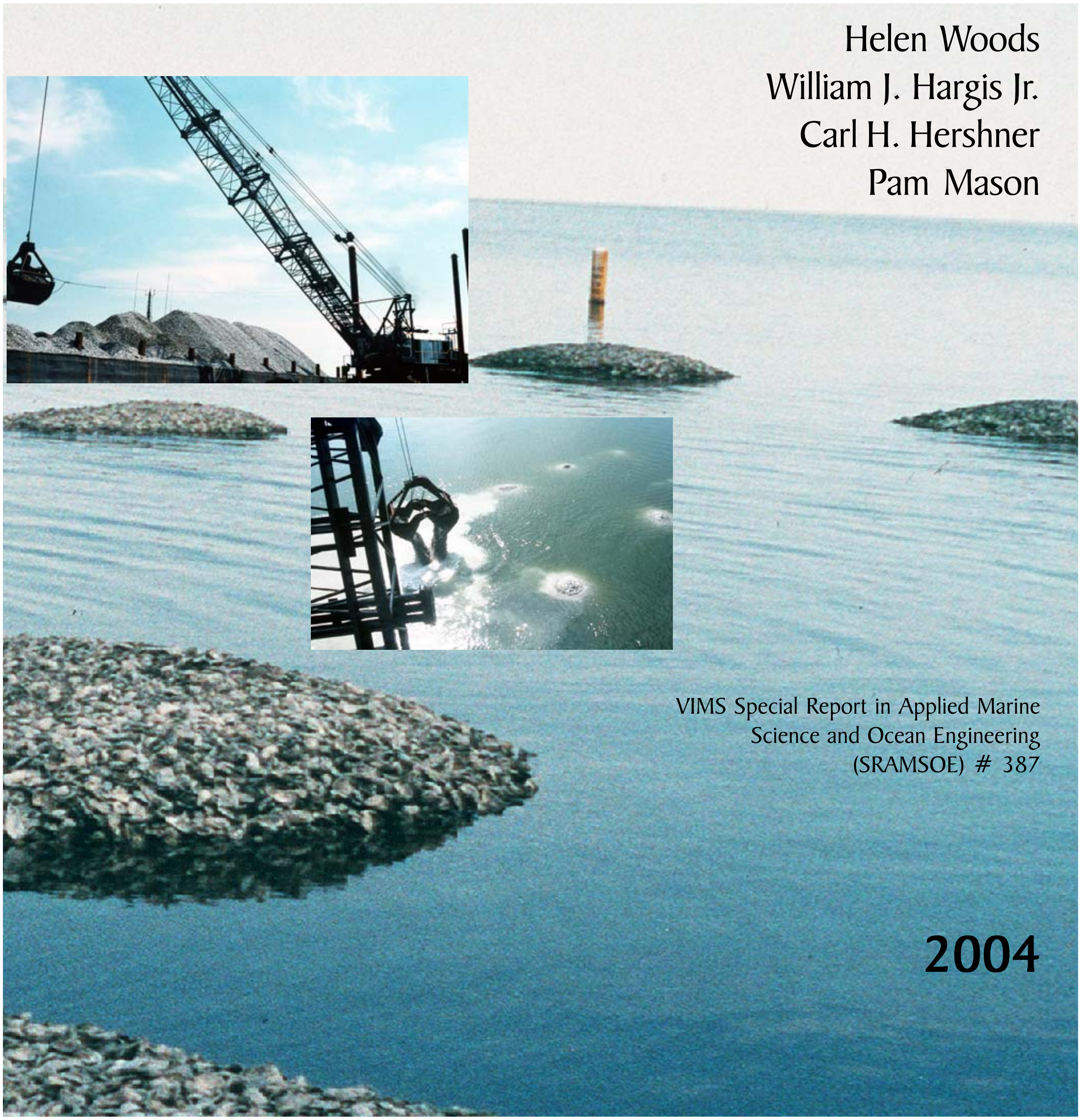
Improving Siting and Construction Criteria for Oyster Reef Restoration

Helen Woods
William J. Hargis Jr.
Carl H. Hershner
Pam Mason



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Center for Coastal Resources Management
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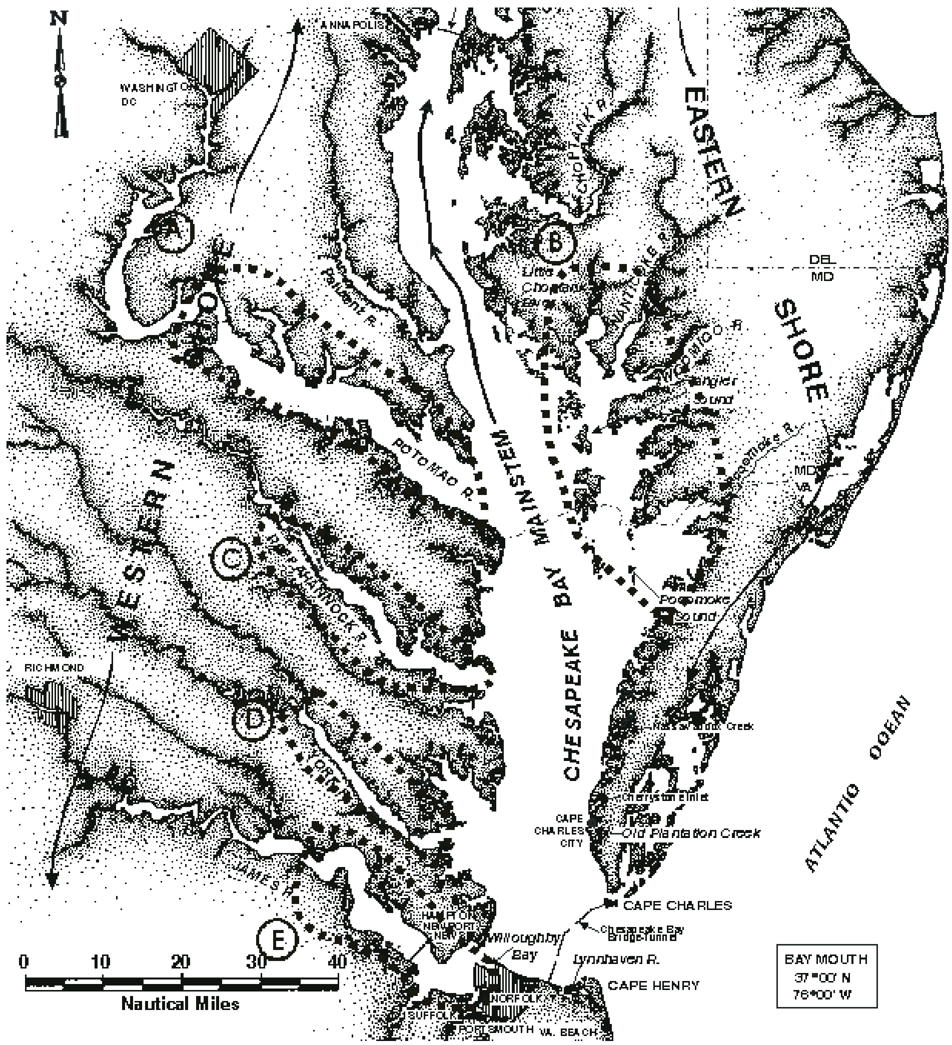

Figure 1. Study sites within the Chesapeake Bay. A. The Potomac River; B. Tangier and Pocomoke Sounds; C. The Rappahannock River; D. The York River; E. The James River

Cover photos by Jim Wesson

Introduction

The Chesapeake Bay, named Chesepiooc, the "great shellfish bay," by the Algonquin speaking native Americans of the region, was once one of the most productive oyster (*Crassostrea virginica)* producing estuaries in the world. With the advent of canning and the development of the railroad system, huge national and international markets were established for Chesapeake Bay oysters (United States Secretary of the Interior 1866,Wennerston 1981). From 1894 to 1912 annual oyster harvests in Virginia alone ranged from 5 to 7.5 million bushels (Hargis and Haven 1988). Shells from harvested oysters were not replaced on oyster grounds but sold for a variety of commercial purposes ranging from road projects to chicken feed. This tremendous, largely unregulated, harvest of oysters and shell, wreaked havoc on oysters and their habitat (Wennerston 1981, Rothschild et al 1994).

In recent years, considerable attention has been paid to the historical anecdotal reports of mariners who reported that Chesapeake Bay oysters once grew in large reef-like colonies. These stories suggest that Chesapeake Bay oyster reefs were once three dimensional structures which breached the surface of the water at low tide. It is believed that the three dimensional structure of these reefs favorably altered the environment for oysters by raising oysters off the bottom into the more favorable upper water column which increased oxygen, water temperature, and food availability for the oysters.

Based upon these reports and beliefs, three dimensional oyster reef habitat restoration efforts in Virginia began in 1993. Studies by the Virginia Institute of Marine Science indicated that the greatest oyster survival rates could be found on reefs created from oyster shell and thus reef restoration focused upon the deployment of large mounds of oyster shell. These shell mounds, or reconstructed reefs, were primarily situated upon areas surveyed in the 1970s (Haven and Whitcomb 1978 & 1983) which were classified as hard oyster bottom. These hard oyster bottom areas were considered to be "reef footprints." Reconstructed reef shape and orientation was based upon the shape and orientation of these "footprints" as well as knowledge of the local site, history of reefs in the area, and navigational and social issues that are unique to the local area. These siting procedures have changed little since 1993.

While the application of these concepts has continued in the field with the aim of increasing viable oyster habitat while decreasing the costs of restoration, research has also continued examining options and techniques for increasing oyster reef success. Much of this research has focused upon understanding the natural function of oyster reefs as they historically existed in hope of applying this knowledge to restoration efforts. This paper outlines some of the things which have been learned through these endeavors and ways which these lessons can be applied to continuing restoration efforts to increase restoration success.

Natural Oyster Reefs in the Chesapeake Bay

The Center for Coastal Resources Management at the Virginia Institute of Marine Science has recently digitized and analyzed the data from numerous historic hydrographic surveys from around the Chesapeake Bay. These surveys primarily date from the mid to late 1800's before extreme harvest pressure had decimated the Chesapeake oyster populations. Areas studied included the Potomac River, the Rappahannock River, the York River, the James River, and Pocomoke and Tangier Sounds area (Figure 1). Oyster bottom survey data indicating areas of high oyster concentration were overlaid upon these data. Oyster bottom data varied in age but it was assumed that areas of dense oyster from later surveys would approximate areas of dense oyster during the survey time as well. The end result of this work was a series of three dimensional digital images which clearly showed the contours of the bottom as they related to dense oyster areas.

The results of this work varied between sites and can be roughly divided by latitude into northern and southern style reef formations. Historic literature on the subject suggests that the Chesapeake Bay was the northern latitudinal extent for southern style oysters reefs and the overall dividing line between the dominance of these two styles of reef formation. It is interesting to note that the 1860 United States Census divided the Eastern Oyster into two species, the Virginia Oyster and the New York Oyster, with the Chesapeake Bay as the primary dividing line (Secretary of the Interior 1866). While speculation, it is possible that the two different styles of reef formation contributed to experts dividing the Eastern Oyster into two species at that time.

The northern study areas Tangier/Pocomoke Sounds, the Potomac River, Rappahannock River, and York River predominantly demonstrated northern style reef development. These northern style oyster reefs appeared along channel edge terraces at the beginning of the shoals. What little relief was present in these reefs ran parallel to and bordered the edge of the channel (Figure 2). No significant biogenic relief was detectable in many of these reefs. Up-thrusting features of bottom, such as points extending from land and the ridges between paleo-channels were, however, covered with dense oyster aggregations (Figure 3). The literature suggests that oyster reefs in estuaries north of the Chesapeake Bay demonstrate this same type of reef formation.

The southern study area, the James River, predominantly demonstrated southern-style reef formations. While some mostly flat, northern-style, channel edge reefs were present, large upthrusting oyster reefs dominated the system. Many of these upthrusting reefs actually breached the surface of the water at low tide and the largest of these reefs extended some 3 km in length (Figure 4). Upthrusting reefs were located along the shoals near the channel edge and were oriented perpendicular to the main flow of the current. Many of these reefs extended from the channel edge towards, but not touching, the shoreline (Figure 5).

Although a few upthrusting reefs were also present in the Potomac and York Rivers, these reefs were few and the systems were dominated by northern style reef development. It is interesting to note that in all three of these systems upthrusting reef formations were limited to the upper, lower salinity portions of the oyster producing reaches and the shallower areas (2 meters or less).

Understanding Natural Oyster Reefs

The Biological Needs of Oysters

Oysters require relatively few things to survive. These include oxygen-rich water of the proper salinity and suitable phytoplankton as a food source.

However, the requirements for an oyster population to survive are somewhat greater. This is because a population needs to be self-sustaining through reproductive success which outpaces mortality. To be so, an oyster population also requires suitable proximity of male and female gametes and hard clean substrate upon which to set.

A number of other factors can be outlined which will increase the success of an oyster population. These factors include:

- Increased abundance of male and female gametes
- Increased abundance of clean hard substrate for spat set
- Increased abundance of phytoplankton
- Extended warm water growing and breeding season
- Decreased sediment concentrations in water to increase feeding efficiency and fouling substrate rate

By adjusting these factors accordingly, an oyster population will not only survive but flourish.

Northern-Style Reefs

- Present along the entire coast although dominant from the Chesapeake Bay north
- Terrace tops, channel edges, geologic relief
- Follow bottom contours
- Large patches, often parallel to channel
- Deeper water
- Little relief
- Relief centered along and parallel to channel edge

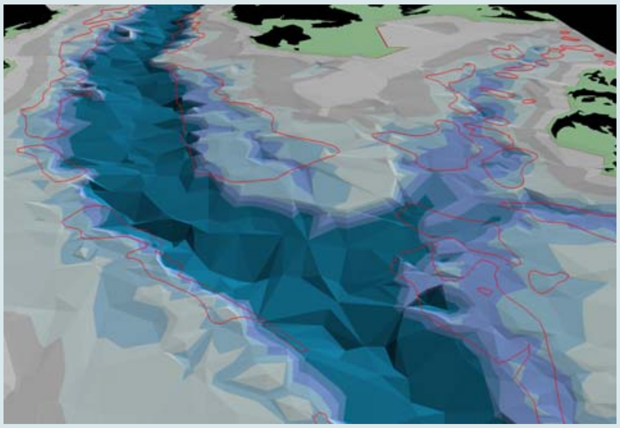

Figure 2. Tangier Sound.. Oysters, outlined in red, clustered along the edges of the channel. What little relief exists runs parallel to the channel.*

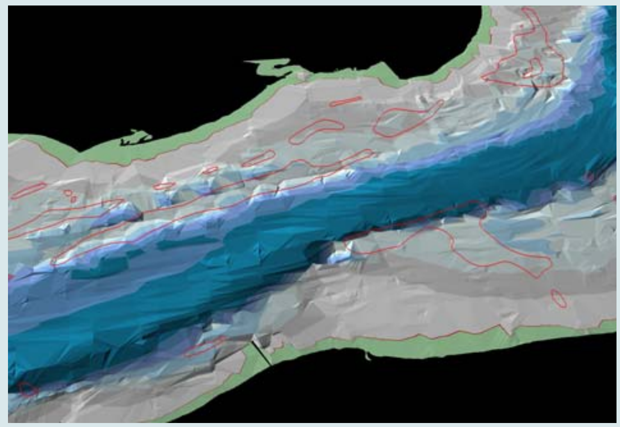

Figure 3. The Rappahannock River, Virginia. Oysters, outlined in red, are clustered along the edges of channels and in areas of geologic relief.*

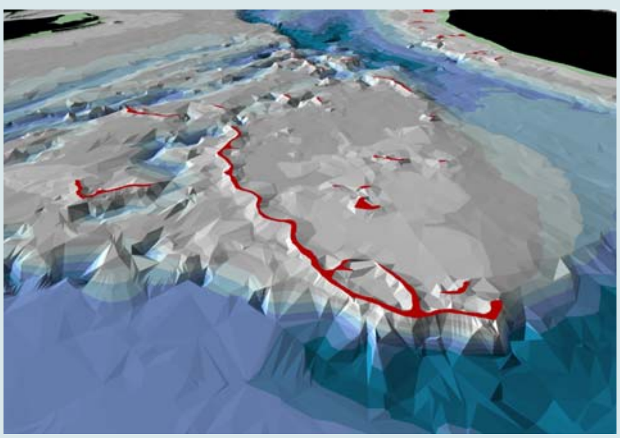

Figure 4. Point of Shoals reef system in the James River. Long Shoal reef extended above water for nearly 3km. Red indicates emergent features.*

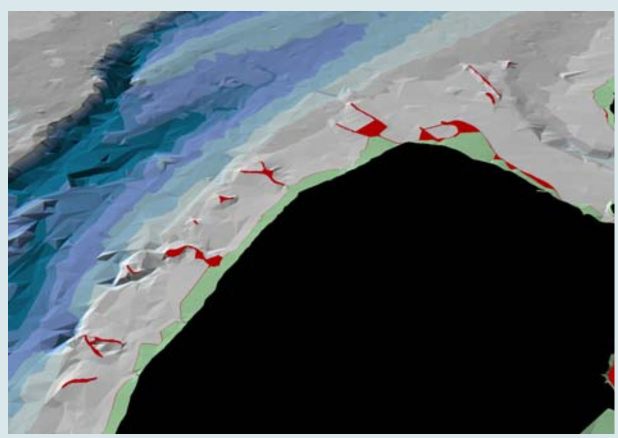

Figure 5. Evenly spaced southern-style reefs of Burwell's Bay, James River, Virginia. Red indicates emergent features.*

Legend: Depths

- Intertidal
- Mean Low Water
- 0m - 1.5m
- 1.5m - 3m
- 3m - 4.5m
- 4.5m - 6m
- 6m - 7.5m
- 7.5m - 9m
- 9m and Below

Southern-Style Reefs

- Present only from the Chesapeake Bay southward
- A lot of relief, often emergent, although many more shoal-like than concept models
- Biogenic lumps and groin-like ridges perpendicular to current
- Often extend from near-shore to channel edge
- Shallow water

** All images vertically exaggerated by a factor of ten.*

The Success of the Natural Reef System

By placing the results of our work into the context of research on the subject of oysters and oyster reefs we can see that the natural Chesapeake oyster reef systems developed in locations and forms which capitalized on many of the factors listed above and therefore maximized the success of the reefs. By understanding the evolution of these systems, we might better understand the factors leading to the success of oyster reef communities and hence better formulate and direct restoration efforts.

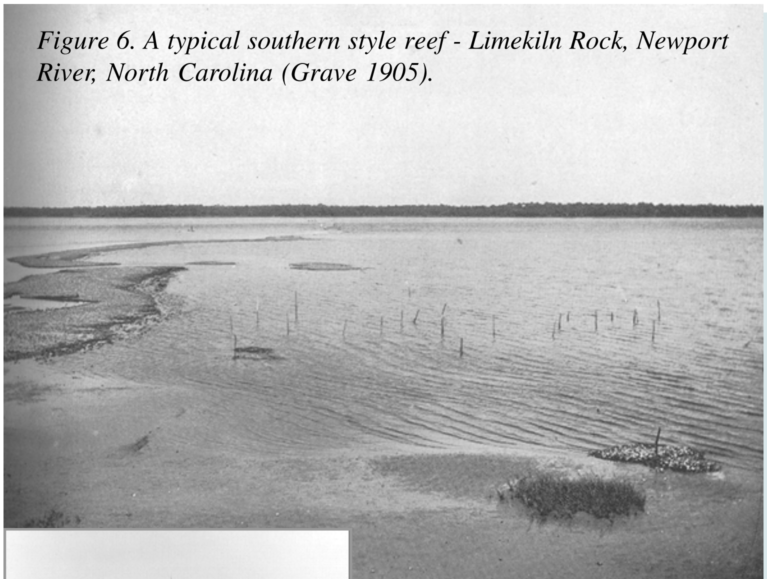

Figure 6. A typical southern style reef - Limekiln Rock, Newport River, North Carolina (Grave 1905).

Figure 7. A typical southern-style reef, Long Shoal Reef, 1885, James River, Virginia. (Photo courtesy of The Mariners' Museum of Virginia)

Southern-Style Reefs

A review of historic literature of southern estuaries indicates that large, upthrusting, and emergent oyster reefs, like those in the James River, were once quite prevalent in the shallow waters of many southern estuaries. These reefs were long, relatively narrow and were situated in the shallow shoal areas running perpendicular to the flow of current. (Figure 6; Figure 7) Writings by late 19th and early 20th century scientists, often referring to this sort of reef formation as a "long reef" or "string reef," suggest that the controlling factor in the development and success of these reefs was water flow (Grave 1905, Moore 1907).

One of the most informative reports on this subject was written by Caswell Grave, Ph.D., in his 1903 report to the United States Fish Commission on the condition of the oyster industry of North Carolina. Grave describes these reefs as a, "long narrow ridge of mud and shells, the tops usually covered with a dense growth of badly shaped oysters known as 'coons'" (Figure 8). The elongated and thin-shelled coon oysters resulted from the massive overcrowding of oysters. In these aggregations, oysters are forced to grow rapidly upward, competing for food and space with neighboring oysters. Sediment settling on the reef, falls between the oysters leaving the tops of the oysters clean. Young oysters often set on the tips of these living oysters with the original oysters being smothered by successive generations. Grave notes that, "...although not favorable to the growth of adult oysters, the conditions on the reefs are most favorable for the attachment of spat." (Grave 1905) This is important to note in the context of reef restoration as it shows that optimizing conditions for individual oysters is not nearly as critical as is optimizing

Figure 8. Coon oysters. Extreme crowding and competition for space caused this typical malformation of shape (Grave 1905).

conditions for the reproductive success of the community.

The conditions for the attachment of spat are improved through a remarkable feat of natural selection which dictates the reef location and shape. Grave notes that reefs such as these begin as clusters of oysters attached to a shoreline. The oysters protrude into the water where the current runs more swiftly. The swifter currents remove sediment and fouling from the tips of the oysters providing a clean surface on which other oysters can set. The swift currents also bring more food for the young oysters to consume, allowing for healthier animals. As this cycle is repeated, the water currents are forced around and over the oysters. The Bernoulli Effect causes the currents to increase in velocity, thus creating an even more favorable environment for the oysters at the tip and on the top of the young reef. The result is the reef growing in length and height and, "The long axes of the reefs are usually at right angles to the shoreline..." Grave explains that the shape, position and orientation of the reef, "shows that their position depends upon the direction not of the shoreline but of the currents which flowed past them during their growth, the formations always making right angles with the direction of flow." (Grave 1905)

While the growth of the long reef increases water velocity along the reef tip and crest, it stifles water flow along the shoreline and downstream of the reef. As a consequence of this suppressed water flow, the reef begins to die landward and become detached from the shoreline. Smaller reefs and outcroppings of oysters which may have begun to grow down stream, are stifled and begin to die as well. Not until water velocity has increased again downstream can another reef begin to grow. (Grave 1905) This explains the even spacing of reefs in the James and other southern estuaries. Eventually the reef reaches the channel where the water flowing around the reef causes a new channel to be cut further out. The flow direction is no longer 90 degrees to the reef and the reef begins to branch at its end.

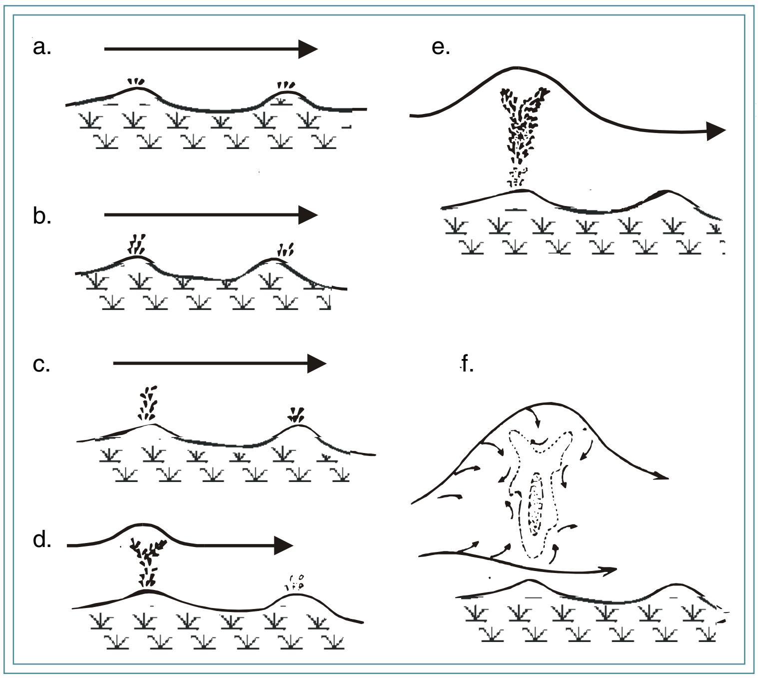

Figure 9. The evolution of a southern-style long reef from clusters along a marsh to a detached reef-like formation as hypothesized by Grave (1905). Figure reproduced from Kennedy and Sanford, 1999.

The reef also reaches a maximum height. At a critical point, oysters on the top center ridge of the reef are exposed between tidal cycles to such a point that they cannot feed long enough to survive. The top-most oysters die and sand, shell, and other debris collect on these dead "islands" or "hogbacks" on top of the living reefs (Grave 1905, Hedgpeth 1953) (Figure 9).

H. F. Moore, in his 1907 Survey of Oyster Bottoms in Matagorda Bay, Texas, expresses the same theory as Grave to explain the long reefs he surveyed there. Moore, however, also describes smaller scale reef morphology and the condition of the oysters on these reefs. "The margin of the bed facing up the bay is comparatively close to this crest, abrupt in its rise from the bottom and continuous in its contour, while the opposite margin is farther removed from the crest, merging more gradually with the adjacent bare bottom and broken up into long projecting ridges or spurs separated by narrow, muddy indentations and sloughs." Observing the condition of the oysters themselves on the reef Moore notes, "In all of these reefs, also, the upper side is the only one resorted to by the oystermen, as there only are large oysters of quality to be found in quantities sufficient to make remunerative tonging. On the lower sides of the reefs not only is the density of all sizes of oysters less, but among those that are found there is a preponderance of small ones, and all are inferior in fatness to those just across the crest." Moore attributes these observations to the superior conditions for spat set and supply of food on the up-bay margins of the reef caused by the greater velocity of water over the reef in this area, "...it is a general condition of oyster growth that, other things being equal, the set of spat, the rate of growth, and the production of fat are greatest in those parts of reefs where the water flows with greatest velocity." Moore continues, "...the flowing surface water is exerting a scouring action on the top of the reef northeast [upstream side] of the crest. The preponderance of oyster growth is therefore at the top of the reef and toward the upper margin of that side, with the result that the margin in question tends to maintain a uniform outline and an abrupt face. The crest itself lies closer to the northeast margin, because it, too, tends to grow in that direction from the same causes - the superior scouring action and food carrying capacity of the currents on that side of the reef" (Moore 1907).

Conversely, Moore correlates areas of low oyster abundance and areas with poor oyster quality to low water flow and associated sediment deposition. He notes that on the up-bay side of the reef, the water stagnates at the foot of the reef, which prevents the reef foot from growing outward on that side. Similarly, on the down-bay side of the reef, the water slows and silt is deposited along the entire back side of the reef, with highest quantity of silt being deposited between the ridges. This in part accounts for the general poor performance of oysters on the back of the reef, and , "that the original oyster clumps ... eventually develop into tongue like ridges at right angles to the general tend of the reef, with muddy silted sloughs between them." Moore also notes that this small scale morphology, while present in all of the reefs, is most prevalent in the largest and uppermost reef (Moore 1907).

Recently, Hunter Lenihan published the findings of his own 1999 North Carolina study where he explored these factors in detail. Lenihan created a series of experimental reefs of different heights where he tested the recruitment, growth, and survival of oysters on different parts of these reefs, with relation to water flow. His work validated the earlier observations by Grave and Moore and found that a staggering 81% of variability in oyster growth and mortality could be linked to variations in water flow. After 10 months the shell growth and condition index were greatest on the crests of tall and short reefs, where flow speed and quality of suspended food material were highest and sediment deposition was lowest. Additionally, the two lowest reef forms in his experiment were nearly completely buried by mud after 16 months (Lenihan 1999).

While not depicted on bathymetric surveys, oyster "ledges" or "fringing reefs" which covered the intertidal portions of the shoreline were also quite common in southern estuaries (Bahr and Lanier 1981, Oemler 1894). Such reefs would form on the concave outer banks of meander loops, in areas immediately adjacent to smaller tidal tributaries and at points of tidal stream confluence (Bahr and Lanier 1981). In other words, like long reefs, these oyster ledge reefs also formed in areas of increased water flow.

Northern-Style Reefs

The northern-style reefs occurred and still occur throughout the range of the eastern oyster. However, in the absence of southern-style reefs, they dominated estuarine systems from the middle Chesapeake Bay northward. These reefs, which are actually rather flat and bed-like, tend to be located along the bottom of rivers in areas of abrupt change in relief, often oriented parallel to the current (Figure 10). Gary Smith and his colleagues in Maryland used subbottom profiling to examine many of these oyster reefs in detail. In their 2003 paper, they found that northern-style reefs almost always grow in areas with a sudden change of bottom relief such as the edge of a channel, a terrace, lump, or an eroded island. Reefs which appeared to be isolated in expanses of flat bottom were actually channel edge reefs at a late state of development where the

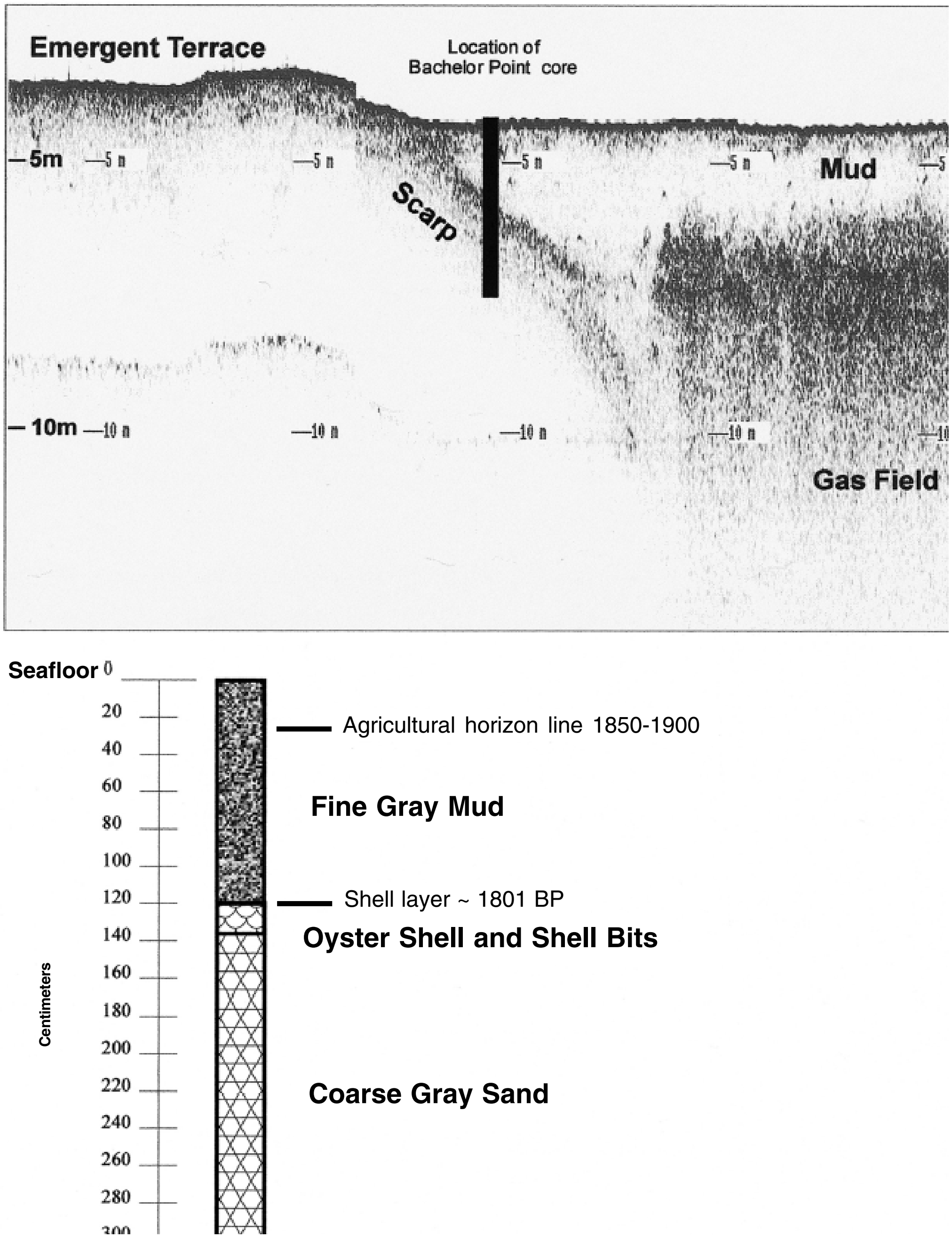

Figure 10. Core stratigraphy indicates that the strong acoustic reflector on the scarp was a thin layer of oyster shells forming a northern-style reef. This reef originally developed along the edge of a channel which has since filled in. An area of biogenic relief running parallel to the original channel is still present along the edge of the terrace (Smith et al., 2003).

original channel filled in, becoming flush with the top of the adjacent oyster bed (Figure 11). They also found many reefs which had been completely buried by the continual deposition of sediment after the channel had been completely filled. In such instances, new channels formed elsewhere and new oyster beds formed along the edges of the new channels. They concluded that northern-style of oyster beds were therefore ephemeral and transitory on a geologic time scale (Smith et al. 2003).

muddy bottom sediments are lethal to young oysters. "The first thing found out was that the floating spawn would not attach itself to or 'set' upon anything which had not a clean surface..." Ingersol also noted, "It was evident that the swifter the current the less ... chance of rapid fouling. Planters, therefore, chose their ground in the swiftest tideways they could find." (Brooks 1891)

It is also important to note that the location of the northern-style oyster reefs along the edges of the

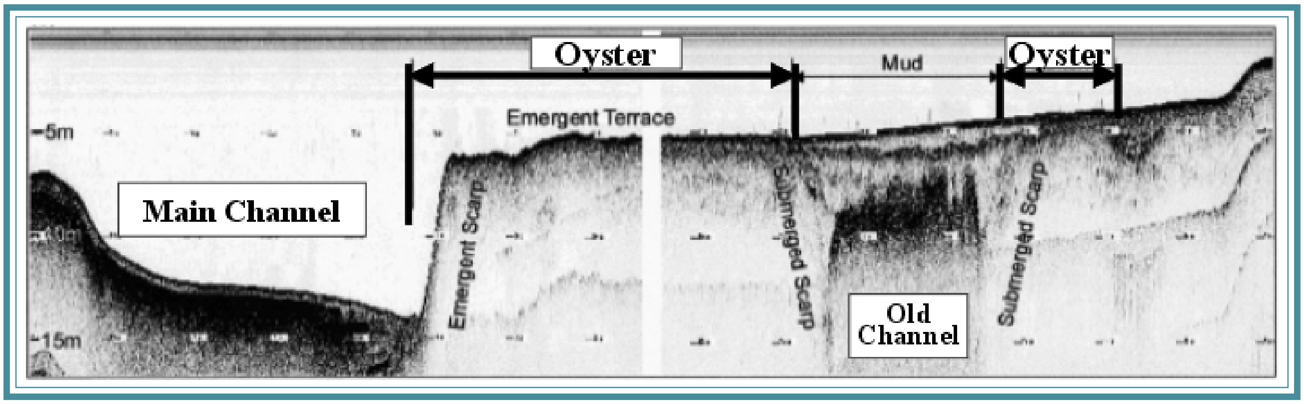

Figure 11. Further evidence that northern-style oyster reefs almost always form along the edges of channels, scarps, and emergent terraces which protrude into the current flow. Sub bottom profiling suggests that the oyster reef to the right which appears isolated in the center of a broad shoal, actually originated along the edges of a now buried channel. Dark areas indicate gases trapped in soft sediments of depositional and buried channels (Smith et al., 2003).

Gary Smith's work also indicates that scouring currents are at work along the scarps which maintain sediment free oysters and likely bring increased food to the oyster bed. (Smith et al. 2003) The importance of strong currents for northern-style oyster bed formation was noted as early as 1891 by Dr. William Keith Brooks of the John's Hopkins Laboratory in Maryland. In his book, The Oyster, which concentrated upon northern-style oyster reefs and aquaculture techniques, he noted that in many places around the Bay, oysters grew in dense patches while other areas were completely devoid of oysters. To help explain this observation, Brooks quotes Ingersol's account of the origin of American oyster farming. Ingersol reports that oyster farming using natural spawn was simple to establish once farmers realized that the water was not spat limited but substrate limited due to the rapid rate at which slimy film develops on submerged objects. This slimy "half-sedimentary, half-vegetable" film, as well as the

channel and tops of upthrusting areas of bottom is not just a remnant artifact of conditions present at lower stands of water. The existence of these reefs is directly attributable to conditions present at the current time. This is documented in the work of Eric Powell and his colleagues in Galveston Bay. Powell documents over 1000 acres of dramatic new oyster reef growth along the Houston Ship channel - a recent man made feature in this bay (Figure 12). Powell also attributes the reef formation to changes in salinity and the increase water velocity caused by the dredging of the channel. The result was the rapid development of northern-style oyster reefs covering the spoil banks paralleling the edges of the channel. Powell notes that the reefs were most dominant along the channel side and crest of the spoil banks. Few oysters exist on the outer sides of the spoil banks (Powell 1995).

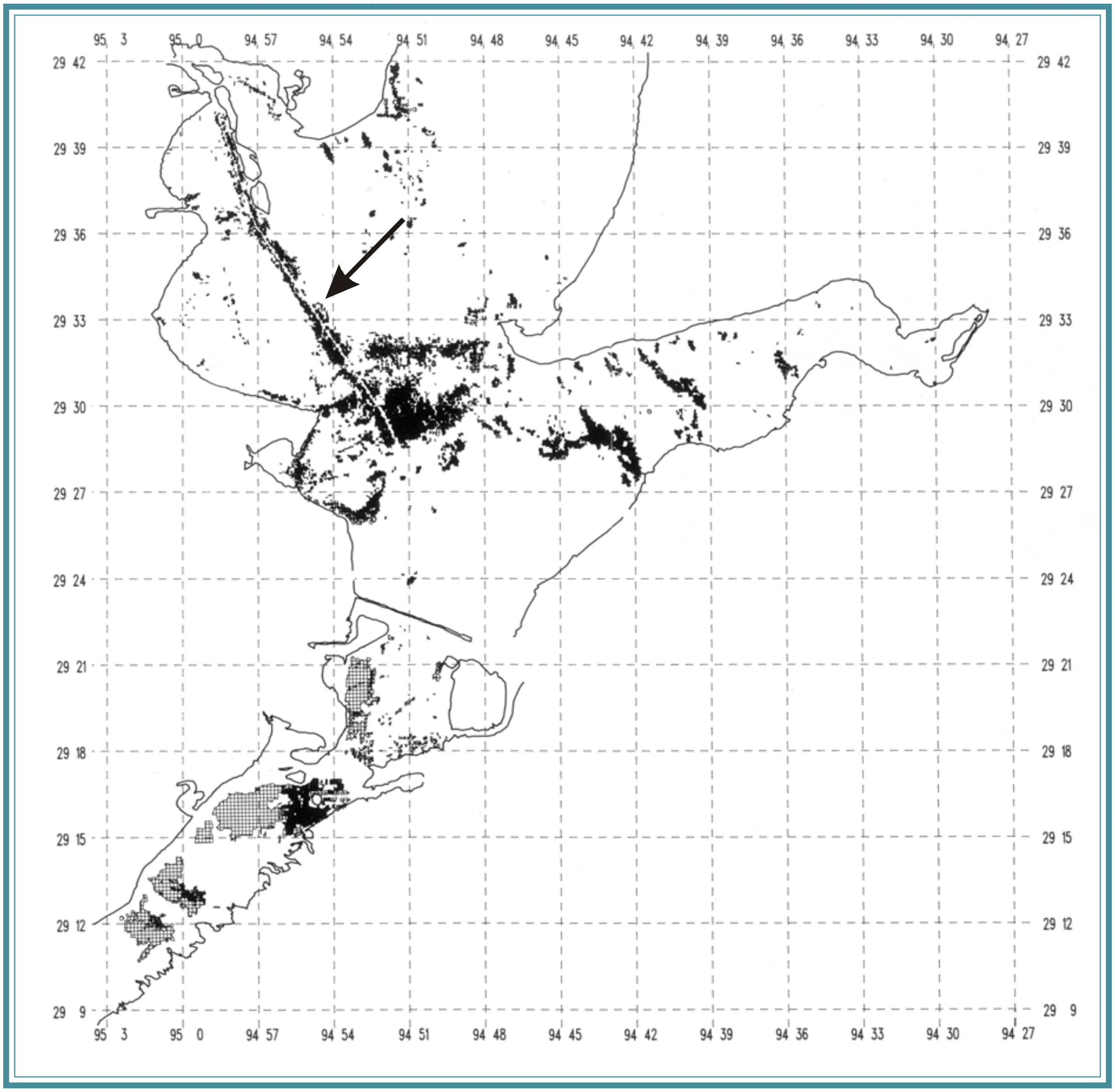

Figure 12. The oyster reefs of Galveston Bay proper (Powell 1995). Areas in black indicate dense oyster. Within a few years of the creation of the northeastern shipping channel, oysters had colonized the edges of the new channel (arrow). This suggests that northern-style reef formation and placement along channel edges is not a remnant artifact of earlier low stands of water, but is caused by conditions now present along channel edges.

Implications of and Recommendations for Increasing Restoration Success

It is certain that a variety of factors such as water temperature, salinity, bottom hardness, food availability, spat availability, etc, interact to dictate the success or failure of an oyster reef. However, a review of modern and historic literature for both northern and southern style oyster reefs indicates that the major controlling factor dictating oyster reef success is water flow. Both northern and southern style oyster reefs and their variations form in areas with a strong scouring current. The exact reason for this is unclear but food supply, substrate cleaning, and spat delivery are all likely enhanced in these areas of high water flow. It should also be noted, that in the southern style long reef, arguably one of the most productive reef forms, the reef development actually controls and enhances the flow of water over the reef thus improving the quality of its own habitat.

These observations have implications for restoration projects. This work strongly suggests that siting of future reef restoration projects should center around selecting sites with high current flow. Additional work will be needed to determine the exact parameters of optimal water flow for an oyster reef community (as opposed to single oysters); however, a starting point might be suggested by selecting sites with the highest possible current flow which still afford low flow during slack tides to allow for spat set. In many cases these areas may occur along channel edges and atop submerged terraces. Historic and modern observations suggest that restoration success may be further enhanced by carefully designing reef shape and orientation with the objective of maximizing current flow over and around the reef.

An oyster reef restoration project in Long Creek, Lynnhaven River, Virginia. Photo courtesy of Erik Moleen, First Landing State Park.

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Yancey Powell and Tommy Leggett of the Chesapeake Bay Foundation add brood stock to a restored oyster reef. Photo courtesy of Chesapeake Bay Foundation.

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