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Oyster Reef Habitat Restoration:
A Synopsis and Synthesis of Approaches

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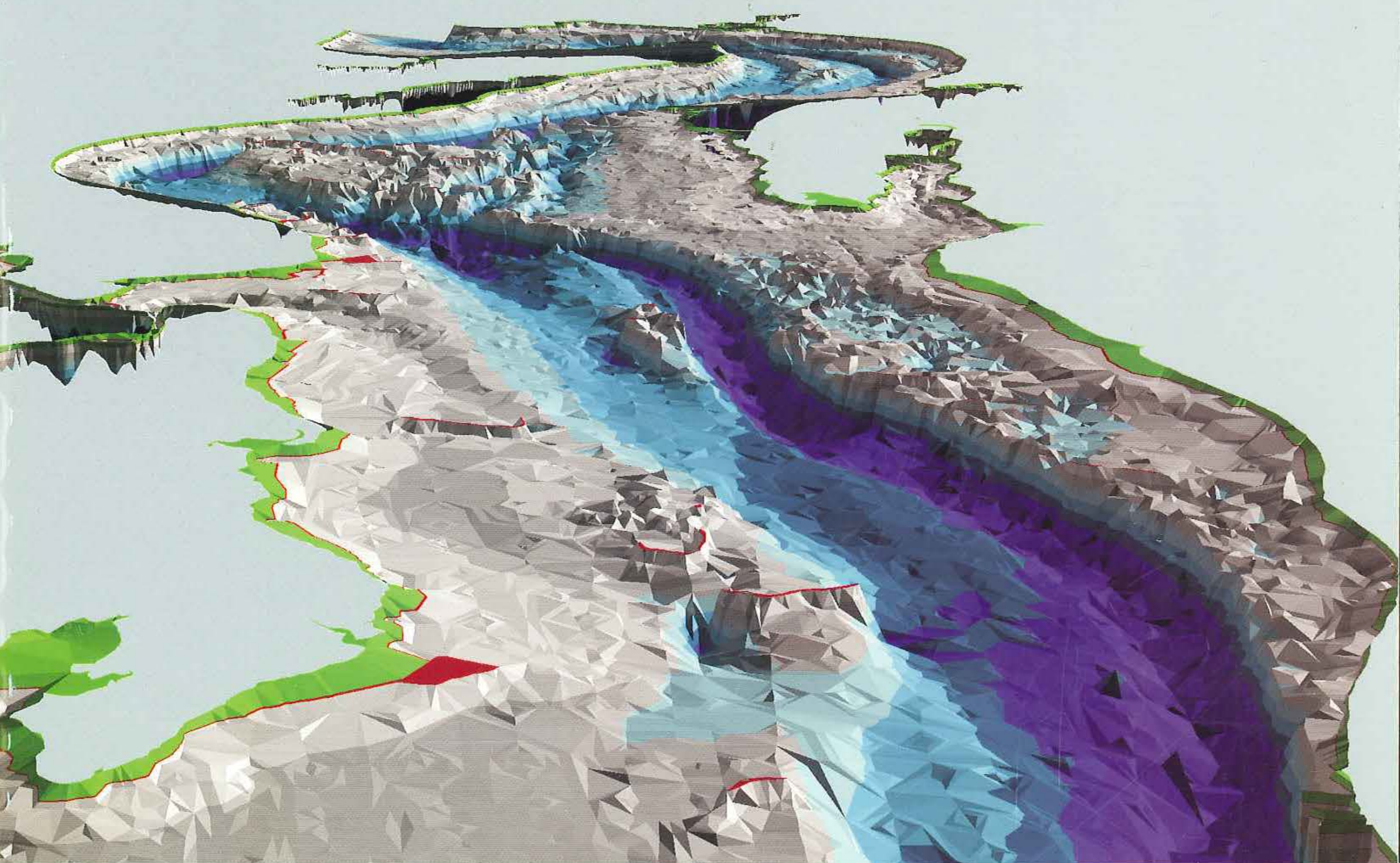

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Chapter 23

Chesapeake Oyster Reefs, Their Importance, Destruction and Guidelines for Restoring Them

by

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Abstract

The eastern oyster, *Crassostrea virginica* (Gmelin), can live any place in coastal marine and estuarine waters of the North American east coast offering suitable setting and survival opportunities. It occurs singly or in small clumps scattered widely but thrives best in colonial aggregations which, like those of tropical corals, are truly reefs. The massive self-renewing oyster reefs ("whole banks and beds") reported by early Chesapeake observers have yielded much. Without readily accessible oyster reefs the first English colonists of Jamestown might have starved. Without them the rich oyster industries of later years could never have developed. But oyster reefs benefitted the oysters that built and maintained them as well as the humans using them.

The oyster reefs of the Chesapeake region, including those on Seaside, developed during some 7,000-6,000 years of Bay evolution during the current (Holocene) Epoch. Until about 200 years ago reef oyster populations were able to maintain themselves and their reef habitats and withstand the inroads of biological enemies, other natural hazards and increasing harvests. By the late 1800s, Chesapeake public market oyster harvests had peaked and total market harvests and the oyster populations which provided them were in decline.

Continued overharvesting had done more than reduce harvestable populations. It had reduced broodstock fecundity and the genetic qualities of the various Chesapeake subpopulations as well. Further, it had diminished natural shell replacement due to excessive removal of shell-producing oysters and their shells, causing reef destruction. Additionally, removal of shells for landfill, road building, construction, chemical production, soil conditioning and poultry grit hastened that destruction. The synergistic cycle of population reduction and habitat destruction accelerated. Today many formerly-productive reefs are mere remnants (or totally obliterated—even eliminated) and Chesapeake *public* (aided or unaided) market oyster production is far less than one percent of its maximum.

If the trend of decline of self-sustaining natural oyster production is to be reversed, public oyster reefs must be restored. Proven guidelines exist. Such factors as location, geometry and materials have been naturally tested over time. The features which developed during the millennia of successful natural oyster reef evolutionary trial-and-error should be employed in well-planned reef-restoration activities. Where improvement is possible it should be done.

An effective reef restoration program will benefit not only the oyster resource, the public owners, the industry and consumers but the Bay's ecology and finfishermen as well. Active oyster reefs harbor many

epifaunal and infaunal organisms, increasing overall estuarine productivity and diversity. Further, they attract finfishes and other browsers and predators. Sportfishing charts identify many formerly-productive oyster reefs as fishing spots. This is no accident! More importantly, better utilization of H. L. Mencken's immense "protein factory" and restoration of such filtering and cleansing capabilities of reef oyster populations and their associates as may occur will benefit all Chesapeake citizens and others region- and nation-wide.

Introduction

Review of numerous reports on details of oyster production by earlier students of oyster ecology and the oyster industry of the Chesapeake Region, and elsewhere (i.e. Winslow 1881, 1882 and 1884; Baylor 1894, Stevenson 1894, Moore 1910, Loosanoff 1932, Marshall 1954), and the recent studies and conclusions of DeAlteris (1988), Hargis and Haven (1988a and b), Hargis and Haven (1995), Newell (1988) and Rothschild et al. (1994), has resulted in our recent realization of the great importance of viable reefs to the past and future natural production of oysters. These and other studies show that brood-stock reduction and impairment of genetic quality by over a century of adverse selection and destruction of the preferred natural habitat of *C. virginica*, the reefs, have been the primary, long-term factors in the tremendous decline in the natural, self-renewing production and harvest of market and seed oysters in the Chesapeake system.

As a consequence, Hargis and Haven (unpublished reports) have urged in several public forums since early 1991 the rebuilding, or replacement, of oyster reefs as a measure in restoring the population levels and viability of *C. virginica* and the industry dependent thereon on the public or natural oyster grounds. We again recommend this restorative action. Doing so, whether by passive (simple recuperative closure) or active (actual replenishment by shells and/or seed, plus significant recuperative closure) restoration or by new construction (also aided by closure), will require careful planning, site selection and design. Below we develop and support these conclusions and offer some guidelines for restoration.

Brief History of Oyster Reefs in the Chesapeake

When English settlers reached the Chesapeake in 1607 they found hundreds of massive, medium-sized and small upthrusting (most common in the Bay, itself) and fringing (most common in the lagoons and embayments of the Eastern Shore) oyster reefs. The heights or crests of many ebbed dry, or nearly so, at low water (Wharton 1957). Harvesting oysters required little effort. One had only to wade, pole, paddle, row or sail to the nearest exposed reef and hand-pick, rake or shovel a sack full, canoe full or boatload.

As time passed and demand and harvests increased, reef elevation and extent diminished and rake and tong handles (tongs are really opposed rakes, operating in scissor-like fashion) had to be lengthened. The harvesting efficiencies, effective depth range and, incidentally, destructive capabilities of tongs were increased with the introduction of mechanically—and later hydraulically, operated patent tongs (Haven et al. 1978).

Dredges (or their lesser relatives, scrapes), which enabled the taking of more oysters more efficiently than with rakes or tongs—and from deeper-lying populations, were brought into service. Reef elevation declined ever more rapidly as live oysters (with their shells) and associated empty shells were removed by tongs and dredges. Then, dredge and patent tong cables and hand tong handles were elongated even further. Removal of living oysters and shells increased and the cycle intensified.

Oyster reefs declined still further in height, base dimensions, volume and surface area. Though the base extent of each was undoubtedly increased for a time as the uppermost or outermost shells and surviving oysters were dragged onto the surrounding bottom by dredges or knocked over onto or deposited there by tongers (as indicated by Winslow 1891, Stevenson 1894, Moore 1910), it, too, eventually shrank as further harvesting and shell removal, over-sedimentation and sinking occurred and that temporary harvest-related advantage was lost. The process continued throughout each harvest year, decade after decade over two centuries or so.

In early times there were no closed seasons and sailing dredge boats remained over the reefs until their holds and decks were filled. Often buy-boats or "runners" emptied the dredge boats while the latter were still over the oyster beds enabling uninterrupted dredging and reduction of populations, and reefs, proceeded relentlessly. Continuous harvesting by tongs (ordinary and patent) did the same, only more slowly (per tong or per tong boat).

Besides taking living oysters for food markets, harvesters have removed shells from the reefs for direct use or transformation into shell by-products. In Colonial times crushed shells were employed in mortar, which often included recognizable shell fragments. Many shells were used to "sweeten" the soil and build walkways. Later huge numbers of whole shells, some with meats still in them, were employed in landfills and in the building of roads, alleys and walkways. For example, much of the city of Crisfield, Maryland was built on shell-filled wetlands and many, probably most, cities, towns and counties of tidewater Maryland and Virginia had oyster shell road beds, roadways and alleys. Shells were also used as ballast for railroad track construction. The total used for these purposes is unknown—probably unknowable.

We are somewhat better informed about the quantities used as ground- or burnt-lime or ground into poultry grit in recent times. Large-scale demand for these shell by-products had developed in the 1800s. By the early 1900's factories producing them had sprung up all around the coasts of the United States. In 1921 the U.S. Bureau of Fisheries reported 54 shell-processing plants nationwide. Of them the majority (29 or 53.7%) were in the Chesapeake Bay region; 18 in Maryland and 11 in Virginia (U.S. Department of Commerce Report for 1922). The Department of Commerce began reporting details of production of oyster shell byproducts in the United States in 1920. It, or the Department of Interior continued to do so until around 1945. Though production of shell byproducts had begun long before 1920 and continued after 1945, reporting of annual production *state-by-state* began in 1920 and continued, with at least one interruption, until 1943. Despite certain variations in the details they contained one can derive useful information from these reports. Briefly, from 1920 to 1944 the two Chesapeake Bay states are reported to have produced over 2,770,000 *tons* of shell byproducts. Of them at least 1,555,000 tons were in the form of poultry grit, with at least 1,215,000 tons as ground and/or burnt lime (Reports of the U.S. Department of Commerce for 1921 through 1939: Reports of the U.S. Department of Interior for 1939 through 1945). We have no ready conversion factors to allow determination of the *number of bushels* of whole shell required in preparing the tonnage of each type of by-product. Obviously, it was great—greater for the fine-grained lime products than for the much coarser grit.

Even after the flattening of reefs occurred, either through removals of live oysters for use as seed, "soup" or market oysters or through incidental and purposeful shell removal, the remaining shells have not escaped use. Large-scale mining activities employing heavy dredging equipment have taken shells from recent reef foundations as well as from remaining older sub-bottom reef deposits since World War II. For example, ancient and recent reef strata were mined by a commercial shell-dredging company (Radcliffe Materials, Inc.) in the lower James River estuary downriver of the current seed beds in the 1960's with the Virginia Marine Resource Commission (VMRC) receiving 1/3 of the harvest as the public's share of the shell (Haven et al. 1978, DeAlteris 1988). During 6 years (1963 through 1968) this activity produced a total of about 39 million bu of so-called "extinct" or "ancient reef" oyster shells. This large-scale commercial mining of shells in Virginia was halted by VMRC, with the urging and concurrence of the Virginia Institute of Marine Science (VIMS), when the mining company requested use of more accessible and more recent shell deposits.

In Maryland, buried reef shell has been commercially mined for about 30 years by Langenfelder and Son, Inc. for landfill, lime manufacture and other commercial uses and to be sold as cultch for Maryland's Oyster Repletion Program. Virginia has purchased Langenfelder-produced shells for the same purpose from time to time as have other states and private parties. According to sources within the Maryland Department of Natural Resources some 5 to 7 million bushels were mined annually. Thus, a total of as many as 150 to 200 million bushels of shells, or more, have been taken to date. Mining of shells from "ancient" and recent oyster reef deposits continues in Maryland, apparently at about the same rate. In both states (especially Virginia) many shells, originally from oysters set and grown on public bottoms and all nurtured by primary and secondary productivity of public waters, have been employed by private planters to firm their leased (private) grounds for subsequent planting of seed oysters.

The total number of shells taken from the reefs and bottoms of the Chesapeake system and employed for the various uses described above will never be known. All shells applied to uses other than *public* reef repletion programs were (and are) essentially removed from any possibility of employment in efforts at replenishment of *natural* reefs by state management agencies. All shells originating from public reefs and disposed of elsewhere contributed to destruction of those reefs and reef-fields!

Realization of possible problems associated with oyster (and shell) harvesting and reef destruction, and their possible ecological and economic significance developed during the late 18th or early 19th century, albeit slowly and fitfully. Dredging was banned early on (1811—Va. and 1820—Md.) but later restored by both states. For most of this century dredging of market and seed oysters has been banned from Virginia's public reefs (Hargis and Haven 1995). Eventually efforts were made by both Chesapeake states to reduce the rate of shell removal, small oyster removal and destruction and reef reduction through requiring the culling of market-oyster catches on the grounds whence they came (Ingersoll 1881, Stevenson 1894, Yates 1913, Kennedy and Breisch 1983). Unfortunately, *in situ* culling was avoided wherever possible by many, probably most, harvesters, and public management agencies were largely unable to effectively enforce cull laws and regulations. Even closures or gear restrictions were often violated.

In 1924, Maryland began a program of reef replenishment, or repletion, by planting shell on the diminishing natural oyster beds. Virginia's public reef shell-planting program began in 1928. Later, both states planted seed on public reefs as well, though shell plantings have always predominated (Haven et al. 1978). These efforts at public reef rehabilitation (for considered carefully that is what they really were, though true rehabilitation was rarely accomplished—probably never) failed to halt the long-term decline of reefs and their living populations. The reason they failed is simple. Instead of being closed to harvest after replenishment (either with shell or seed, or both) for sufficient time to allow restorative or even recuperative rebuilding of their oyster populations or of the reef structure, itself, the "repleted" beds were quickly opened. Without known exceptions, they were rapidly harvested. Repleted public oyster grounds came to be operated (essentially) as "put-and-take" fisheries in both Chesapeake states. Since monies developed from non-industry sources, including state General Funds, were often employed, the repletion programs (shell and/or seed planting) have been, in large measure, public subsidies to harvesters. Ultimately, these reef-improvement efforts were not enough and in some cases, accelerated by sedimentation, predation, disease and effects of toxicants (all of which must be factored into management decisions and allocations), production on the public grounds plummeted, due—primarily—to continued habitat destruction and population reduction. Additionally, many natural public reefs were allowed to be reduced without regular replenishment efforts. Neither state could afford to attempt to maintain all of its dwindling or already barren public reefs!

That oyster reefs have been overharvested and mined away (reduced in height, volume and surface area volume) can be documented not only by records of reduced harvests of market and seed oysters from the Chesapeake's many once very productive public reefs and reef fields, but by other reliable means. Already mentioned are early reports that many reefs reached upward into the intertidal zone in Colonial times (Wharton 1957 and others).

Though well over half century of harvesting had already destroyed many, some reefs continued emergent in the market and seed oyster areas of the James River into Civil War times. As late as 1871-73, soundings made by the U.S. Coast Survey (USCS 1872 & 1874) showed a number of reefs breaking the surface at mean low water. Some were extensive. For example, the emergent portion of Long Shoal Reef in the James River seed area near Point of Shoals Light was over a mile-and-a half long (USCS 1872 and 1874). (See Hargis, Chapter 1, this volume.) Certain of these emergent reefs persisted into the 20th century.

Marshall (1954) surveyed elevations of several oyster reefs in the lower James River and compared his depth data with those shown on older hydrographic charts. After allowing for changes in sea level he reported a loss in elevation of about 30 cm (12 in.) in about 90 years. This finding of declining reef height was reinforced by Hargis (1966) who confirmed reef height reductions and other geomorphological changes by harvesters after a large-scale VIMS study of the James estuary. Later, DeAlteris (1988), comparing old and recent hydrographic charts, estimated an elevation reduction of 1.2 to 1.8 m (4 to 6 ft.) at Wreck Shoal in the James River seed area (upriver from the market oyster area that Marshall had studied) over the 130 years preceding his field work. Unquestionably the reefs in the James River have been severely reduced by harvesting and shell mining.
The same has happened elsewhere in the Bay. Bailey (1941), who studied oysters of the York River for the Virginia Fisheries Laboratory (predecessor of the Virginia Institute of Marine Science), wrote:

"Oysters have in the course of their long evolutionary period evolved as reef animals.... Prior to 1880 good oyster rocks (bottoms) were common in the York River. They were the results of generation after generation of oyster shells settling on top of the previous crop, until finally the "oyster bars" were exposed at low tide. Those the results of natural conditions, but not for long."

"By 1900 the oystermen had tonged up most of the oysters and had failed to return any appreciable amount of the shells. They sold the shells as well as the meats. The shells were ground and sold as chicken grit or burned into lime."

"No better proof of this lowering or even total removal of the oyster rocks can be presented than the examination and comparison of a York River Coast and Geodetic Chart of 1858 with a recent one.[1] "Bare at low water" is the notation on the 1858 chart at Pages Rock Lighthouse. Today the reading at the same spot shows a depth of three feet and the bottom is soft mud."

Clearly, destruction of Chesapeake oyster reefs has resulted from oyster harvesting and shell mining activities. Equally clearly, reef

[1]In 1858 the organization was officially titled the U. S. Coast Survey. It did not become the U.S. Coast and Geodetic Survey until the late 1870s or early 1880s.

destruction in the Chesapeake system has resulted in reduction of self-renewing oyster populations and in declining market oyster production among other adverse effects!

Location of Oyster Reefs in Virginia - Their Sizes, Shapes and Associated Bottom Types

We are most familiar with and have access to considerable information on the reefs of the lower Chesapeake, especially those of the James River which, of those in Virginia's waters, have been studied most. Consequently, we emphasize them here; however, the same principles, results and conclusions derived from study of the James can be applied to oyster reefs throughout the Chesapeake!

The James estuary is similar in essential geomorphological and hydrological features to Maryland's upper Bay northward of the mouth of the Patuxent River as well as to the estuary of the Potomac River. The estuarine areas of all three systems are affected significantly by freshwater inflow from extensive piedmont and montane watersheds. (Annually, the Susquehanna River normally contributes about 49% of all riverine freshwater entering the Bay, the Potomac about 18% and the James about 16%, or about 83% all together—Figure 1. Obviously, all of the rest of the rivers and creeks around the Bay contribute relatively little freshwater—about 17% of average annual inflow.) The normal freshwater inflow patterns of the upper Bay and of the Potomac and James estuaries and their effects on the hydrographic and ecological aspects of those systems are similar. The same is true of their hydrographic and ecological responses to abnormal precipitation in their upper watersheds. Hence, their freshets and salinity advances and retreats and other freshwater-inflow-affected dynamics are similar. Historically, all three of these mesohaline estuarine areas have produced many market (and seed) oysters on extensive reefs and reef fields. Undoubtedly, common favorable ecological factors have contributed to their successes. Today natural market oyster production in all three is markedly reduced to less than one percent of former maxima (Hargis and Haven, 1995).

Some of the Bay's "natural", or public, oyster reefs were first investigated systematically by Lt. Francis Winslow USN, then working for the U.S. Coast and Geodetic Survey. Winslow (1882) examined reefs in both Maryland and Virginia and did the earliest such work in the James River. Winslow's surveys, especially those of Tangier and Pocomoke Sounds, established reef contours and provided some population-relevant information.

The locations of Virginia's natural oyster reefs were identified in 1892-93 by Lt. John Bowen Baylor, USN, also with the Coast and Geodetic Survey. This survey identified and plotted the borders of areas within which oysters and oyster reefs had occurred historically according to the collective memories of the participating watermen, many of whom were Commissioners (Baylor 1894). Unfortunately, it did not carefully examine the condition of the reefs within these areas or establish the size (i.e. height, basal area, slope, or surface area) of the then-surviving reefs or the nature of the bottoms around them (Haven et al. 1981). It is reported that the Baylor boundaries included at least 391 known, named reefs and large areas of unproductive bottom. The official public oyster grounds of Virginia were legally established in 1892 by Acts of Assembly. Actual legal boundaries were based on Baylor's survey results. They have been resurveyed since 1894 and occasionally augmented by General Assembly action. At present, some 243,000 acres are *officially* designated as public grounds (also called Baylor grounds) in Virginia. About 199,000 acres are within the Chesapeake system. Some 43,000 to 44,000 are on Seaside of the Eastern Shore (Figure 2).

Surveys conducted during the years 1906-1912 established the numbers, boundaries and names of the public grounds in each oyster-producing county of Maryland, see Yates 1913.

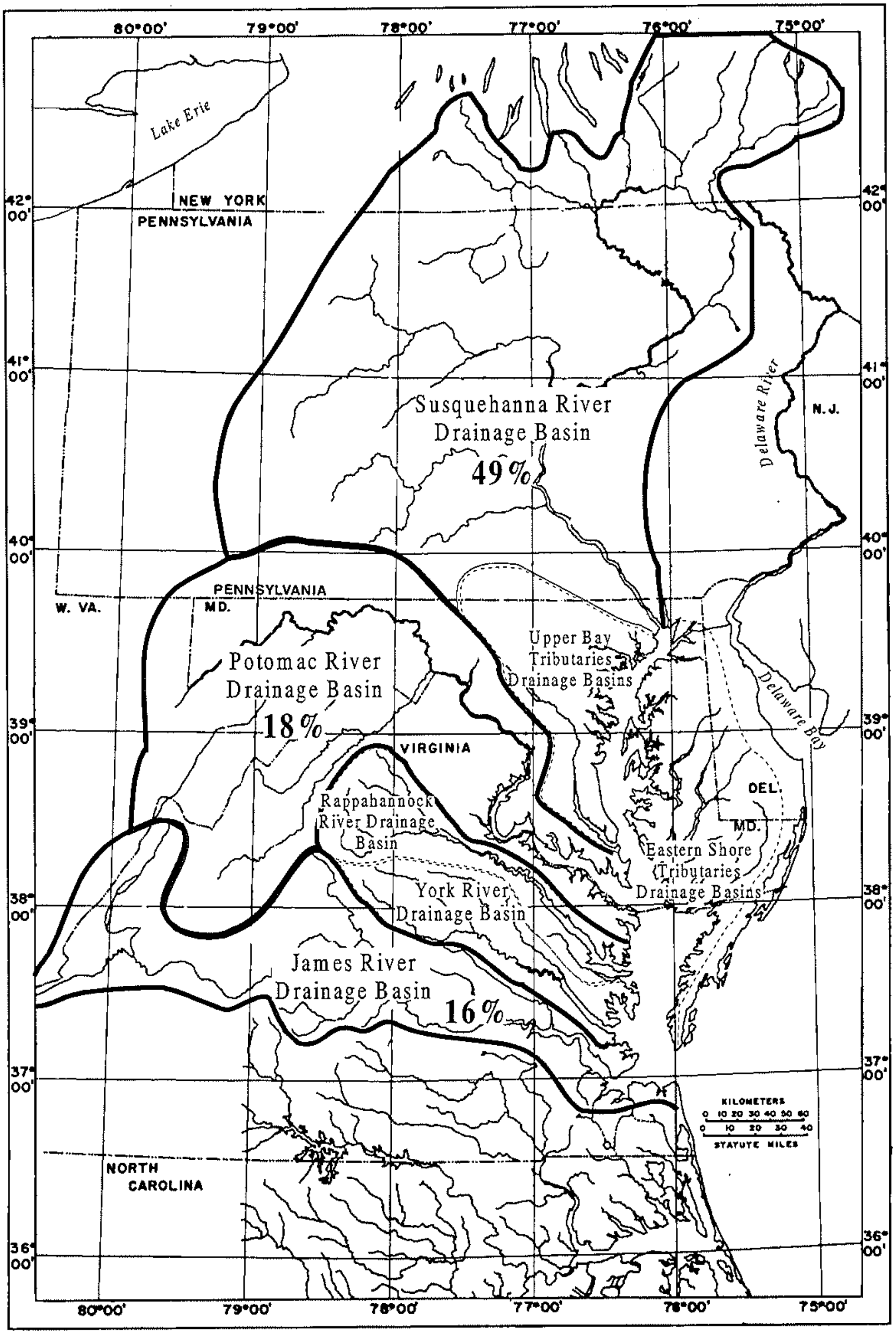

***Figure 1**. The Chesapeake Bay Drainage System Showing the Average Annual Freshwater Inflows of the Three Major Drainage Basins. The Susquehanna, Potomac, and James Drainage Basins, comprising most of the overall drainage area and contributing most of the Bay's riverine freshwater, are clearly identified.*

In all, this extensive survey covered 741 named reefs in 11 counties bordering Maryland's Chesapeake. Most occurred in the areas which Stevenson had outlined in 1894 (Figure 3). But, Yate's surveys involved more than areal outlines. They actually determined availability of oysters and bottom types as well as the areas and locations of the reefs. The surveys of Yates were used to establish the official (legislatively established) public oyster beds of Maryland.

It is known that the natural oyster reefs in both states had been extensively reduced by harvesting activities long before either of these two official surveys (i.e. Baylor, 1894; Yates, 1913) was conducted (Ingersoll 1881, Stevenson 1894, Hargis and Haven 1995).

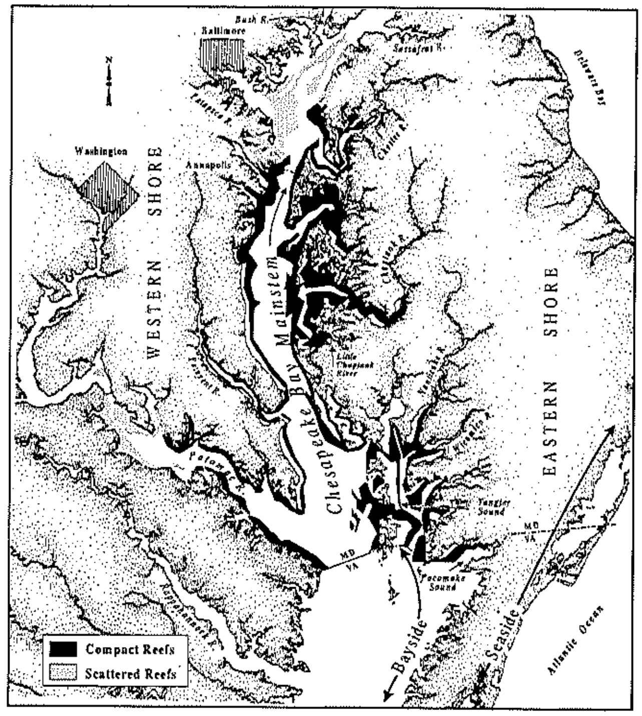

Figure 3. General Distribution of Oyster Reefs and Reef Fields in Maryland's Chesapeake Bay System, early 1890s. (Modified from Stevenson, 1894)

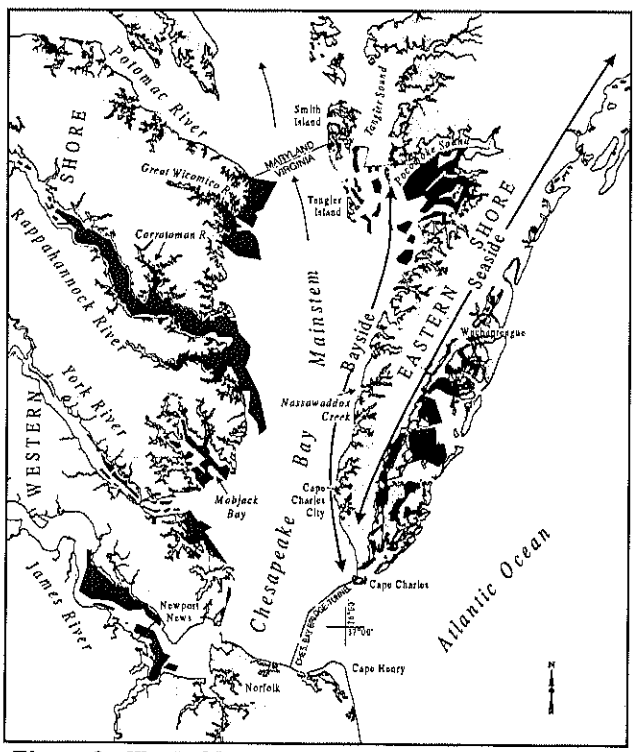

***Figure 2.** The Public Oyster Grounds of Virginia. Black areas outline and contain the natural (public or"Baylor") oyster reefs and reef fields of Virginia at the time of the Baylor Surveys of 1892 and 1893 as modified by later official additions. (Modified from Haven et al, 1978)*

The Structure and Special Ecological Features of An Oyster Reef

No one, to our knowledge has "dissected" an *unharvested*, upthrusting natural Chesapeake oyster reef to determine its detailed structure. However, De Alteris (1988) examined the structure and age of the once-important Wreck Shoal reef in 1986 and 1987. Unfortunately, by then Wreck Shoal had been largely destroyed.

It is possible to make some inferences from early charts and descriptions such as those prepared by the U.S. Coast Survey for the James estuary in 1871, '72, and '73 (USCS 1872 and 1874). (See Hargis 1998, Chapter 1, this volume.) As well, past field observations in the Chesapeake, and reports therefrom provide some information about reef morphology (Winslow, 1882, Stevenson 1894, Moore 1910, Loosanoff 1932, Haven et al. 1981, Haven and Whitcomb 1983 and 1989, DeAlteris 1988, and Whitcomb and Haven 1987).

We have attempted a diagrammatic "reconstruction" of an idealized unharvested reef in Figure 4. Consisting of two main above-bottom components, the "core" and the "veneer", the entire reef rests on a foundation of shells, shell fragments, and other persistent materials embedded in a matrix of sand-mud or silt. The core consists of depositional materials such as shell, shell fragments, sand, silt or clays in various proportions. The veneer consists mostly of living oysters, shells of recently-dead oysters, biological associates and persistent depositional materials. This whole structure rests typically on old shoreline and adjacent upland features existing prior to Holocene sea level flooding in the particular section of the estuary in which the reef was developed (Hargis, Chapter 1, this volume).

The masses of shell in the underlying core of an "undisturbed" successful living reef kept growing vertically and horizontally by accretion as successive generations of oysters set, grew, reproduced and died, leaving their shells behind. Eventually these shells were themselves overlain by new ones deposited as the oysters in the veneer died and by living oysters as the reef grew upward and outward. Of course, many individuals of each age group died of various causes, including disease undoubtedly (all animals and plants harbor parasites and have

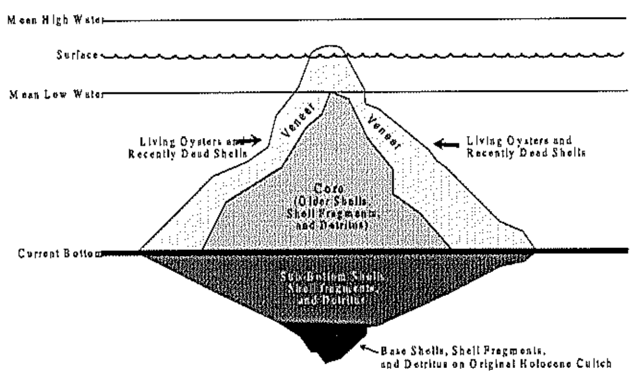

Figure 4. Diagram of an "Upthrusting" Chesapeake Oyster Reef, the Oyster's (a communal animal) "Favored" Habitat. (Details of the early post-Wisconsinan, "original Holocene Cultch" Base are hypothetical. To our knowledge, no one has carefully "dissected" the sub-bottom portion of an upthrusting reef.)

diseases), before maturing but enough survived to perpetuate themselves and contribute to growing populations and reefs. Or so it went until excessive seed and market oyster harvesting and shell mining upset the progression.

The interstices between shells and shell fragments provide places where sediment particles and reef wastes from upper levels may be sequestered even though the residence time therein of some of this material may be more or less temporary. Undoubtedly some is transferred, transformed, and even consumed by biological and chemical processes in the interim. A certain residue probably remains sequestered as long as the core remains undisturbed. Particulate material dropping away from reef "heights" can also settle onto the adjacent estuary bottom or be swept away from the reef by currents. Thereby, portions of the exposed outer surfaces of the veneer of the reefs, themselves, remain relatively clean of particulates. At the same time increasing reef elevation, bolstered by the shell being continually added to the core, and by new spatfall and growth in the veneer keeps the living oysters away from the bottom (the sediment-water interface) even though the surrounding sediment layer and associated nephalic layer may, themselves, thicken. Consequently, stresses exerted on living reef oysters by proximity to the bottom (bottom effects) are lessened and survival enhanced. Further, infective materials released by living, moribund or dead animals are more likely to drop or be carried away from other oysters living on the heights (or in the upper layers) of the reef's veneer than they would on a flat bed, or even on a low, bottom-hugging "lump".

The reef topography also increases the overall surface area significantly (as intestinal rugae and villi do in the guts of in higher vertebrates) available to setting and growing oysters. Consequently, chances of successful setting on suitably clean, exposed surfaces are improved.

Hidu (1969) and others have shown that the presence of living oysters enhances spatfall. The presence of living oysters in the veneer should, therefore, improve setting.

While general patterns of estuarine salinity are dominated by fluvial freshwater input and salty water intrusions from down- estuary and/or the nearby ocean, it is highly likely that significant local rainfall events and temperature changes affect the oysters on the crests and upper elevations of the reefs. Most probably there are (or were) vertical differences in salinity and temperature related to local weather phenomena as well as normal estuarine stratification on the upthrusting reefs of the Chesapeake. Likely, these micro-environmental variations are (or were) sufficient to affect survival of the oysters. This possibility deserves further scientific attention.

Upthrusting reefs also interdict and modify surrounding currents. Undoubtedly a large group of upthrusting oyster reefs (hereafter called a reef field) exerts considerable influence upon local current patterns and other hydrographic and geological features (Hargis, Chapter 1, this volume).

Taken together, paleontological, archaeological, historical, geological and ecological evidence shows that oysters set, survive and grow better on elevated reefs with substantial "cores" of oyster shells and "cinders", and other suitable substrate, and healthy "veneers" of living oysters than on beds near or on the bottom. Spatfall is better, growth is faster, predation effects are lower and disease-related effects reduced. Oysters lying flat on the bottom or partially submerged in the bottom do not fare nearly as well. Relative successes of "off-bottom culture" efforts employing man-made structures to maintain the living oysters off of the bottom in disease- and predation-prone areas confirm this.

Oyster reefs benefit other biota as well. Hundreds of micro-organism and small macro-organism species colonize them using oyster shell surfaces and interstices and wastes and those of other reef-associated invertebrates for support, shelter and sustenance. The oyster reef biocoenose (Moebius 1883) includes organisms of many life styles and food web levels. Attached and infaunal sessile plants and animals abound as does associated nekton. In the Chesapeake several finfishes (oyster toadfish, skilletfish, gobies, blennies and others) are among the regular inhabitants and the whole reef attracts many other grazers, browsers and predators. Though this aspect is generally ignored, it is highly likely that the oyster-reef biocoenose was the most prominent one in the Chesapeake system!

On reefs which have been heavily worked (overworked) live oysters mixed with shell and shell fragments and some organic matter and inorganic sand, silt or clays form a flat, hard crust up to 15 to 46 cm (6-18 in.) thick on the less-solid estuary floor. Typically a mixture of oyster shell and shell fragments ("cinder") embedded in a stiff matrix of sand-mud and silt lies below (Table 1). These latter substances (*i.e.* sand, silt or clay) may often form 50% of the total mix, and sometimes more (Haven *et al.* 1981, DeAlteris 1988). Oyster reefs usually extend below the surface sediment as shown in the Gulf of Mexico by Bouma (1976) and in the Chesapeake Bay by DeAlteris (1988) and by Nichols, Johnson and Peebles (1991). In the Wreck Shoal area of the James River the foundations of extant oyster reefs may extend into the bottom 6 m (19.7 ft) or more. Still older buried shell reefs associated with the changes in sea level during earlier interglacial oceanic transgressions may lie beneath the foundation layers of some recent reefs.

In summary, it is evident that reefs, nature's off-bottom culture "devices", have been important to the survival and natural renewal of *C. virginica*. If they were not, oyster populations would not have survived and produced so well on the many reefs that they "built" during the evolution of the current (Holocene) Chesapeake. Without those reefs and their accumulated populations the valuable public oyster fisheries of the Bay states would never have developed. Wherever natural reefs have been destroyed by natural forces or human activities (or both) along the Atlantic or Gulf coasts, economically significant *natural (unaided)* production of oysters has declined—even disappeared. Overall estuarine productivity has been reduced and finfish have declined as well.

TABLE 1. Subenvironment sediment sample made in the vicinity of Wreck Shoals, James River, Va. (Means and standard deviations) (From De Alteris 1988)

	Hard-Rock		Sand-Shell		Mud-Shell	
Parameter	Mean	S.D.	Mean	S.D.	Mean	S.D.
Water Depth (ft)	11.9	0.9	11.9	0.6	17.0	1.8
(m)	3.6		3.6		5.2	
Volume of Exposed Cultch (qt)	5.0	2.8	2.0	1.2	2.5	1.4
(l)	4.7		1.9		2.3	
Total Number of Live Oysters	74.4	22.8	90.9	30.8	24.9	12.7
Volume of Live Oysters (qt)	5.3	1.4	4.9	1.2	3.1	1.3
(1)	5.0		4.6		2.9	
Number of Oyster Boxes[1]	8.3	4.5	6.5	3.6	4.4	3.1
Sediment, Percent Gravel[1]	39.4	6.2	34.0	7.4	8.1	8.7
Sediment, Percent Sand	38.0	6.1	41.6	7.2	25.5	6.2
Sediment, Percent Silt-Clay	22.5	5.0	23.8	5.4	66.5	7.9

1 Gravel consisted mostly of shell fragments.

Decline in Chesapeake Oyster Populations Related to Overharvesting and Concomitant Reef Destruction and Vice-Versa

Hargis and Haven (1995) established that both Maryland and Virginia natural (or public) oyster populations have been overharvested over the last 150 years or more. Many others, including Ingersoll 1881, Winslow 1882, Brooks 1891 and 1905, Stevenson 1894, Baylor 1894, Moore 1910, Yates 1913, Loosanoff 1932, Bailey 1941, Kennedy and Breisch 1983 and Rothschild et al. 1994, have concluded likewise. The relationship between harvesting effort and the Chesapeake oyster population decline is simple and direct. When more living adult (or any other sought-after age- or size-class) animals are removed from any population than nature (aided or unaided) can replace, overharvesting is taking place and the demise of the overall (or target) population (economically or even ecologically) is inevitable as long as the process continues. When any population's genetic strength is reduced by continuous adverse selection, their ability to survive environmental adversity, including disease, is weakened. When the essential habitat is destroyed in the process the population decline occurs faster and the likelihood of its self-restoration is seriously diminished. These are immutable and implacable "laws of nature". Their violation endangers the economic utility of those natural resources and may ultimately destroy the resource as well. Human wishes, political solutions (compromises), harvesting goals and management plans which are not consistent with these natural laws *are irrelevant and doomed to failure*! The question becomes not whether the resource will decline and the fishery will fail—but merely when.

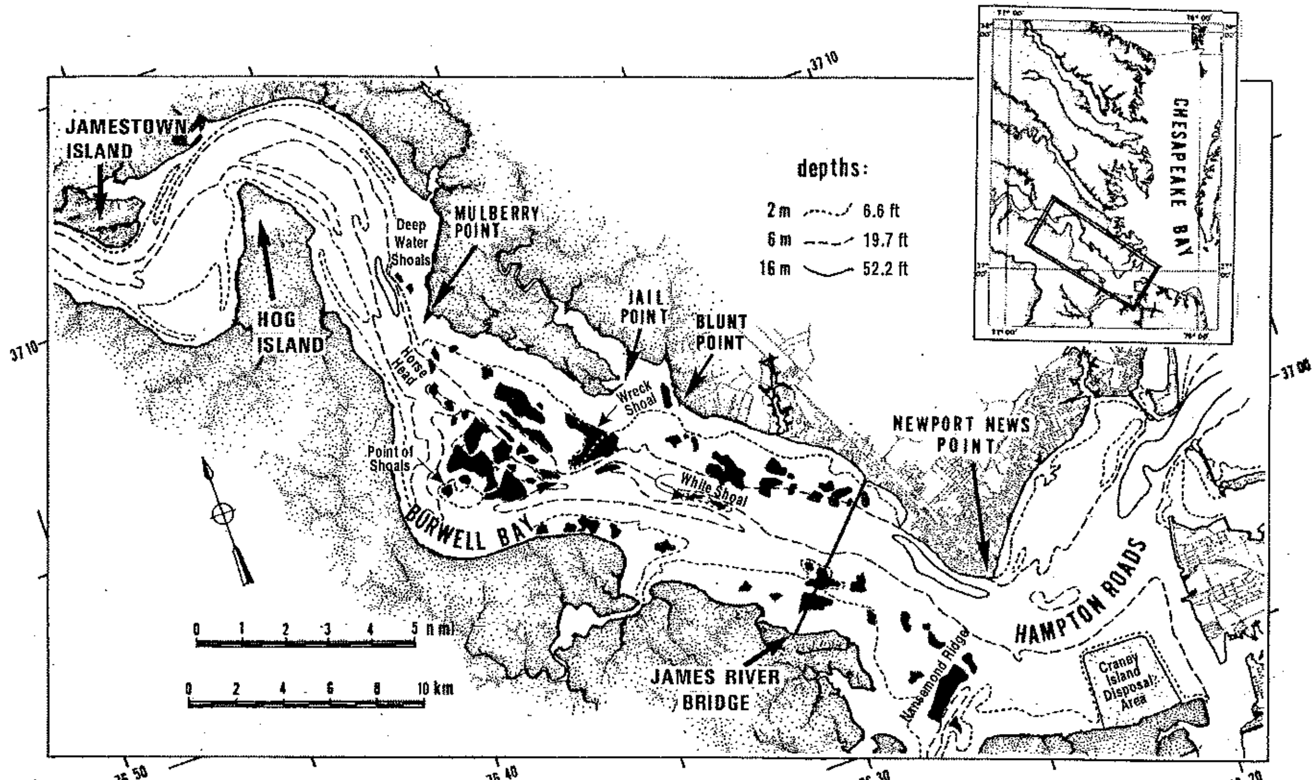

Figure 5. James River Estuary Chart Showing General Bathymetry, Location of Public Seed Oyster Beds and Named Features Referred to in Text. Inset shows location of James relative to Chesapeake Bay.

The "first" rule of responsible renewable-resource management is: The essential habitat must be preserved. The "second" is: the essential survival-related features of the target populations must be preserved. The "third" is: harvests must be limited to available "surpluses". Determination of "available surpluses" must consider all applicable negative ecological factors such as diseases, predators, adverse water quality, poor spawning and poor setting years, etc! The surplus available for harvesting in any harvest period is that which remains after these and other adverse factors have been considered: That and no more! Because of the natural uncertainties involved in the quantitative affects of thees processes, the approach to determining "available surpluses" must be conservative!

Responsibility for Preservation and Restoration of Public Oyster Populations and Their Habitats

Oysters of the Chesapeake and their natural habitats belong to all of the people of Virginia. They are truly part of the common wealth as former Governor Harry F. Byrd wrote in 1928 (Hargis and Haven 1995). As with other "common-property" resources their effective management is a responsibility and function of government. Regulation of their use and condition is, therefore, not an unjustified or unreasonable imposition by government upon private rights of harvesters and other users but a necessity to preserve the common-property resource and its future social and economic benefits. Public managers may allow socioeconomic use but must also preserve the people's (and posterity's) long-term socioeconomic interests in the resource. Where they do not do so the interests of the present and future owners are damaged, and the public managers are derelict. Prevention of abuse of common property resources should be the state's ultimate management goal: Where abuse has already occurred, restoration of that resource must be a priority!

As state governments undertake to restore natural oyster production on the *public* oyster grounds of the Chesapeake they must restore the oyster's "favored" habitats - the reefs. In doing so they would do well to emulate nature's reefs as closely as possible, including height and other dimensional features. Nature has been "experimenting" with *C. virginica* and its reefs along the western North Atlantic coast for some 18 million years or more under all of the varied ecological, geological, meteorological conditions that have transpired, through interglacial and glacial periods and in both estuarine and marine environments. On such reefs, under pressures of competition, predation and disease, *C. virginica* has survived for millennia.

Scientists talk much of experimentation, and there is room for reef experiments for special purposes. But "nature" has already accomplished the basic experimentation on reefs as suitable natural habitats for *C. virginica.* We can, and should, make use of her efforts and results!

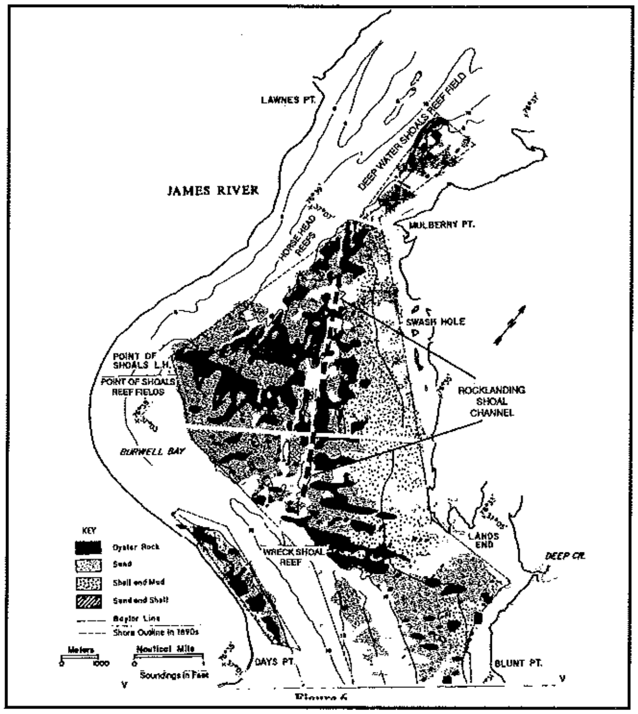

Figure 6. Distribution and Base Outlines of Oyster Reefs and Reef Fields in Upper Reaches of the Estuarine Portion of the James River in the Early 1980s. Area shown encompasses all of the James River "seed oyster area" as identified by Moore (1910). The bottom types existing in the 1980s are identified -- see key to symbols. (Modified from Haven and Whitcomb, 1983).

The remainder of our paper is directed at technical aspects relevant to the Chesapeake oyster reefs and their oyster populations.

Ecological Conditions Under Which Oyster Reefs Originate and Survive

Large oyster populations, as exemplified by living oyster reefs, develop and persist only where and when ecological conditions are favorable. For example, large (economically significant) oyster populations occur naturally in locations where biogeological and hydrographic features favor them. Such features include:

1. Salinity range from about 5‰ to full-strength or undiluted seawater—32-35‰. Within this salinity range, areas experiencing salinities averaging between (5‰ to 20‰) are probably most suitable for oyster survival. In contrast, many common oyster predators , such as the oyster drilling snails, *Urosalpinx cinerea* and *Eupleura caudata*,and parasites [including *Perkinsus marinus* (Dermo) and *Haplosporidium nelsoni* (MSX)] do best in salinities averaging higher than 15‰. On the other end of the salinity spectrum frequent and prolonged freshwater conditions (0.5-5.0‰) mitigate against accumulation of living oysters and development of significant reefs. Frequent exposure to prolonged freshets increases mortality, depending on water temperatures, and results in (relatively) more rapid rates of reef shell deposition and build-up, but at the same time populations of living oysters are generally smaller and their growth (including shell growth) is slower. This is illustrated by oyster reefs in the James seed area (i.e. Wreck Shoal and above—Figures 5 and 6) where

oysters become fewer and reefs fewer and smaller (relative to age) as one progresses upriver to the area around the Horsehead Reefs and especially around and above Mulberry Point, *i.e.* the Deepwater Shoals area. The same would apply to the lower salinity reaches of the Potomac and the upper Chesapeake and its tributaries. Low salinity, or upper estuarine areas are not good candidates for "commercial" (as opposed to experimental) reef restoration.

2. Depth range from mid-intertidal to about 8 m (26.2 ft), sometimes more, but mostly between 2.5-5.5 m (8.2-18 ft);
3. Oxygen levels of from about 20% saturation to saturation. Mature, healthy oysters are able to close-up and survive under low oxygen conditions as they can in very low salinity water, but only for relatively short periods of time. Prolonged anoxia leads to the development of H_2S in the water which is quickly lethal;
4. A relatively sheltered area, protected against excessive wave action yet appropriately exposed to water movements which permit and/or facilitate setting, feeding, cleansing and reproduction;
5. Levels of natural predation low enough to permit accumulation of sexually mature oysters of an appropriate sexual mix of mature oysters;
6. Levels of mortality (related to disease and other natural or man-made causes) low enough to permit survival, adaptation and accumulation of favorable genetically transmissible characteristics;
7. Levels of competition from other filter-feeders low enough to permit the same as in 6.
8. Production of viable larvae in numbers sufficient to maintain the endemic oyster populations and the reef habitat, and meet the demands of environmental pressures, including adverse ecological factors such as sedimentation, diseases, competitors and predators, including man.
9. A hydrographic circulation pattern which retains, preferably gathers as well, maturing oyster larvae in the vicinity of the reef or reef field and, optimally, carries oyster larvae from nearby and distant oyster populations to that reef during the season of active setting;
10. Current patterns and velocities sufficient to prevent or reduce the rate of accumulation of fine sand, mud and/or silt, on developing reefs and of infective materials (particles), feces, and pseudofeces or other organic materials on or around the living oysters, and;
11. Sufficient elevation to provide the advantages of height and vertical differences in distribution of water of varying salinity.

Surveys Relevant to Reef Rehabilitation Activities

Moore (1910), using surveying gear, a chain-drag and oyster tongs, delineated the actual outlines and acreage of oyster reefs in the James River. He also established the outlines and acreage of various bottom types and the density of oysters (in terms of economically harvestable quantities available) on the four types of bottom he identified. Unfortunately, reef elevations and contours were not reported.

The first truly comprehensive investigation of Virginia's public oyster bottoms was made during the period from 1978 to 1981 by Dexter S. Haven and his colleagues of VIMS. This three and a half year study employed electronic positioning gear (Hastings Raydist©) and a recording fathometer to establish depth contours, plus a sonic bottom drag to locate and outline reefs (in 2 dimensions, 3 with the fathometer) and to secure data on bottom types. Standardized patent tong samples were used to estimate oyster and shell density and further identify bottom constituents. The data were used to prepare a series of charts and tables presenting basal outlines of existing oyster reefs, acreages of various types of bottoms, estimates of living oysters and shells, setting potentials, and occurrences of diseases and predators. Most of the study was published in an extensive series of reports (Haven et al. 1978, Haven et al. 1981, Haven and Whitcomb 1983 and 1989 and Whitcomb and Haven 1987).

These documents, particularly Haven et al. 1981, provide information relative to reef location, condition and other data needed to plan and conduct reef restoration programs in Virginia. Almost all tributary and Bay bottoms and those of the lagoons and embayments of the Seaside of the Eastern Shore were sampled and described. Until data even more accurate and comprehensive are available the results of Haven et al. (1981) *must* be employed to provide the basis for such work in Virginia and *should not be ignored*! Their conscientious use in developing reef rehabilitation programs is vital!

Specifically, these charts and tables showed:

1. Areas of thick, hard bottom with living oysters and shells;
2. Bottoms less firm than those mentioned above (1) but with a firm crust of live oysters and shell fragments ("cinder") in a matrix consisting largely of sandy sediments;
3. The same as (2) but with a firm matrix of dense sand, silt and clay;
4. Sandy bottoms containing few to no oysters or shells;
5. Mud bottoms containing few to no oysters or shell, and,
6. Buried shell 6-12 inches below the bottom, *i.e.* overlain by sand-mud or other sedimentary material.

A study in 1985 in the James River seed area utilizing patent tongs confirmed the validity of the designation of bottom types by Haven et al. 1981 and their location in a small section of the Wreck Shoal area (DeAlteris, 1988). It also showed that sand or silt-clay may form over 50% of the substrate matrix even on active or producing Hard Rock (Reef) bottoms, i.e. those which continue to produce oysters despite having been severely reduced by harvesting and being merely "bumps" on the bottom (Table 1).

Haven and his colleagues (1981) evaluated about 203,405 acres of the state's approximately 243,000 acres of public (Baylor) bottoms, including both Seaside and Bayside of the Eastern Shore (Figure 2) . They showed that in the James River (Figures 5, 6, and 7), which encompassed about 25,152 acres of all public bottoms, a lesser but still substantial acreage (16,245 acres or 64.6%, i.e. 1 to 3, below) of it was suitable for growing oysters. These can be categorized as follows:

1. Hard Oyster Rock, generally with live oyster and some profile;	4,310 acres
2. Shell-Oysters - Mud;	7,487 acres
3. Shell-Oysters - Sand;	4,448 acres
4, Sand - few or no oysters;	1,540 acres
5. Buried shell;	420 acres
6. Soft Mud or Channel Areas	6,947 acres
	25,152 acres

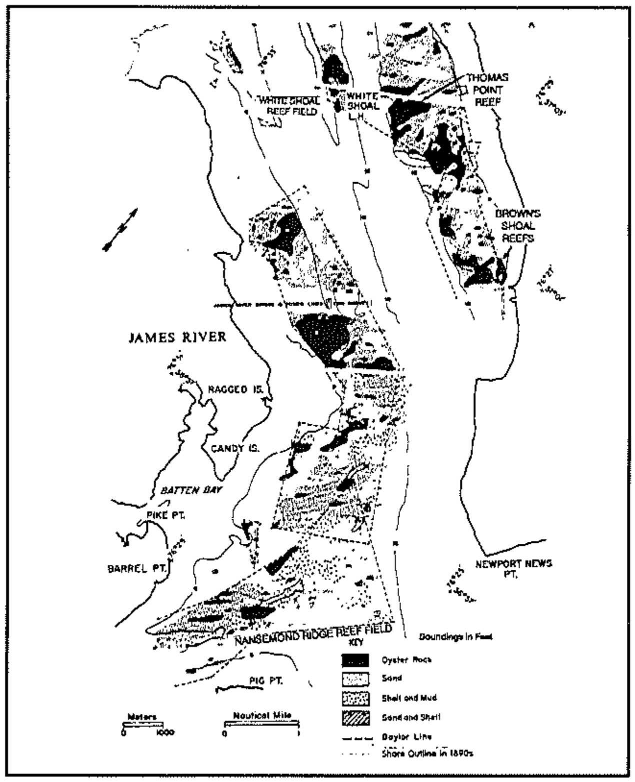

Figure 7. Distribution and Base Outlines of Oyster Reefs and Reef Fields in Lower Reaches of the Estuarine Portion of the James River above Newport News Point in the Early 1980s. Area shown encompasses most of the James River "market oyster area" as identified by Moore (1910). The bottom types present in the 1980s are identified -- see key to symbols. (Modified from Haven and Whitcomb, 1983).

Unfortunately only a small amount (about 3,000-4,000 acres) continues to produce appreciable quantities of seed and very few (5,178 Va. bu. in 1993-94) market oysters. In the James River seed area market oysters were defined as those at least 2 1/2 inches in shell length in 1986-87. In early 1994 it was restored to 3". In the James River seed area size limits mean very little in terms of population protection and conservation because oysters called "seed" can be any size. Additionally, for many years small individuals from the "market" oyster area of the James were harvested for use in the making of oyster soup. Such oysters were called "soups." Soup oysters could be any size but buyers preferred small ones. With such variations in the sizes allowed to be harvested, it is obvious that size limits actually meant very little in the James!

If the primary objective of reef rehabilitation or rebuilding activity is to increase *natural production* (self-reproducing populations) of oysters and restore reef structure as quickly and effectively as possible, *as it should be*, the reefs in the Hard Oyster Rock category (No. 1 above) should receive the most effort. Even if expense is a concern, rehabilitating this category of reef should receive more (and more effective) management efforts since they are in the best condition to rehabilitate themselves with or without addition of shell or seed (more rapidly with both, clearly), but—given adequate respite from harvesting pressures. The implications of this last condition are obvious: To rehabilitate active or inactive reefs most quickly, harvesting pressures must be reduced severely—preferably eliminated, for a significant period of time! Rehabilitation of reefs without closing them and leaving them closed until they achieve significant rebuilding will be wasteful. Even after rebuilding is accomplished and production reefs are opened, harvest levels must be strictly controlled!

Categories 2 or 3 reefs are older depleted ones and are good candidates for reef rebuilding efforts as well. Reefs of these three categories (1, 2 and 3) are sufficiently numerous and extensive that "barren" bottoms need not be considered—except for special purposes. Further, category 1, 2 and 3 reefs are sufficiently widespread to provide suitable "platforms" for rebuilding efforts in every part of Virginia's Bay and its tributaries where oysters once flourished. The same is probably true of Maryland's waters except where shell mining has removed too much sub-bottom shell.

Sizes and Shapes of Oyster Reefs in the James River

As stated above, the survey by Haven et al. (1981) determined size, bottom types and water depths of Virginia's Baylor bottoms. All surveyed were charted and the charts deposited in the VIMS library. Those occurring in the James River above Newport News Point are shown in Figures 5, 6 and 7.

The Hard Oyster Rock areas (reefs) shown in black in those figures are most often irregular in shape. Many are elongated, presumably on sites of old elevated river bank or river bed topography or along prevailing bottom currents, or along the long axis of the river. Many are situated at right angles to the long axis of the river (i.e. to the prevailing bottom tidal currents). The long axes of many are arranged across-river, perhaps reflecting the water mass movements driven by the west to east, wind-driven cross-river currents occurring during the setting season and/or topographic features of the bottom. (Obviously, both the location and orientation of cultch and the prevailing currents have affected the locations and shapes of the reefs.) Some were a mile (6.4 km) or more in length and 1,000 feet (305 m), or more, wide. [The crests of a large number of them are known to have breached the water's surface at mean low water: Some in the not so distant past (Hargis, Chapter 1, this volume.)] Many, however, are much smaller and are often called "lumps" by watermen.

The Haven et al. (1981) study measured the area of discrete Hard Rock Reefs surviving in the James River (Table 2) and elsewhere in

Table 2. Location, Acreage and Percent Total of Hard Oyster Rock (Reef) Areas (Category 1) in the James River by Sections

A. Deep Water Shoals to Mulberry Point — Total - 37.7 acres	
1. 0 to 20 acres	100.0 %
B. Mulberry Point to Point of Shoals — Total 1750.2 acres	
1. <20 acres	4.6 %
2. 20.1 - 100 acres	10.8 %
3. >100 acres	84.6 %
C. Point of Shoals to White Shoals — Total 1355.9 acres	
1. <20 acres	27.1 %
2. 20.1 - 10 acres	30.5 %
3. >100 acres	42.4 %
D. White Shoals to Fishing Point — Total 1031.4 acres	
1. <20 acres	10.9 %
2. 20.1 - 100 acres	17.6 %
3. >100 acres	71.5 %
E. Fishing Point to Nansemond Ridge — Total 135.1 acres	
1. <20 acres	44.6
2. 20.1 - 100 acres	55.4

Virginia's tidal waters at the time of the surveys. These data showed about 4,310 acres of Hard Oyster Reefs in the entire James estuary, i.e. above and below Wreck Shoal. These areas were locations where more extensive reefs existed prior to being subjected to intensive exploitation. Areas classed as Shell-Oyster Sand and Shell-Oyster-Mud were reefs which are gradually being covered with sediments after having been harvested and mined away.

The Vertical Elevation of "Hard Rock" Bottoms in the James River

Fathometer traces of bottom depths were made during the study of Haven et al. (1981). Significantly, these traces showed that most of the "tops" of the hard reef areas in the upper James around Burwell Bay were at least 0.6 m (2 ft) below the water surface at MLW. Further downriver in the important Wreck Shoal area the tops of most reef areas were about 2.4 m (7.9 ft) below MLW. A few areas of reef still showed the classic "peak" or emergent ridge formation as presented in Figure 4 and in early U. S. Coast Survey (USCS) charts, but most showed gradually sloping configurations with little elevation above the surrounding bottom. No oyster-bearing reef crests breached the surface at any normal low tide. This indicates clearly that the natural oyster reefs in the James River, as elsewhere, have been largely "planed" away by over two centuries of harvest by rake and dredge (very early) and tong.. Few "reefs" with significant elevation remain. Most surviving "reefs" are "footprints" only. Shell-oyster-mud and shell-oyster-sand beds showed no appreciable elevation above the surrounding bottom (Haven and Whitcomb 1983).

Review of the studies of Haven and his associates and others discloses clearly that the condition of the natural oyster reefs of the "former" James River seed area (i.e. Wreck Shoals and upriver) is serious! Very little remains of the numerous upthrusting reefs reported in the early 17th century and surveyed and charted over two centuries years later in 1871, '72 and '73 by the USCS that have yielded seed and market oysters for over 200 years. This finding was surprising! Haven and his colleagues expected to find many reefs with greater elevations in the most productive reef fields of the James River seed area. Considering the poor condition of the oyster reefs of the James, it is no surprise that populations of small seed-sized (and market oyster yields) are so low! Nor is it a surprise that surviving populations and setting are so sparse.

The reefs in the lower James below Wreck Shoal (Figures 5 and 7), shown as a market oyster area in the text and charts of Moore (1910), are in worse shape. In fact, most had been significantly reduced before Moore actually made his survey in 1909.

For the James River oyster reef fields to recover as quickly as possible (or even to survive) it is important that the destruction of the structure of existing reefs be halted and that the reefs, themselves, be augmented and/or restored. The oyster's favored habitat must be restored so that self-renewing populations can be rebuilt and/or assisted to rebuild themselves to near their former levels!

The need for this is obvious. Today most public market oyster production in Virginia comes from the James River "seed beds" as it has in the past. If that is to continue, rebuilding is essential. In the past and today *most private oyster* production originated on the same seed beds, as it does today. For example, in the early and mid-1950s private oyster planters were harvesting as many as 2-3 million bushels of market oysters from their rented grounds annually. In fact, from 1930 on, and probably before, about 80 to 85% of the seed oysters for Virginia's large private market oyster production (which reached levels of as much as 70-80% of the total state market production) *came from the public reefs in the James estuary*. If the reefs around the Burwell Bay seed area continue to be depleted and the reef "footprints" become covered over with sediments their present and future utility as a source of seed will be destroyed. Consequently, the likelihood of recovery of the Virginia's private oyster (*C. virginica*) planting industry to former levels will be reduced severely—probably eliminated. Silt-covered reef remnants can produce few oysters.

Restoration (Enhancement) of Oyster Reefs (In the James) and Their Management

Rebuilding oyster reefs in the James River, or elsewhere in the Chesapeake (or on Seaside), should only be attempted if sound plans and procedures for doing so are fully adopted by the entire decision-making apparatus of the management agency (ies) responsible in both states. Money spent on poorly-planned or "half-hearted" attempts is largely wasted. Furthermore, for most rapid Bay-wide recovery, both states must develop clear plans and procedures for future maintenance. We urged reef restoration in several public forums in 1991! Thereafter we recommended establishment of a system of sanctuary broodstock reefs (SBR) and satellite production reefs (SPR), Figure 8. This recommendation is reiterated—forcefully! Since then some reef restoration has been undertaken in both Maryland and Virginia. The trend is encouraging. A few of these projects appear to be showing some positive results. Unfortunately, many, probably most, will fail because of faulty planning, poor placement, inadequate construction and maintenance and/or ineffective post-construction management. Some watermen in both Bay states continue to resist effective oyster management. In fact, some who oppose reef construction actually serve on committees to select sites and other details of reef construction!

To assist in reef rehabilitation we have prepared a list of factors to be employed as guidelines. The features which a reef rebuilding

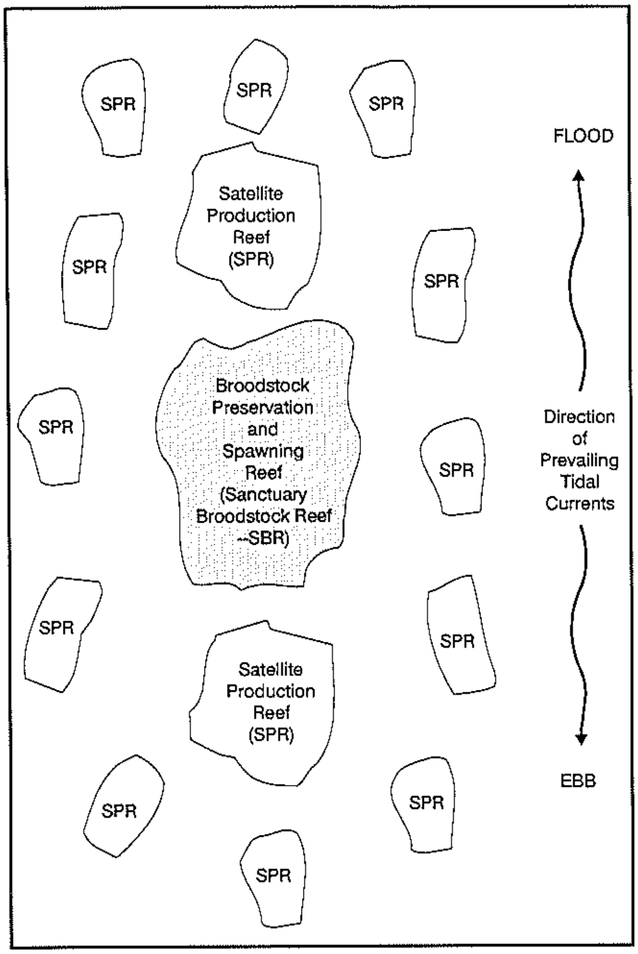

Figure 8. *Diagram of a Two-Tier System of Reef (Reef Field) Restoration Involving Preservation of Broodstock and Spawning Populations and Market or Seed Oyster Production. "[Idealized—Actual configurations may have to differ depending on geomorphological, hydrographic and other important ecological characteristics of the locality in which reefs (or reef fields) are to be restored or built.]*

program designed to produce oysters for harvest should incorporate are:

1) First priority should be given to identification and rapid rebuilding of reefs designated as broodstock sanctuary areas, which we have called Sanctuary Reefs (SR) or Sanctuary Broodstock Reefs (SBR). Harvesting should not be allowed on sanctuary broodstock reefs!
2) These reefs will be the core or central building blocks of our two-tier reef system, or any serious reef rebuilding program. A conceptual design of a combination, or two-tiered reef system is shown in Figure 8. It includes one or, preferably, more sanctuary broodstock reefs (SBR) which must remain closed after establishment and several surrounding satellite oyster production reefs (SPR), reefs which, when restored and ready, can be opened to "controlled" harvesting.

   It is important to note that only the essential features [*i.e.* one, preferably more, sanctuary (SR) or sanctuary broodstock reefs (SBR), surrounded by several satellite production reefs (SPR) appropriately situated] presented in our conceptual diagram are critical. Where geomorphological or hydrographic conditions around existing or planned reef fields do not lend themselves to the idealized or diagrammatic geometric arrangement shown in Figure 8 an approximation would be satisfactory. Where local current patterns suggest different axial alignment(s) of SBRs and SPRs, some rearrangement would certainly be in order.
3) Reefs designated as satellite oyster production reefs (SPR) must be closed until natural production of oysters has returned. When the satellite production reefs (SPR) are opened to commercial or recreational harvest the quantities available for annual harvest (quotas) should be carefully limited to the ability of those SPR reefs to sustain those harvests and, at the same time, maintain themselves. If prolonged rebuilding of the SPR reefs is intended, annual harvest quotas must be even more restricted. In most instances continual rebuilding of SPRs would be desirable in the long run. In every case, managers should be conservative in setting harvesting quotas. Enough animals should be left on the reef to allow for changes in rates of survival brought about by variations in adverse environmental conditions.

   Unfortunately, the fishery management agencies, including legislators whenever they have interfered with rational closure decisions, in both Chesapeake states, and it is they who are ultimately responsible, have consistently avoided (even actively and mistakenly resisted) adoption of management plans which actually limit oyster harvests from public reefs to biologically reasonable levels. Even on reefs being "replenished" at significant public expense, they have not done so! Further, they have never favored actual closure of any producing reefs, even to restore them to formal actual or potential "high" productivity. *This is one of the most significant reasons that state management of the public oyster resource and the fishery that exploits it in both Virginia and Maryland has been ineffective! Biologically reasonable and necessary harvest controls have never been instituted and enforced!*

4) Until truly sound management arrangements and practices can be instituted and enforced, extensive reef rebuilding projects or programs are not to be recommended. Money spent on restoring production reefs which are not appropriately managed will not achieve long-term restoration of public oyster productivity. At best it will be a gift from the state treasury, a subsidy, to public watermen as it has always been—largely. At worst, it will be a waste, as it has most often been. Effective post-repletion, post-reconstruction or post-construction management is the most important aspect of any reef restoration program!

There are valid purposes for reef restoration other than for development of sanctuary reefs or rebuilding or enhancement of commercial, subsistence or recreational harvests of seed and market oysters. These are: 1) Restoration of broodstock levels, and as the oysters mature, of an appropriate sexual mix; 2) Genetic enhancement, i.e. development of desirable characteristics such as disease resistance, rapid-growth or other features by native *C. virginica* by allowing forces of natural selection to act on unharvested, self-reproducing populations of naturally-produced oysters or those from "laboratory-enhanced" populations; 3) Restoration of the filtering, sequestering and transformation capacities of massive oyster populations on revitalized upthrusting oyster reefs, strategically placed as natural pollution reduction measures, and; 4) Restoration of oyster reef-associated communities once so prevalent in the Chesapeake. Oyster reefs are natural fishing reefs (often clearly identified as such on charts intended for use by sportfishermen) which attract and help support desirable finfish. Enhancement of recreational and commercial fin fishing will be a significant bonus of reef restoration. (Actually, efforts, funds and expenditures designed to construct "finfishing" and/or "ecological improvement", or "filtering" reefs, can be adapted to development of sanctuary and even economic production oyster reefs and double- or triple-purpose reefs will result, enhancing ecological and economic benefits and allowing sharing of costs between objectives.) Also, increased water clarity, if such results from the filtering activities of active reef oysters and/or other filter-feeding reef associates, should enhance phytoplankton production and recovery of submerged aquatic vegetation (SAV) in areas influenced by reefs or reef fields and reduce other undesirable effects of excessive sedimentation. Both would be valuable bonuses of oyster reef reconstruction. Yet another benefit of well-situated, properly-designed and constructed oyster reefs would be stabilization of affected lee shores. Further, restoration of reef populations may result in reduction of deleterious micro-organisms by increased filtration of waters in their zones of influence.

Technical Aspects of Reef Rebuilding Which Can Be Recommended

Sufficient information now exists to allow planning for and design of reef restoration activities and pursuit of actual rebuilding or restoration of effective reefs. As we have suggested, all that is required is to emulate nature as closely as possible in the placement and "shaping" of reefs. However, technical aspects pertaining to actual details of reef restoration activities should be examined deliberately to see if nature can be improved upon or, where natural materials such as oyster shell for reef "core" rebuilding are not readily or economically available, to facilitate acquisition and utilization of substitute materials. Further on we will comment in more detail on them and make recommendations. (Also, see the several papers on alternate substrates in this volume).

Ideally, it would be excellent if reef restoration could be undertaken in every tributary or Bay area which formerly held successful and productive reefs. But, doing so would probably cost more than will be available at times when governmental budgets at all levels are apparently constrained. Consequently, priority areas must be chosen. In some measure these can be selected (screened) on the basis of ultimate purpose of the reefs, i.e. ecological restoration, possible pollution reduction and/or economic restoration—or even multipurpose fishing reefs. There may be some geographic areas which favor one or the other (or several) of these objectives. Further, design of reef structure and layout might be varied to achieve one or more of the purposes selected. In many areas of extensive and potentially productive public bottoms one design could serve all functions. Selection of such versatile reef designs should assist in justification, planning, and development of actual reef rehabilitation or rebuilding projects.

To achieve maximum restoration with minimum cost, effort and time we must take our cues from nature in making any site selections. Locations at which nature has been most effective in the past are prime candidates. This can be established from reliable scientific survey data. Early hydrographic charts, including boat sheets, incorporating the results of naval and civilian hydrographic expeditions can be useful. Most valuable will be actual oyster ground surveys reported by Winslow (1882—Md. and Va.), Baylor (1894—VA), Moore (1910—VA), Yates (1913—MD), Haven et al. (1981), Haven and Whitcomb (1983 and 1989) and Whitcomb and Haven 1987—VA) and others. When results of the survey recently conducted by the Maryland Department of Natural Resources (Jordan, personal communication) are finally processed, charted and made available, they should be employed for Maryland waters.

Data from objective and carefully done research and management surveys of both states are of great value and must be employed. Records of such activities as annual oyster ground (reef) surveys, spatfall surveys, disease and survival surveys and other such information are important. (If obtained and treated competently these fishery-independent data, coupled with available ***objective*** survey results, are the most valuable.) Reef rebuilding efforts which fail to incorporate all of the available useful elements of such sources of information should not be pursued. Funding agencies should demand no less.

In Virginia, preselection of sites for reef rebuilding should be based on Haven et al. 1981, and recent data obtained by Mann (personal communication) plus such other relevant site-specific data as are available. Additionally, once a likely reef area or even a specific reef has been identified the site selected should be carefully surveyed employing the most effective positioning and sounding techniques available. Actual probing and positive sampling should be conducted at each site to establish a sound basis for project design and later performance evaluations. Such surveys can be quickly conducted if confined to specific sites and pursued vigorously. Neither design nor construction should be done without this step.

From this discussion it should be apparent that the commonly employed process of selection and design and management by the political committees or pressure groups of "practical" watermen, or their allies, supporters or apologists, should not be utilized! The process *has never worked* in either Maryland or Virginia! It will not work in reef restoration efforts! Experienced, competent watermen can and should be involved (especially informed and responsible ones) but actual selection of sites, design or management *must be controlled* by applicable technical factors and by persons qualified to interpret them objectively and scientifically and not by harvester prejudice and preference. The overall interests of the public and its posterity as well as the users and the resource must be represented fully and fairly. History has clearly shown that management decisions based on political popularity or acceptability to industry or on compromise have been wasteful and fruitless! Management efforts of the past 125+ years *have not* achieved desired goals of restoration and subsequent continuation of self-renewing natural oyster populations and sustained yields! Most have failed completely (Kennedy and Breisch 1983, Hargis and Haven 1995, Rothschild *et al.* 1994)). The long-term interests of the general citizens of both states and their natural oyster resources and the potential productivity thereof *have not been well attended* by state managers!

Concerning possible sources of financing for sustained reef programs, each state has undertaken repletion activities for over a half century. Monies devoted to these state programs can and should be employed in state reef rehabilitation programs. Funds designed for habitat restoration and pollution-control activities can also be applied. Additionally, monies allocated to research and technological development could justifiably be used in reef rebuilding programs. Of major importance are careful follow-up studies of each reconstructed reef. Data, which must be collected annually at least (more often if necessary), should include oyster density, setting experience, growth, condition, disease levels, predator levels and mortality. Details of harvests and other removals are needed. Knowledge of applicable environmental parameters is necessary!

There is room for construction of experimental reefs. Some could even depart somewhat from nature's "tried-and-true" experiments. This is not a new concept. Oyster scientists have talked for decades of using experimental reefs to enhance the introduction and spread of scientifically-developed, disease-resistant or faster-growing broodstocks into estuaries with oyster-producing potential (Ruzecki and Hargis 1989). Were broodstock possessing such desirable genetic features available it could be "seeded", or distributed, to existing, rehabilitated or new reef areas by including it among the oyster shells (and live oysters) of the "veneer" layer. Different geometric configurations can be tried as well.

In Virginia the James River estuary has been the most successful, long-lived and persistent producer of seed, soup and market oysters of any estuary in the Commonwealth. At present, about 3,000-4,000 acres of the former James River "seed" area (or 1.5% to 2.0%) is the last economically significant oyster producer (market and seed oysters) of all 199,000 acres of Virginia's Chesapeake public beds. Its remaining producing reefs should be considered prime candidates as the foundation of reef recovery efforts. Because the public oyster reefs of the James have been so productive of market and seed oysters over the years and have actually been the basis of most market oyster production of private planters, restoration of the area is critical to the recovery of private planting activity using native *C. virginica.*

Based upon these factors we have recommended that reef rehabilitation and enhancement activities in Virginia be pursued in the James River "seed" area on a priority basis! This is not to discourage efforts in other areas such as the Piankatank or Great Wicomico seed areas or in the Rappahannock, which has been so productive of market oysters in the past, but the James should be given highest priority. Political pressures to the contrary should be strongly resisted. *Acquisence to them in the past has* *negated effective management of the public oyster resources of the James!*

Similar areas exist in the estuary of Maryland's Potomac River and its middle Chesapeake and in the lagoons and embayments of the Eastern Shores of both states. A larger area and number of Maryland's historically most-productive public reefs are in generally ecologically favorable situations than those of Virginia. Therefore, restoration of her public reefs should be easier and more economical and more quickly accomplished than those in most areas of Virginia's lower Bay.

Aspects of Reef Rebuilding Which Can be Recommended Today for the James River and Similar Estuarine Reaches of the Potomac and Maryland's Mid Bay on Both the Eastern and Western Shores

1. The most rapid and least costly recovery of reefs can be obtained by employing those Hard Oyster Reefs that retain significant (some) vertical relief and shell volume, have living young and adult oysters upon them and are known to "catch" spat. Simple closure, adequately enforced, is all that is required. The better the shape the selected reef is in [*i.e.* elevation above the bottom, firmness, suitable volume (size) and relief and similar geomorphological as well as favorable hydrographic factors] to begin with, the more rapid the recovery will be. Recovery of such active reefs could be hastened by judicial addition of oyster shell to the core, *i.e.* by "lifting" some of the living veneer off and replacing it after core enhancement, or replacing the displaced veneer by addition of living oysters from elsewhere. [Here we have attempted to separate the Hard Oyster Reefs into those with appreciable living oysters and those without (*i.e.* Hard Oyster Reef footprints).] A light "dusting" of clean oyster shells (*i.e.* 2,000 bu. per acre) over the living veneer of Hard Oyster Reefs each year will enhance set and survival in succeeding years. Of the various restorative techniques offered here and below, this is the best since it causes the least destruction to the oysters already living in the veneer. Closing the reef to harvesting for a period suitable to the intended function and future of that reef must follow shelling!
2. Where "living" producing reefs exist, their productivity can be restored and their recovery to former (or new) conditions and dimensions enhanced by adding new core materials, preferably clean oyster shells, to immediately adjacent hard bottoms, thus extending the basal extent of these reefs. Some of the living oysters in the veneer could be gently transferred to the enhanced "core."
3. On reef rebuilding sites with significant quantities of living oysters (*i.e.* 500 to 1,000 bu per acre) in the "veneer" some of the living oysters could be tonged or gently dredged and moved to other areas or stockpiled overboard nearby for replacement in the veneer of the reef being restored. Thus, possible destruction of living oysters by "smothering" would be reduced or avoided.

   However, great care must be exercised in conducting this phase of the operation to avoid destroying that which is being "saved." Moving of living oysters, which might have to be done twice should this course be decided upon, is usually destructive of the oysters being moved as well as those left behind. Perhaps the best strategy in such a situation is to add only small quantities of shells and/or seed, but to do so each year for a number of years.
4. Where appreciable quantities of living oysters are lacking on existing reefs, reef

rebuilding in the James, and similar areas, should take place on the "footprints" of Hard Oyster Rock as identified in Haven et al. 1981.

5. Some "experimental" reefs should be rebuilt or established anew in waters with depths of 1.8-2.4 m (5.9-7.9 ft) at M.L.W. (or greater if funds permit) and should extend upward into the intertidal. This will permit determination of the differences between setting and survival (and of levels of disease and predation) at one vertical level versus another. Provided, of course, that the experimental reefs are closed and protected and the time and methods of sampling and monitoring are adequate. It is extremely likely that the more-or-less persistent microhydroclimatological differences found at the different depth levels (or heights) of active three-dimensional reefs have been important to the overall past successes of those reefs, and will be to the new or restored reefs.
6. Rebuild some depleted reefs in strategic locations by reshelling to a depth of about 1 foot (30 cm). This will raise the bed slightly above the surrounding bottom and enhance setting and allow comparing results between activities numbers 5 & 6. This technique should be effective in areas of low sedimentation rates and on reefs with low disease and predator levels.
7. Where oyster shells are limited in availability reefs with greater vertical height and volume might be built with "<u>cores</u>" of locally-obtained mollusc shells such as surf clams, ocean scallop or oceanic and estuarine hard clam shells since they are similar in chemical and physical composition to oyster shells. However, cores can also be constructed of shale, small stones or cobbles, crushed rocks, railroad ballast stones, ceramics, ceramic and glass fragments (cullet "dulled," of course) bricks, clean building rubble of appropriate size, large stones, rocks or dolmans or even artificial cultch manufactured from other biologically-neutral materials. Whichever is employed, all should be topped with a veneer of clean oyster shell at least 15 cm (6.0 in.) thick. It is known that setting occurs on shell surfaces several inches or more beneath the outer layer of shells. Survival of spat on "interior" shell is often better than on that right at the surface because blue crabs and other such predators cannot get at them readily. The veneer also can be "seeded" with living oysters taken from similar sites to speed rebuilding. Living oysters apparently encourage setting (Hidu 1969). As indicated above, oysters with desired special genetic features could also be employed in the veneer if available.
8. All reefs (reconstructed, rehabilitated or new) must be closed to harvest and closely monitored.
9. Those restored reefs intended for economic harvests (*i.e.* Satellite Oyster Production Reefs—SPR, see Figure 8) should not be opened for harvest until they are ready, and when they are opened it should be done on an "allowable harvest quota" basis only. When the "allowed" harvest level is reached the reef should be *promptly closed* and allowed or even assisted to recover before harvesting thereon is permitted again.
10. Harvest quotas on SPR reefs can be adjusted to accomplish desirable rates of rebuilding as can further replenishment efforts and closure times. The quota concept could be modified or enhanced by employment of other "limited access" techniques but, whichever is employed, harvests must be restricted to the reef population's replacement and survival capabilities and to plans for eventual reef building.
11. Actual establishment of reefs or reef sites must be carefully done by competent personnel using accurate positioning

equipment. Adequate records of positions, including Loran, Raydist©, or GPS bearings (whichever is employed) and latitude and longitude are necessary.

12. Any SPR harvests permitted should be recorded accurately as to amount and kind taken (*i.e.* markets, soups, seeds, etc.) from *each specific reef* and the manner of and the time required for removal. Accurate and detailed knowledge of harvest location and time and effort devoted to harvests must be acquired in order to allow evaluation of success or failure of each reef and of the reef-rebuilding program.
13. Where harvesting is allowed after a reef is restored and producing, *in situ* culling of shell should be mandatory and strictly enforced. After shucking of market oysters, shells should be returned to the public reef program.
14. The status of all public reefs should be established twice yearly (or more as necessary) by careful fishery-independent surveys especially designed for such monitoring efforts.

Possible Sources of Oyster Shells for Cultch

Because their shapes and surface texture were established by the evolutionary processes of many millennia and are found in nature's successful "experimental" reefs, clean oyster shells (preferably recent; secondarily ancient) are the most desirable of all natural cultch materials for "core" construction or enhancement. Other suitable materials may be substituted in core construction if necessary, but clean oyster shells are by far the best material for reconstruction or enhancement of the veneer. For veneer rehabilitation every effort should be devoted to securing oyster shells. Some dilution by other suitable materials might be employed to "stretch" shell supplies, but *no* dilution is preferable.

Unfortunately, due to their destruction, misuse, misapplication and employment elsewhere (*i.e.* private plantings and previous public repletion efforts) oyster shells are now scarce. To secure oyster shells for reef enhancement or replacement programs may require the location of new sources, recovery of previously-used shells, use of mined "fossil"[2] shell, or in Virginia even by renewed harvesting of shells from extinct reefs (they are already being mined in Maryland). To assist in the reef rehabilitation efforts we have considered several different possible sources of oyster shells and offer the following:

Where Shell May Be Obtained

1. As late as November 1994 shell could be purchased from Langenfelder and Son, Inc. in Maryland and barged to the James River. Cost for 300,000 or more bushels, delivered to the James River seed area was then about $0.62/bu. Since there are 16.7 bushels per cubic yard, the cost was about $10.35 yd^3, according to Langenfelder personnel. Costs would have been higher for delivery to shallow sites since the cost advantages, economies of scale, of shipping in and planting from large, deep-draft barges are lost when shallow-water planting is required and smaller, shallow-draft barges must be used.
2. Recent and ancient shell deposits exist in Virginia. In the 1950s large volumes of shell were mined by a large suction dredge operated by Radcliffe Materials, Inc. in the lower James River. A study by VIMS in the late 1980s showed some "relict" shell deposits in other areas (Hobbs 1988). There are undoubtedly others. Hobb's study was purposely limited; it could be profitably expanded. It is suggested that the VMRC investi-

[2] These shells may well be merely "ancient" or old and many probably are. Use of the term fossil is probably inappropriate.

gate the possibility of controlled mining of shell for reef rebuilding in Virginia. Shell could be stockpiled on the Craney Island Disposal Area or some similar site for later use. (Incidentally, no further outward expansion of Craney Island disposal area shouild be conducted without prior removal of sub-bottom shells where they exist.)

3. Shell planted by the VMRC previously in areas currently unproductive might be recovered by VMRC dredge boats (or those of carefully controlled contractors —perhaps even paid cooperating watermen) and used again. Locations where shells have been planted are known to VMRC. Cleansing of such shells prior to planting would be important. One or more such boats could be equipped with rotating "washer" drums to clean the shells. Costs of such an operation should be investigated, and gear developed if cost-effective. One of us (Haven) was involved in the design and construction of relevant equipment in the 1970s. And it is known that others were also. Undoubtedly plans survive. It is entirely possible that such equipment still exists and that it is little used and could be acquired inexpensively.
4. In high set areas depleted beds might be restored by using shell currently buried around the margins of the reef. This shell could be lifted from the sand-mud cover by mechanical revolving steel fingers or tines on the head of a Maryland-type soft clam harvester. Such a machine was developed by VIMS in 1973 to harvest oysters and hard clams (Haven et al. 1979). It could be modified and improved to raise and clean old buried shell to be redeposited on reefs being "shelled".
5. For compelling socioeconomic reasons, sattelite production restoration reefs (SPR) might be located near isolated communities such as Smith Island in Maryland and Virginia and Tangier Island in Virginia early on. The inhabitants of these locations have very few choices in remunerative employment.

Summary and Conclusions

Natural oyster reefs consist of a supportive "core" of "cultch" --oyster shells, and shell fragments in a matrix of sand, clays or silts overlain by a veneer of living oysters and shells of the "recently" dead. The core of dead oyster shells continually renewed by receiving the "mortal remains" of successive populations of live oysters living in and on the "veneer" constitutes the greatest volume by far. The core is the reef's "framework" and provides (undergirds) the basic height and contours of the reef.

It is the veneer of the shells of living oysters and recently dead ones which "welcomes" maturing eyed-larvae, receives spatfall, and provides support for the survivors and shelter from predators. The living oysters on and in this veneer encourage the setting of mature larvae. They also filter particulate matter from the water and thereby clarify and cleanse it. Other benefits to living oysters are provided by the upthrusting reefs. Their elevation enables a sizeable portion of the reef's oyster population to be above the disturbing influences of the estuary's bottom thereby reducing the negative effects of sedimentation and of exposure to their own wastes and those of other infauna and epifauna. Also, it is likely that exposure to infective particles is reduced for those individuals on the upper levels of the reef. Zonational microhydrological effects resulting from three-dimensional aspects of such reefs may also enhance setting, survivability, growth, reproduction and recruitment.

The larger (older) mature living oysters of the reef provide the essential genetic building blocks which, given time and proper management, will lead to improvements in such features as rapid, robust growth, disease resistance, adaptation to other natural and man-made stressors. Further, it is these living oysters of the reef's veneer which provide the most spawn and larvae per individual to the home reef, nearby reefs and others "downstream". Of course, smaller and younger sexually mature and reproductively active oysters supply gametes as well.

Rational restoration of existing reefs (i.e. with appropriate elevation), or rebuilding (on old reef "footprints" now at or sufficiently close to the surface to provide a ready foundation) will restore natural oyster production in Virginia and Maryland—eventually. Restoration or rebuilding should be based upon the locations of currently active or recent reefs (preferably) or old ones (secondarily) to take advantage of nature's past successful experimentations. The former dimensions of the historically-productive reefs should be emulated as closely as possible as should the materials employed.

Actual sites for reef enhancement should be selected by competent oyster biologists, with assistance of other scientific personnel, including estuarine circulation specialists, hydraulic engineers, geologists, toxicologists, and such other specialists as may be necessary. Information from knowledgeable and responsible oyster harvesters should be sought. All available relevant information, including past survey and monitoring data, harvest data, information related to current distribution and abundance of oysters (including reliable input from harvesters) should be employed.

To have a significant reef rehabilitation or reconstruction program the successful "designs" of nature (outcomes of countless evolutionary experimentations) should be fully employed, as emphasized above. But, there is room for consideration of alternate materials and different "designs", and even alternate sites, where such might enhance reef rebuilding or replacement activities or where the new reef to be built will perform some desirable purpose. For example, some sites in disease-endemic areas might be chosen for development of disease resistance in surviving reef populations. Those sites now bearing surviving adults should receive priority (of course, surviving older oysters from such areas could be used to provide "resistant" young on reefs being rebuilt in disease endemic areas.) Other places might be selected to enhance filtering of sediments and pollution control to encourage SAV recovery in a specific site or sites. Still others might be selected to provide fishing reefs readily accessible to numbers of sport fishermen. Also, experimentation with alternate materials in selected sites may be desirable to improve reef planning, construction or performance and/or reduce costs. Further, it is highly likely that deliberately designed reef restoration configurations should be used to modify local hydrodynamic features so as to enhance and speed reef rejuvenation.

If rapid (relatively speaking) repopulation is the primary objective, the initial and basic reef rebuilding effort should be directed at those sites which are known to have received "good" sets in the past (and likely could do so again), and/or which offer the best chances of survival. Preference should be given to those with significant populations of living oysters. Seeding with appropriate broodstock could enhance reef rehabilitation. In the James River seed area (and similar systems elsewhere in the Chesapeake) existing productive reefs *are the best such sites!* Numerous suitable reef areas exist. In the James estuary of Virginia priority should be given to those in the Point of Shoals—Swash region, *i.e.* East and South-East of Mulberry Island (see Figures 4 and 5). The Wreck Shoal area, and/or suitable sites nearby, would probably be prime locations for disease-resistance monitoring and experimentation. (In 1992-93 and 1993-94 both prevalence and intensity of MSX and Dermo disease declined in these two areas as did disease-induced mortality.)

Additional studies or surveys may be necessary, especially those directed at location of new or more economic sources of oyster shell. Other activities should be directed at discovering or developing alternate materials for "core" and the non-living portion of the veneer. Studies on costs and availability are needed.

Past oyster repletion programs, while ineffective at restoring natural oyster populations over the long run, do provide information which will help future reef restoration and maintenance efforts. For example, a Maryland study established that 2,240 Md. bushels of "ancient" oyster shells would cover 1 acre of bottom, about 2.5 cm (1 in) deep and at a cost of $1,388 per acre (at the time of that study). Obviously, future shelling efforts or extensive reef rebuilding or construction efforts would be enhanced by careful evaluation of the various options available and of the cost-benefits thereof.

We conclude that restoration of oyster reefs, the "preferred" habitat of our native oyster (*C. virginica*), on the public oyster grounds of the Chesapeake followed by subsequent effective management (as indicated in detail above) offers *the best hope* for restoration of self-renewing natural oyster populations. (Most likely, other aggregating crassostreid oysters do best in off-bottom situations as well.) *Even in areas where* C. virginica *populations are at a very low level, sufficient potential for such renewal exists as to offer the most likely opportunity for "relatively rapid" restoration of oyster populations in the Bay and on the Eastern Shore, and elsewhere.* Surviving, reproductively-capable native oysters occur in many places in the Bay and its tributaries. These resources should be carefully husbanded and employed in the public reef restoration effort in responsible fashion! To be effective, all reef rebuilding or replenishment efforts must be accompanied by effective closures—closures adequate to the purposes of the restoration program. Upon an effective reef renewal program depends the future of the Chesapeake (*C.virginica*) oyster resource and its ecological functions and economic utility. Should Bay "public" oyster populations be allowed to continue their decline into ecological insignificance and economic oblivion the citizens of both states, and their posterity will suffer. And Virginia and Maryland watermen and their posterity will lose access to yet another economically-productive resource. Soft clam and hard clam populations are much reduced in Maryland and self-renewing, harvestable populations of natural hard clams are destined to drop in Virginia. As well, populations and commercial catches of many edible finfish are down Baywide and Chesapeake blue crab populations appear threatened. Economic disappearance of the oyster will seriously reduce the economic opportunities of Chesapeake watermen. It will also cause the attention of remaining watermen to be focussed even more heavily on blue crabs and hard clams and hasten their economic demise.

As matters now stand, the future of public watermen in the Bay is not bright. All of these self-renewing natural resources of the Chesapeake must be carefully and realistically restored and/or husbanded if watermen and their livelihoods and the character, productivity, ecological stability and diversity of the Chesapeake, itself, are to persist. Both Virginia and Maryland should make strenuous efforts to rehabilitate oyster populations by restoring their "favored" habitat, the self-renewing public reefs.

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