about 0.3 m (1.0 ft)".

REFERENCES CITED

Andrews, J. D. 1968. Oyster mortality studies in Virginia. VII. Review of epizootiology and origin of *Minchinia nelsoni*. *Proc. Natl. Shellfish. Assoc.* 58:23–36.

______. 1982. The James River public seed oyster areas in Virginia. *Va. Inst. Mar. Sci., Spec. Rep., Appl. Mar. Sci. Ocean Eng.* No. 261:1–60.

______, D. S. Haven & D. B. Quayle. 1959. Fresh water kill of oysters (*Crassostrea virginica*) in the James River, Virginia, 1958. *Proc. Natl. Shellfish. Assoc.* 49:29–49.

Baylor, J. B. 1894. Method of defining and locating natural oyster beds, rocks, and shoals. *Oyster Records* (pamphlets, one for each Tidewater, VA, county, that listed the precise boundaries of the Baylor Survey). Board of Fisheries of Virginia.

Bouma, A. H. 1976. Subbottom characteristics of San Antonio Bay. Bouma, A. H., ed. *Shell Dredging and Its Influence in Gulf Coast Environments.* Houston, TX: Gulf Publishing Co.; 132–148.

Emery, K. O. &. E. Uchupi. 1972. *Western North Atlantic Ocean: Topography, Rocks Structure, Water, Life and Sediments.* Tulsa, OK: Am. Assoc. Pet. Geol. 532 p.

Graves, C. 1905. Investigation for the promotion of the oyster industry in North Carolina. *U.S. Comm. Fish. Rep.* 1903: 247–341.

Haas, L. W. 1977. The effect of the spring-neap tidal cycle on the vertical salinity structure of the James, York and Rappahannock Rivers, Virginia, U.S.A. *Estuarine Coastal Shelf Sci.* 5:485–496.

Haskin, H. H., A. Stauber & J. Makin. 1966. *Minchinia nelsoni* n. sp. (Haplosporida, Haplosporidiidae): causative agent of the Delaware Bay oyster epizootic. *Science* 153:1414–1416.

Haven, D. S., W. J. Hargis, Jr., J. G. Loesch & J. P. Whitcomb. 1976. The effect of Tropical Storm Agnes on oysters, hard clams, soft clams, and oyster drills in Virginia. Haven, D. S., W. J. Hargis, Jr., J. Loesch, and J. P. Whitcomb, eds. *The Effects of Tropical Storm Agnes on the Chesapeake Bay Estuarine Systems.* Baltimore, MD: John Hopkins Press. (CRC Publ. 54:488–407.)

Haven, D. S., J. P. Whitcomb, J. M. Zeigler & W. C. Hale. 1979. The use of sonic gear to chart locations of natural oyster bars in lower Chesapeake Bay. *Proc. Natl. Shellfish. Assoc.* 69:11–14.

Haven, D. S., J. P. Whitcomb & P. Kendall. 1981a. The present and potential productivity of the Baylor Grounds in Virginia. *Va. Inst. Mar. Sci., Spec. Rep. Appl. Mar. Sci. Ocean. Eng.* No. 243: 1–154.

Haven, D. S., W. J. Hargis, Jr. & P. Kendall. 1981b. The oyster industry of Virginia: Its status, problems and promise. 1981 (revised). *Va. Inst. Mar. Sci., Spec. Pap. Mar. Sci.* No. 4: 1024 p.

Hedgpeth, J. W. 1953. An introduction to the zoogeography of the northwestern Gulf of Mexico with reference to invertebrate fauna. *Publ. Inst. Mar. Sci. Univ. Tex.* 3(1):107–224.

Loesch, J. G., D. S. Haven & J. P. Whitcomb. 1975. An investigation of the seed oyster reserves in Virginia and testing and identifying gear to harvest oysters. Gloucester Point, VA: Va. Inst. Mar. Sci. Final Rep. Contract No. 3–193R, Natl. Mar. Fish. Serv.; 133 p.

Loosanoff, V. L. 1931. *Observation on Propagation of Oysters in the James and Corrotoman Rivers and the Seaside of Virginia.* Newport News, VA: Virginia Comm. Fish.; 46 p.

MacKenzie, C. L., Jr. 1983. To increase oyster production in northeastern United States. *U.S. Natl. Mar. Fish. Serv. Mar. Fish. Rev.* 45(3):1–23.

Marshall, N. 1954. Changes in the physiography of oyster bars in James River, Virginia. *Va. J. Sci.* 5(3):23–28.

Moore, H. F. 1911. Condition and extent of oyster beds in the James River. *U.S. Bur. Fish. Doc.* No. 729: 83 p.

Nichols, M. M. 1972a. Sediments in the James River, Va. Nelson, B. W., ed. *Environmental Framework of Coastal Plain Estuaries. Geol. Soc. Am. Mem.* 133:169–212.

______. 1972b. Effect of increasing depth on salinity in the James River estuary. Nelson, B. W., ed. *Environmental Framework of Coastal Plain Estuaries. Geol. Soc. Am. Mem.* 133: 571–589.

Norris, R. M. 1953. Buried oyster reefs in some Texas Bays. *J. Paleontol.* 27(4):569–576.

Price, W. A. 1954. Oyster reefs of the Gulf of Mexico. Galtsoff, P. S., coordinator, Gulf of Mexico, its origin, waters, and marine life. *U.S. Fish Wildl. Serv. Fish. Bull.* 89(55):491.

Pritchard, D. W. 1953. Distribution of oyster larvae in relation to hydrographic conditions. *Proc. Gulf Caribb. Fish. Inst.* 5:123–132.

Scott, A. J. 1968. Environmental factors controlling oyster shell deposits. Texas Coast. From Fourth Forum on Geology of Industrial Minerals. Austin, TX: Univ. of Texas; 1968:131–150.

Sokal, R. R. & F. J. Rohlf. 1981. *Biometry, the Principles and Practices of Statistics in Biological Research.* San Francisco, CA: W. H. Freeman and Co. 859 p.

Stroup, E. D. & R. J. Lynn. 1963. Atlas of salinity and temperature distributions in Chesapeake Bay 1952 – 1961 and seasonal averages 1949–1961. Baltimore, MD:Chesapeake Bay Inst., John Hopkins Univ. Graph. Sum. Rep. 2. (Ref. 63–1: 410 p.)

Virginia Commission of Fisheries. 1969. Annual Report to the Governor of Virginia. Richmond, VA: Virginia Dept. of Fisheries; 129 p.