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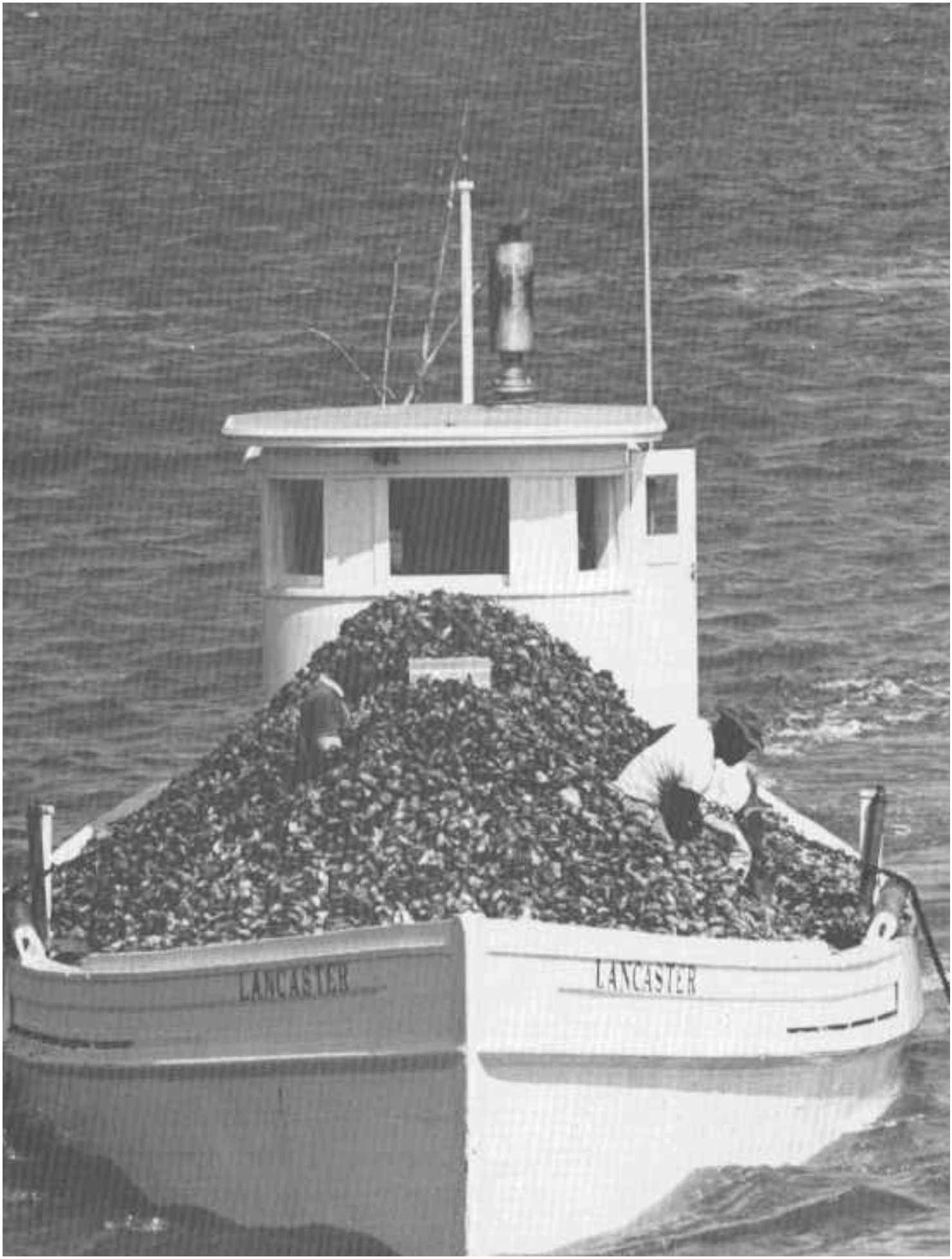
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Managing Maryland's Oyster Industry

For more than 150 years, management of Maryland's oyster resource has been the subject of varying degrees of controversy. Different commissions and boards and departments have been established to oversee the general management of the resource and its harvesters. But the Maryland General Assembly has had the major influence on its use, through the various laws it has promulgated. Because legislators are sensitive to the concerns of watermen and processors, many laws have been passed which have affected management of the oyster resource but which have had no sound basis in biological or economic reality.

In this section, we trace first a general history of the fishery, in the belief that "Those who cannot remember the past are condemned to repeat it." It is instructive to note that 1981 is the centenary of an insightful report by Lieutenant Francis Winslow who carefully surveyed the oyster grounds of Pocomoke and Tangier Sounds. Winslow recommended the appointment of an investigative and regulatory commission for oversight and management of the then declining resource. Thus, the Oyster Commission was formed in 1882. It produced the first of at least six major reports (the rest from five other commissions or committees of one kind or another) that were written during the next century detailing the decline of the Maryland oyster and the actions that might halt and reverse that decline.

Our historical survey is followed by a physical description of the Bay's oyster grounds in Maryland, as they were and are. Then we survey the rehabilitation measures that have been proposed in the past by many investigators. There is a certain similarity to the reports which we will focus on to demonstrate that there has been long and general agreement over the past 100 years as to what the rehabilitative measures should be. For that reason also, we do not really make any recommendations of our own. We let the weight of past statements speak for themselves. Finally, we conclude with considerations of aspects of oyster farming or cultivation.

Throughout this section, we rarely refer to the situation concerning the Potomac River oyster resource. Because this river is totally in Maryland, yet with its southerly bank being Virginia territory, the management of the oyster resource

An oyster buyboat dredges up spat-holding shell from the state's oyster seed grounds for replanting on the public fishing grounds, an important part of the annual oyster repletion program managed by the Maryland Department of Natural Resources.

and its partitioning among watermen of the two states has been, until recently, a matter of long-standing controversy (Ingersoll 1881, Stevenson 1894, Power 1970). The mainstem of the river is administered by the Potomac River Fisheries Commission, a bi-state organization, whereas the tributary creeks come under the administration of the respective state resource agencies. A description of the oyster grounds and the fishery, along with management recommendations, is included in Davis et al. (1976).

HISTORICAL BACKGROUND

When the first European settlers arrived in the Chesapeake Bay region, they encountered a cornucopia of biological resources, not the least of which was the oyster. Reports of this bounty are described by Wharton (1957) in his historical treatment of colonial Virginia's fishing activities. Two examples are impressive: He quotes William Strachey who wrote in 1612,

> "Oysters there be in whole banks and beds and those of the best. I have seen some thirteen inches long. [The Indians]...hang the oysters upon strings...and [dry them] in the smoke, thereby to preserve them all the year."

He also quotes a Swiss visitor, Francis Louis Michel, who wrote in 1701,

> "The abundance of oysters is incredible. There are whole banks of them so that the ships must avoid them. A sloop, which was to land us at Kingscreek, struck an oyster bed, where we had to wait about two hours for the tide. They surpass those in England by far in size, indeed they are four times as large. I often cut them in two, before I could put them into my mouth."

The presence of such bounty presumably was welcome to those dependent on a subsistence existence in the early days of the colonial period, although some "Kent Islanders," in the Clairborne suit of 1680 related hardships so severe that: "...their supply of provisions becoming exhausted, it was necessary for them, in order to keep from starvation, to eat the oysters taken from along the shores" (Stevenson 1894). However, as immigrant populations increased and tongs and then dredges appeared, inroads into the oyster population began. Quantitative production data were apparently not collected until about 1839, when the yield in Maryland was 710,000 bushels. Soon, many of the large reefs in Tangier Sound were discovered and the fishery expanded greatly (Stevenson 1894).

Meanwhile, the oyster beds of New England had become badly depleted throughout the 18th Century by overfishing (Ingersoll 1881, Sweet 1941). The

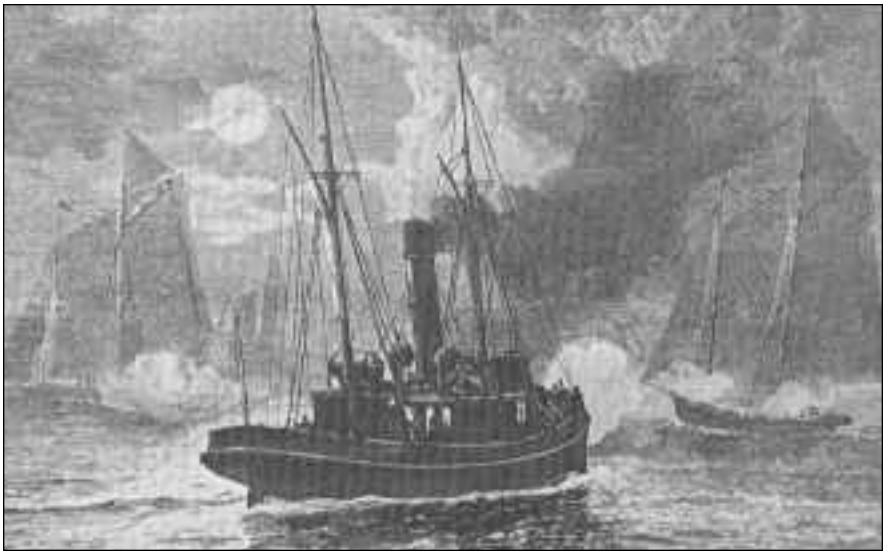
center of the U.S. oyster industry had been in Connecticut; from there, apparently beginning about 1808 (Stevenson 1894), dredge schooners traveled to New Jersey and Virginia. In 1811, Virginia passed legislation prohibiting dredging in its waters, forcing the fleet north up the Bay to Maryland. Concern about such fishing led the Maryland legislature in 1820 to enact its earliest oyster-related law, prohibiting both oyster dredging in the state and the transport of oysters from the state in ships not wholly owned for the preceding year by Maryland residents (Stevenson 1894, Grave 1912, Nichol 1937). This fact (Grave 1912), coupled with the building and improvement of transportation systems such as the Baltimore and Ohio railway and national turnpikes (Nichol 1937) and the desire to be closer to the principal source of supply (Sweet 1941), led established Northern oyster packers to open branch plants in Baltimore in the mid-1830's. These plants exported increasing quantities of oysters to western communities. The demand on Maryland oyster resources thus rose, with the number of processing establishments (including raw packers and steam packers or canners) in Baltimore increasing from one in 1836 to 80 in 1868 (Nichol 1937). By 1869-1870 the oyster harvest amounted to about nine million bushels.

Associated with this great increase in harvest were changes in legislation concerning harvesting techniques and fishing regulations (Stevenson 1894, Grave 1912). In 1836 (Dorchester and St. Mary Counties) and 1840 (Somerset County), burning oysters for agricultural fertilizer (lime) was prohibited. In 1846, Worcester County established a closed season (April 13 to September 1), the first in Maryland and one of the earliest in America. In 1852, Worcester County banned the removal of any shell from its reefs. In 1854, the use of small dredges (scrapes) was allowed in certain waters of Somerset County with a license that cost $15; it was the first oyster license law in Maryland and one of the first in the nation. Similar laws were enacted in 1870 and 1874 with regard to certain waters in Dorchester and Talbot Counties, respectively. In 1865, the old general oystering laws were abolished and a new set enacted, including adoption of a state-wide license system governing tongers, scrapers, and dredgers. However, the revenue anticipated as a result of this General License Law was not forthcoming because of its unpopularity with watermen, so, in 1868, a State Fishery Force ("Oyster Police") was established. For the first decade or so, the "Oyster Navy" was maintained by the licensing revenue, but thereafter the fees were insufficient to underwrite all costs (Grave 1912).

In terms of oyster culture, in 1865 and 1867, legislation was enacted to allow individuals to plant oysters on five-acre plots of barren bottom. This was an increase from the one-acre provision of a similar law passed in 1830 (Stevenson 1894, Power 1970). Grave (1912) noted, however, that the 11,000 or more acres of bottom that were preempted in this way were used mainly to hold oysters ("bedding") rather than for the growing or culturing of young oysters.

A major problem facing those who wished to manage the oyster resource scientifically a century ago was the recalcitrance and suspicion of watermen and their local elected representatives towards such management attempts. This, indeed, remains a problem even today, when the resource has declined to a frac-

tion of its potential. In 1905, Brooks noted that no one would risk oyster farming on leased bottom because dredgers and tongers did not recognize private property rights on oyster grounds. Numerous incidents involving theft of oysters from leases occurred in early years (Brooks 1905, Green 1916) although this problem declined in severity with the strengthening of the oyster police force.



Maryland State Fisheries' patrol boat in an engagement with oyster pirates in 1886

However, a prevailing attitude in tidewater communities has been that oysters were, and are, a common property resource and that no one, especially non-Marylanders, should be allowed private control over good oyster grounds. Coupled with this has been a concern that private corporations might take advantage of leasing laws and occupy large tracts of oyster grounds, denying access to independent watermen. Further, packing houses might stock oysters on leased ground to ensure a constant, reliable supply, using its own employees to harvest this stock as needed and bypassing the oystermen. Watermen have always feared that they would eventually lose out in any competition with big business for oyster grounds.

Finally, there remains a concern that oyster farming activities would lead to such an increase in oyster production that supply would far exceed demand. Watermen have feared the depressed prices that might result from glutted markets; thus, they have consistently pressured their representatives to protect their perceived interests. As a result (as will be shown below), sound management practices have been delayed or hindered by Tidewater legislators who have held great power in the legislative bodies which enact regulations governing the oyster fishery.

Intensive Biological Studies

Oyster harvests continued to increase to a peak of 14 million bushels in 1874. A five-year decline followed, the harvest reaching 10 1/2 million bushels in 1879. This decline resulted in the commissioning of a survey of oyster grounds in Pocomoke and Tangier Sounds, Maryland, in 1877-79 under the direction of Lieutenant Francis Winslow of the U.S. Coast and Geodetic Survey (Winslow 1882). These two sounds had very extensive oyster beds then subject to intensive fishing pressure. This thorough survey, using a coast-survey schooner, delineated a large area of the beds and estimated the number of oysters they held. The character of the bottom beneath the beds and the condition of sedimentation were determined, temperatures and specific gravities of surface and bottom waters were measured, and spat collectors (tiles) were deployed to study settlement of oysters and their growth rates. (All but one of 24 bundles of these tiles were destroyed by vandals, demonstrating the early resistance of oystermen to any attempts to study the resource scientifically). The information collected in this survey provides insight into conditions prevailing on oyster grounds a century ago when only a few major areas had been fished intensively. Winslow (1881) summarized his findings:

1. The once-compact beds had been enlarged by dredging, which dragged oysters off the rocks and on to the surrounding soft bottom, and by culling, which dropped shell and undersized oysters overboard onto new ground.

2. In spite of such a real enlargement, the number of oysters had declined since the fishery began, as documented from 1878 to 1879 on certain beds in both Sounds.

3. Unfished oyster beds were found in Chesapeake Bay waters adjoining the sounds. They had distinct and contrasting characteristics when compared with deteriorating oyster beds in the sounds. Overworked beds generally had much mud or sand among the shells which in turn were infested with worms and were broken and bored in many places; oysters were found singly or in clumps of two or three and were large and broad, not long and thin; the meat was plump. Unfished beds contained oysters in clusters of three to fifteen, with clean shells free from worms and often with large red sponges attached. The mature oysters were long and narrow with thin sharp bills and long, thin bodies.

4. Unfished beds were hard, requiring greater force to dredge the oysters from the main body of the bed than was required on previously worked oyster beds. Broken shell and debris made up about 30% of the material dredged up from unfished grounds. On worked beds, this percentage was higher, reaching 97% on some beds in Pocomoke Sound.

5. In 1879, all oysters examined were classified into two mature classes and two young classes. Over 20,000 oysters were measured and classi-

fied from unfished beds. The ratio of young to mature oysters was 3:2. Over 100,000 oysters were collected from fished beds in the sounds and a ratio of 3:6 was noted. Thus, on unfished beds the young outnumbered the mature oysters, whereas on fished beds the reverse was true.

6. In Pocomoke Sound in 1879, the number of oysters per square yard on every bed was considerably less than in 1878 and was also much lower than the number per square yard in the unfished beds of the Bay.

Winslow (1881) recommended two actions. The first involved placing materials such as ballast, water pipes, and shells on appropriate bottom in the direction of tidal currents to serve as spat settlement areas which could extend the beds. This cultch would be exposed late in spring to ensure its cleanliness. Mature oysters would be added with this material to aid in providing for and attracting spat. The second recommendation involved appointment of a commission of "intelligent individuals" having specialized knowledge of the oyster and its industry which was to be allowed considerable power (free of political interference) to regulate dredging, protect spat and young oysters, close beds when necessary, destroy predators, and expose cultch in order to rehabilitate oyster grounds.

In 1882, an Oyster Commission comprising three men, including Dr. W. K. Brooks of Johns Hopkins University, was appointed "to examine the oyster beds and to advise as to their protection and improvement" (Brooks 1905). Brooks had earlier discovered that Crassostrea *virginica*, unlike the European *Ostrea edulis*, expelled its gametes into the water where external fertilization and development occurred (Brooks 1880) and he was very familiar with the eastern oyster and its fishery. However, not everyone considered Brooks to be knowledgeable. He noted (1905):

> "I speak on this subject with the diffidence of one who has been frequently snubbed and repressed; for while I am myself sure of the errors of the man who tonged oysters long before I was born, and who loudly asserts his rights to know all about it, it is easier to acquiesce than to struggle against such overwhelming ignorance, so I have learned to be submissive in the presence of the elderly gentleman who studied the embryology of the oyster when years ago as a boy he visited his grandfather on the Eastern Shore, and to listen with deference to the shucker as he demonstrates to me at his raw-box, by the aid of his hammer and shucking-knife, the fallacy of my notions of the structure of the animal."

The Oyster Commission made a survey of oyster beds throughout Maryland's portion of the Bay and noted a rapid deterioration. In 1882, they found an average ratio of 1.3 bushels of oysters to each bushel of shell. This was a decrease from Winslow's ratio of 1.9 bushels in 1879 and from Lugger's ratio of 3.7 bushels in 1876 (Winslow 1884). Similarly, Winslow's survey of Tangier Sound in 1878-79 recorded about one oyster in every 2.3 yd^2. In 1883, Brooks found only one oyster per 4.2 yd^2 in the same sound (Winslow 1884). Thus the decline in oyster landings was found to parallel the decline in and deterioration of the oyster grounds in the Bay.

Oyster Culture Recommended

The Oyster Commission recommended conservation measures, the establishment of a system of oyster farming, and also a system of private oyster culture beyond that envisaged in the Five Acre Planting Law (Brooks 1905, Grave 1912). But in 1884-85, about 15 million oysters were harvested, apparently due to an excellent set of oysters in 1883 (Stevenson 1894). It was the peak harvest ever for the Bay and it served to encourage state legislators to ignore the Commission's recommendations (Grave 1912). The catch thereafter declined to its present low level, with only a few periods of slight increase.

The legislature did pass the Cull Law of 1890, which Grave (1912) considered to be the most efficient method ever devised for the protection of natural oyster beds. Among other things, the law required that shells with spat and young oysters be thrown back ("culled") on the beds from which they were dredged. It also set a minimum legal size of 2 1/2 inches for market oysters. Maryland was one of the first states to attempt the enforcement of such a law (Stevenson 1894).

As catches continued to decline at the turn of the century, a Baltimore attorney, B. H. Haman, defended the concept of oyster culture and submitted bills on this matter to the legislature. He was backed by farmer's clubs and organizations which favored the Oyster Commission's recommendations. However, delegates from the tidewater counties derided these bills, expecting the fishery to repeat its 1885 rebound (Grave 1912). But the decline had set in, resulting in the closing of a number of packing houses in Baltimore as the export source steadily withered away (Nichol 1937). As Commissioner Brooks (a strong supporter of private culture) noted in the preface of the second edition (1905) of his important report on the results of the Oyster Commission:

> "...the oyster grounds of Virginia and North Carolina, and those of Georgia and Louisiana, are increasing in value, and many of our packing houses are being moved to the south, but there is no oyster farming in Maryland, and our oyster beds are still in a state of nature, affording a scanty and precarious livelihood to those who depend upon them."

These comments came fifteen years after the first edition appeared with its extensive recommendations.

Thus, by 1906, the time was ripe for passage of the Haman Oyster Bill. The law, as amended in 1912, allowed individual leases up to 30 acres in county waters (except Tangier Sound where 100 acres was the limit) and up to 500 acres in the Bay beyond county boundary limits. Though it was made largely ineffectual by amendments by its opponents (Grave 1912), the Haman Law did provide for a Shell Fish Commission in 1906 (one of its members was C. Grave, a student of W. K. Brooks). As the oyster catch continued to decrease, the Shell Fish Commission in 1908 and then in 1910 attempted to persuade the legislature to amend the Haman Law to allow for successful oyster farming. Instead, the Commission's recommendations were ignored, and the 1910 Reshelling Act was passed. It provided for a one cent per bushel tax to provide a fund for the reshelling of certain depleted bars. The courts declared it unconstitutional (Grave 1912). In 1914, the Maryland General Assembly passed the Shepherd Act to allow for resurveying of disputed bottom and to distinguish between "natural" and "barren" grounds, with the result that additional acreage was reclassified to "natural" oyster bar and not available for leased ground. These procedures have greatly hindered granting of oyster leases (Power 1970).

Continued Decline

In 1906, the Shell Fish Commission embarked on an ambitious six-year survey of the natural oyster bars of the state in cooperation with the U.S. Coast and Geodetic Survey. It was called the Maryland Oyster Survey, and was under the control of C. C. Yates, who published a series of very important reports dealing with distribution of oyster beds in different regions of the Bay.

The Maryland Oyster Survey was the last extensive biological and environmental survey of Maryland's oyster bars until the last decade or two. After six years' work, it resulted in publication of 17 official documents and 43 large-scale charts, for a total of 2400 printed pages and 400 square feet of charts (Yates 1913). This was coupled with a comprehensive technical report by the Board of Shell Fish Commissioners (Grave 1912).

All of this material supplemented the earlier work of the 1882-1884 Oyster Commission (Brooks 1905) and the Winslow survey of 1878-79. In addition, the economic, historical, and social aspects of the fishery had been treated by Ingersoll (1881) and Stevenson (1894).

This tremendous accumulation of information, although incomplete in some details of the life history of oysters (for example, the behavior of oyster larvae and the factors affecting spat settlement were unknown), was undoubtedly sufficient for arresting the decline in production and for restoring the former economic strength of the industry, including the oyster packing industry. However, the efforts at rehabilitation were of minimal value because the socio-political roots of the problem were ignored or only partially considered.

In 1916, the Maryland Conservation Commission was created, consolidating the Shell Fish Commission, Fish Commissioners, the State Game Warden, and the State Fishery Force (Oyster Police) under one administration (Earle 1932). The sailing vessels of the State Fishery Force were replaced by a steamer and power boats.

In 1922, legislation allowed for annual, extensive placement of shell as cultch on depleted oyster bars, but funds were limited. Funds were supplemented in 1927 by an act requiring oyster packers to make 10% of their shucked shells available for state use. Work boat gasoline taxes and a small appropriation allowed for the establishment of an annual rehabilitation fund. By 1932, the State was planting about one million bushels of oyster shell on natural bars as cultch (Earle 1932). However, due to the nature of local politics, in which watermen were consulted on the placement of shell, the initial planting activities were generally failures, with but few exceptions (Truitt and Mook 1925, Beaven 1945).

In 1931, construction of the Chesapeake Biological Laboratory was begun, providing a base for the work on oysters of R. V. Truitt and later of G. F. Beaven and other associates. In conjunction with the laboratory, an experimental "oyster farm" was established in the Honga River (State Planning Commission 1935). This was a 1000-acre area of bottom which was established as a reserve for experimental use by the laboratory. It was in a region which had proven to have numerous oyster larvae in the water, although the oyster grounds had been badly overfished. Over a three-year period, 42,000 bushels of shell were planted on one 50-acre section. About 4,000 bushels of seed were harvested in fall 1934 from a four-acre patch within the planted section. It was estimated that 50,000 bushels of seed had set where oysters had not been produced for years (State Planning Commission 1935). Dr. Truitt continued research in this area for a few more years but then the experimental region was turned over to public use as a tonging bar, apparently against Dr. Truitt's advice and to the ultimate detriment of the area and the seed program (Wharton 1959).

In their report of 1935, the State Planning Commission noted that the 51% decline in oyster yield in Maryland from 1910 to 1932 resulted from "...a continuation of the unsound conditions and short-sighted policies that have characterized and controlled the industry's operations over a long series of years." They noted that the decline could be traced to overfishing, the wholesale export of seed oysters out of state (for example, in 1879 over two million bushels of seed oysters were shipped north from Maryland), and the failure to return adequate supplies of cultch to the Bay. This had resulted in the destruction of the canning industry with a loss of $750,000, a loss of employment for watermen and canning industry workers, and a dependence on other states for large, high-quality oysters. Their recommendations included:

1. Resurveying of oyster bars for effective policing, determination of developmental areas, and guidance in formulation of conservation policies. They estimated such a survey to require one year.

2. Developing seed areas such as Eastern Bay, upper Honga River, and the Head of the Bay (the latter area now no longer suitable due to the depletion of oyster grounds and the danger of high mortalities from fresh-water runoff from the Susquehanna River).

3. Planting of two-thirds of the seed developed on seed areas in public bars of proven ability with the remainder being made available for private use.

4. Planting of shells as cultch on suitable grounds having sufficient brood stock.

5. Amending leasing laws to allow a lease to include 250 acres of ground, and removal of limitations on who holds a lease (note that Powers (1970) declared that such discrimination is unconstitutional).

6. Increasing potential lease areas.

Finally, the State Planning Commission's report (1935) described some successes and failures in the state's shell planting activities. On Harris Rock, where 60,000 bushels had been planted, little or no set resulted over a five-year period. On Carrol's Bank, a good oyster ground in the Patuxent River, shells were planted on top of oysters, smothering them and injuring the bar. On the other hand, 9,000 bushels planted on Middleground Bar in the Patuxent yielded one bushel of oysters for each bushel of shell planted, a ratio also attained on the experimental area in the Honga River. The report urged that shell plantings be made with an understanding of conditions in the area being restored. Further, the greatest benefit from shell planting came in areas which produced Maryland's least desirable oysters (presumably stunted, although this was not stated) due to an abundance of brood oysters and, therefore, of spat. In ravaged Tangier Sound, shell plantings were generally a failure at the time because of limited numbers of brood oysters. The State Planning Commission (1935) recommended that every shell taken from Maryland waters be returned in order to meet the great need for restoration of the oyster grounds.

In 1942, the Tidewater Fisheries Commission undertook a large seedgrowing and transplanting operation (Maryland Commission 1948). This was to be made self-supporting by collection of ten to twenty cents per bushel of oysters taken from planted bars. From 1940 to 1946, 211,000 bushels of oysters were harvested. The planted seed had cost the State $96,000. Taxes recovered were $42,000 (Maryland Commission 1948).

In 1947, the shell tax on shucking houses was increased to 20% of the shell produced during shucking of the catch (Maryland Board of Natural Resources 1951). Apparently the idea was that shells of oysters are containers which belong to the state and which must be returned to the water (Maryland Board of Natural Resources 1951). In 1951, new legislation required that the state receive 20% of

all shells shucked by commercial establishments, plus the option to purchase an additional 30% (Maryland Board of Natural Resources 1952). Only Baltimore City shucking houses were exempt, because of the ban on storing shells within city limits. In 1953, the state was empowered to collect 50% of all shells produced by packers, etc. (Maryland Board of Natural Resources 1955). However, even this amount was not enough to provide for the appropriate level of shelling activity, and efforts were made to find quantities of dredged shell to supplement the fresh shell (Maryland Board of Natural Resources 1960).

In the early 1960's, state resource managers again recognized that overfishing was rapidly depleting the resource. They reported that many small oysters were being sold and that much shell was being lost. Scarcity was causing high prices, and undersized oysters were sold readily (Maryland Board of Natural Resources 1962). In 1961, the state implemented an oyster repletion program with oyster shells from non-producing areas of the Bay being dredged and distributed over public oyster beds. By 1963, the amount of fresh shell planted by the state was the smallest for many years, due in part to the sale of oysters to out-of-state buyers (Maryland Board of Natural Resources 1963).

In spite of the well-demonstrated need to retain shell as cultch, in 1965 Maryland passed a law that reduced the percentage of fresh shell that packers were required to make available to the state from 50 percent to 25 percent (Maryland Board of Natural Resources 1965). What is more, the packers had the option of keeping the shell and paying the state cash for it instead. In the early 1960's, large deposits of old "fossil" shell had been found and were being dredged at the state's behest to supplement the planting program that had previously depended exclusively on fresh shell. Presumably, with the supply of old shell then available, packers were free to find other markets for their fresh shell. In a recent study, Cabraal and Wheaton (1981) determined that fresh shell was a better cultch material than dredged shell. This seems to be the only economic study detailing the benefits that accrue to the state from its purchase and planting of dredged old shell. The concept that the state owns the "container" from which the processor is privileged to extract oyster meat apparently fell out of style in the mid-1960's. Some statistics on shell planting activity are available in Suttor and Corrigan (1968) and Outten (1980).

Current Management

Management of the contemporary oyster fishery is the responsibility of the Tidewater Fisheries Administration of the Maryland Department of Natural Resources. Their shellfish effort includes traditional management practices such as:

1. Establishing fishing seasons, catch limits, and harvesting gear.

2. Granting licenses for harvesting from the public grounds and leasing plots for private planting.

3. Resolving conflicts between oystermen and clammers, between dredgers and tongers, or tongers and divers.

4. Keeping records on annual harvests and on recruitment of new oysters on public fishing grounds, seed areas and private planting plots.

5. Reviewing with the Maryland Department of Health and Mental Hygiene the public health quality of shellfish beds.

6, Transporting oysters from shellfish beds closed because of potential pollution to unpolluted growing and harvesting areas.

7. Organizing an annual oyster seeding and shell planting program to rehabilitate the fishing grounds.

8. Planning and participating in research efforts designed to improve efficiency and harvest productivity.

In addition, the Maryland oyster management program is currently conducting a resurvey of all the state's traditional and potential oyster grounds, the first new survey since the Maryland Oyster Survey of 1906. The resurvey will establish the extent and character of the fishing grounds and may provide a basis for re-instituting the awards of new leases for oyster farming. The General Assembly in 1972 declared a moratorium on the award of new leases, pending completion of the survey (Jensen 1981).

The annual oyster seed and shell planting program is considered one of the most important management practices for maintaining levels of production during periods of poor natural reproduction (Ulanowicz et al. 1980). The major sources of shell for this effort are: (1) fresh shell acquired from local shucking houses under the current shell tax, and (2) dredged shell dug up from beneath the sediment covering "fossil" beds of shell in the northern Bay. During the 1960's and 1970's, the state was normally contracting for the dredging, washing, and replanting of 5 million bushels of dredged shell a year.

Those "fossil" shells provide the vast bulk of the shell planting effort, outranking fresh shells during the late 1970's by more than nine to one (Cabraal 1978). In 1976, for example, dredged shell totaled 90 percent of the new cultch, fresh shell only 9.6 percent. For dredged shell, 4.4 million bushels went to permanent plantings along the public fishing grounds, 560,000 bushels went to seed areas. For fresh shell, 531,000 went to the public grounds, only 1900 to seed areas.

Nearly all the oyster seed for the program comes from 1200 acres of off-limits seed areas that have proven highly productive in the past for spat settlement (Cabraal 1978). Every spring the Tidewater Fisheries Administration organizes a major seed planting program, contracting with watermen who dredge spat-carrying shell off the seed areas and replant them along the open fishing grounds. In a

very literal way, this shell and seed planting program lays the foundation for future harvest.

To organize this effort every spring, fishery managers draw up a distribution plan that outlines where in the Bay the seed and shell will go. They review the plan with committees of watermen and consider a variety of factors including economic conditions in each county, the number of watermen living in each county, the number of shell bushels and seed bushels planted in each region in recent years, the biological condition of the waters, and the number of oysters harvested there (Cabraal 1978). Their plan usually combines economic, political, and biological factors.

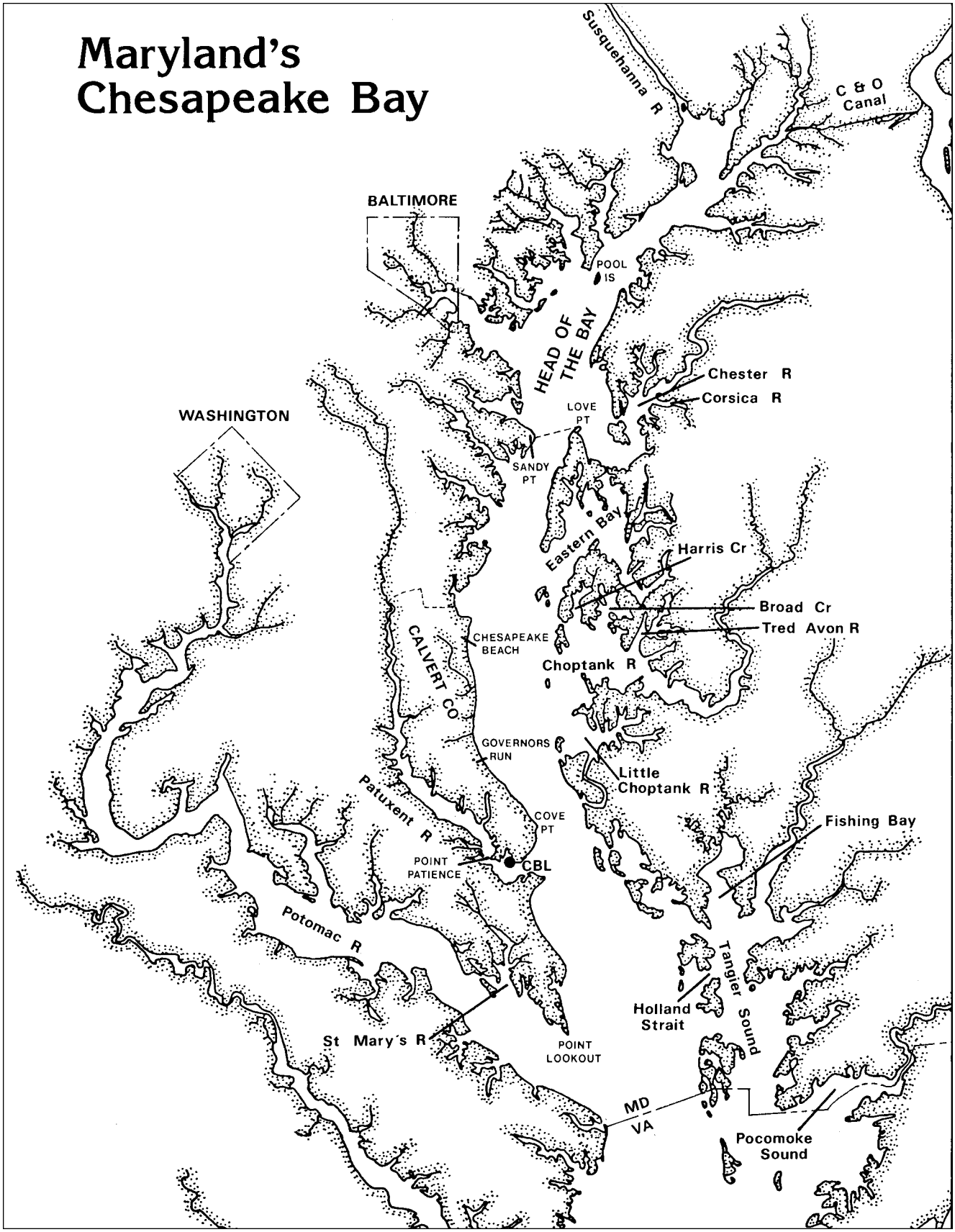
New studies of the seeding and shelling program are analyzing the regional productivity of these plantings and developing models useful in identifying the most biologically productive and cost-effective distribution plans (Cabraal and Wheaton 1981; D. Swartz, Sea Grant Marine Advisory Program, pers. comm., 1981). While some of these studies question the effectiveness of past dredge shell plantings, they all reaffirm the role of seed plantings in sustaining harvests.

The value of seed plantings has stimulated new research work on developing cheaper sources of seed. Cooperative research projects have been investigating new seed hatchery technology, ground-based oyster growout troughs or "raceways," and new spat-catching devices for seed areas. Cooperating organizations have included the Department of Natural Resources, the University of Maryland Center for Environmental and Estuarine Studies, and the University of Maryland Sea Grant Program. Spurring interest in this work are rising costs and erratic sets of new oysters, factors which led to declines in the numbers of seed oysters planted during the last half of the 1970's. Annual plantings for these years averaged half the annual averages for the preceding decade (D. Swartz, pers. comm., 1981).

Funds for the seed and shell planting effort come from: (1) license fees charged to watermen and planters; (2) an oyster tax collected from processors on each bushel purchased from harvesters; and, when these sources fail to cover the costs, (3) a commitment of funds from the state treasury. In a fairly typical year, 1976, the costs for the program totaled $1.31 million, not counting overhead costs such as salaries of state employees and their expenses for transportation, equipment replacement and maintenance (Department of Natural Resources, Commercial Fisheries Newsletter, 1976). In the 1970's, these planting programs required annual subsidies from state funds ranging from $250,000 to $500,000 (J. Bandolin, Maryland Tidewater Administration, pers. comm. to D. Swartz, 1981).

Four Problem Areas

As mentioned, the mass of data collected and analyzed by diligent researchers over a 30-year period from about 1880 to 1910 led to a number of conclusions concerning management of the industry which, if implemented, would probably have kept the oyster fishery as a highly productive enterprise.


Maryland's
Chesapeake Bay
Susquehanna R
C & O
Canal
BALTIMORE
POOL
IS
HEAD OF
THE BAY
Chester R
Corsica R
WASHINGTON
LOVE
PT
SANDY
PT
Eastern Bay
Harris Cr
Broad Cr
Tred Avon R
CHESAPEAKE
BEACH
CALVERT CO
Choptank R
GOVERNORS
RUN
Little
Choptank R
Fishing Bay
Patuxent R
COVE
PT
POINT
PATIENCE
CBL
Potomac R
Tangier
Sound
Holland
Strait
St Mary's R
POINT
LOOKOUT
MD
VA
Pocomoke
Sound

Woven throughout these early reports, and extending into the later literature, are four dominant refrains:

1. The decline of the fishery is predominantly a result of overfishing and ineffectual conservation efforts.

2. It is important to protect spat, to conserve the available shell stock as cultch, and to expand and protect natural seed areas.

3. Oyster culture by means of leasing should have the stimulating effect it has had elsewhere (e.g., Connecticut, Louisiana). It should help revitalize the industry and increase yield, with economic benefit to all involved.

4. Many efforts to improve the industry by preventing overfishing, implementing biologically sound shell planting efforts, enforcing cull laws, and encouraging private oyster culture have been hampered by the determined resistance of watermen and Tidewater politicians.

These points will re-occur in the section dealing with management and rehabilitation. Figure 5 summarizes the reported landings for the past 140 years and indicates the periods of major legislation, biological surveys and studies, and environmental factors affecting the resources. We turn now to a general description of Maryland's oyster grounds, including information on past and present conditions.

DESCRIPTION OF MARYLAND'S OYSTER GROUNDS

Stevenson (1894) noted that oyster reefs in Maryland were found generally along the shores of Chesapeake Bay and its tributaries, extending mainly in the direction of the current. Reefs were most abundant at the mouths of estuaries and in locations with sudden depth changes.

Before oyster harvesting became extensive, Maryland oysters were generally found on "hard" bottom (Grave 1912). They were usually not found inshore on shallow sandy bottoms because this material tends to shift easily with breaking waves. However, in quieter waters and areas with larger particles such as gravel and shell fragments, oysters could be found to low water mark. Thus, oysters were found inshore in Smith's Creek in the Potomac River (quiet waters), and along the Bay shore between the Patuxent and Potomac rivers where gravel and stones provided stable substrate suitable for spat settlement, even above low water mark. However, within this latter region, near Point No Point, no oysters grew along a 1.2 mi. (2 km) stretch of shore, apparently because this region's sandy bottom shifted with storms, smothering any cultch material or spat which might be present.

Oysters thrived on bottoms of sticky mud. As the bottom became softer and muddier (e.g., towards the channel) oysters tended to be found in "lumps," or iso-

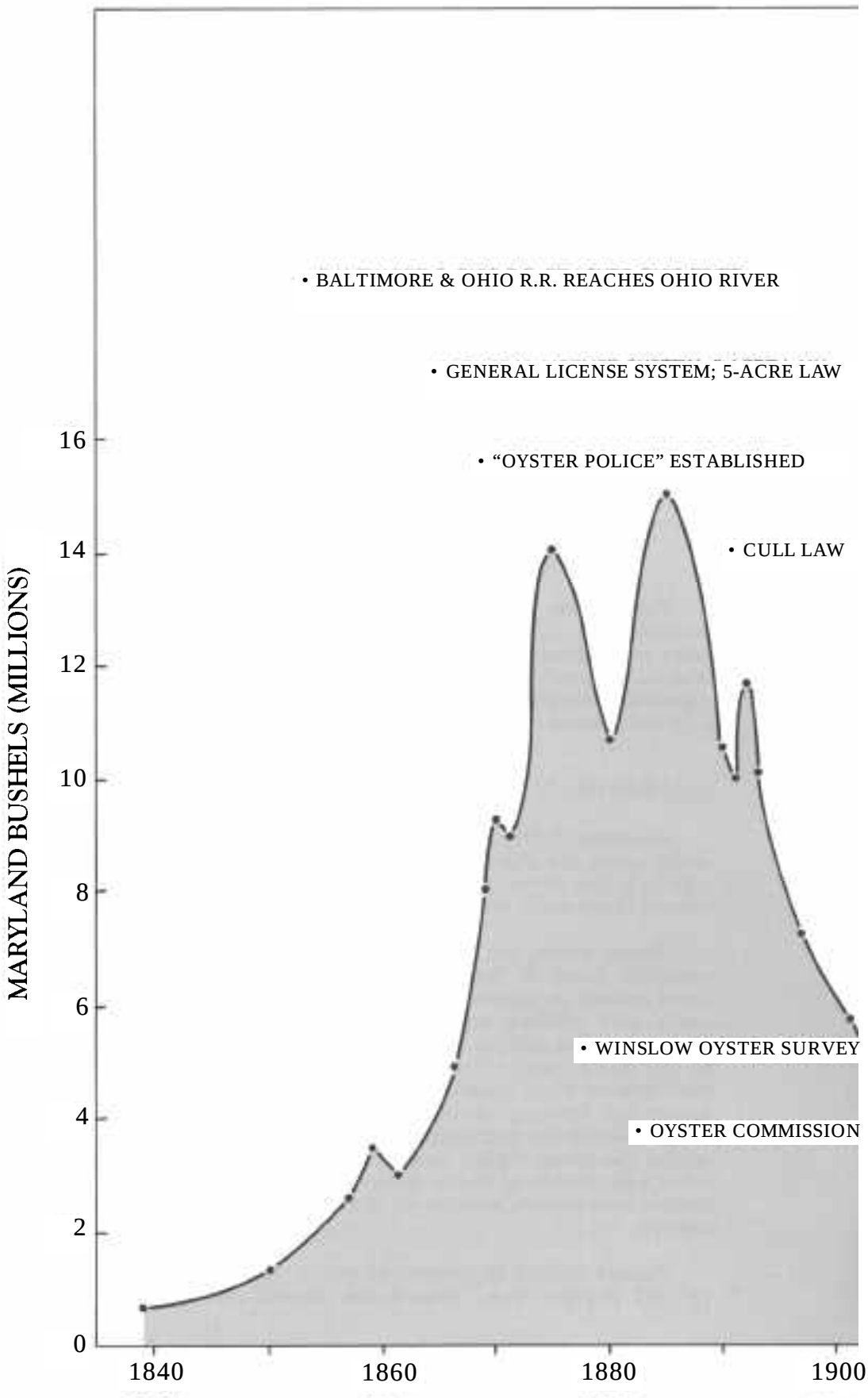


Figure 5. Reported landings of oysters in Maryland over the past 14 decades, in millions of bushels (approx. 1.3 times standard U.S. bushel). The harvest period for oysters begins

c. 1852: Baltimore & Ohio Railroad Reaches Ohio River. Expanded the oyster market to western communities; northern oyster packers opened plants in Baltimore.

1865: General License System; Five-Acre Law. State-wide license system regulated oystermen; leasing law allowed oyster planting on five-acre plots.

1868: "Oyster Police." Collected license fees, enforced fishing restrictions, and protected private grounds.

1877-79: Winslow Oyster Survey. Documented expansion of oyster beds and decline in number of oysters in Pocomoke and Tangier Sounds.

1882: Oyster Commission. Surveyed Maryland oyster beds; recommended conservation measures and oyster farming.

1890: Cull Law. Set minimum legal size for market oysters; required return of shells with spat and young oysters to natural oyster bars.

1906: Haman Oyster Culture Law; Shellfish Commission. Increased leasing allowance, a proposal rendered ineffectual by later legislation; commissioned Maryland Oyster Survey (Yates Survey).

1906-12: Yates Survey of Natural Oyster Bars. Conducted extensive biological and environmental surveys of Maryland's oyster bars.

1916: Maryland Conservation Commission. Consolidated Shell Fish Commission, Fish Commissioners, State Game Warden, and State Fishery Force (Oyster Police) into one agency.

1922: Shell-Planting Legislation. Initiated annual placement of shell as cultch for depleted oyster bars.

1927: Ten-Percent Shell Tax. Required oyster processors to make 10 percent of their shucked shell available for state use in planting.

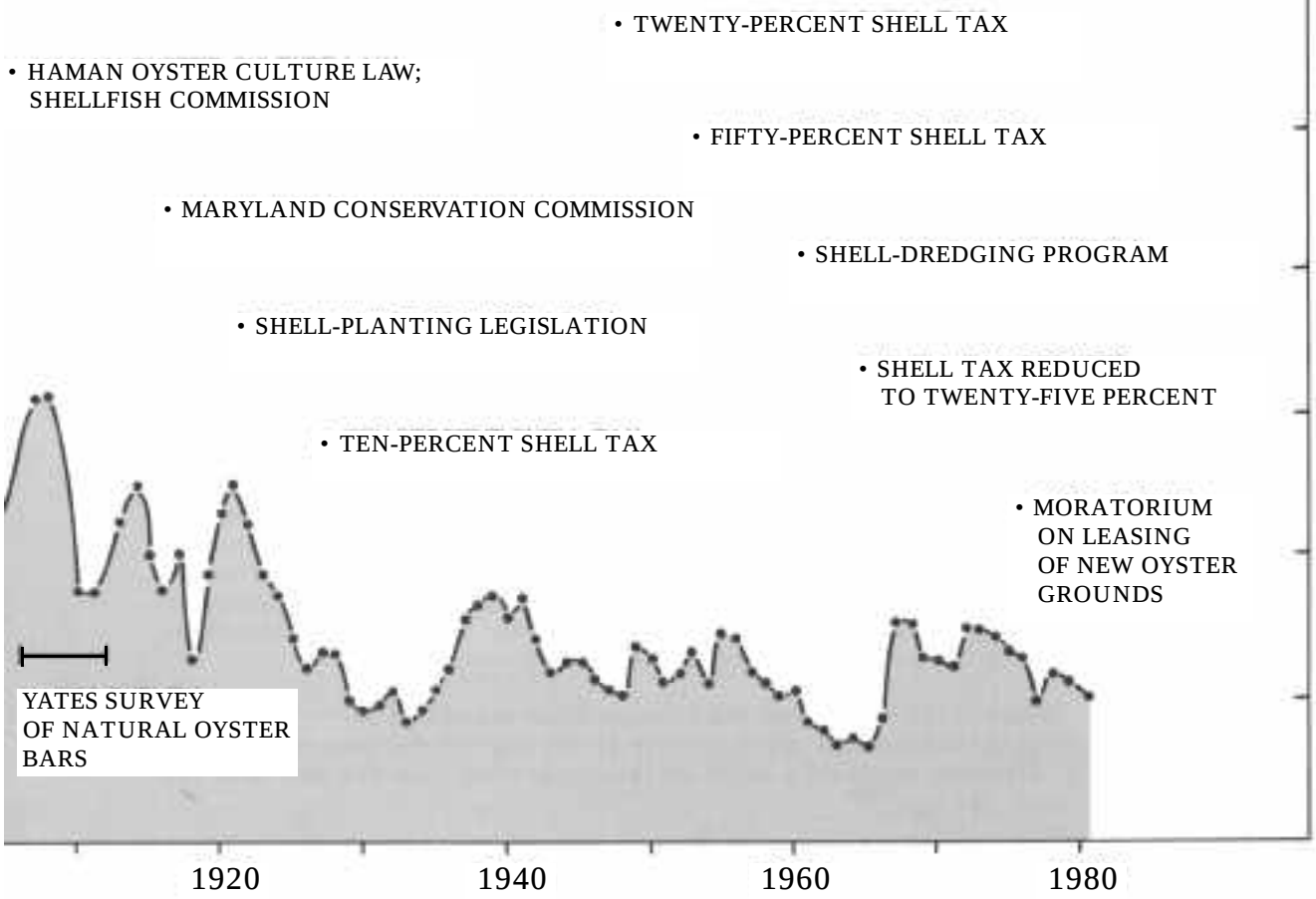
1947: Twenty-Percent Shell Tax. Increased shell tax on processors.

1953: Fifty-Percent Shell Tax. Increased shell tax again, but the supply still proved insufficient.

1961: Shell-Dredging Program. Initiated new oyster repletion program using old shells dredged from non-producing areas

1965: Twenty-Five Percent Shell Tax. Reduced shell tax; allowed processors the option of cash payment, in place of shell.

1972: Moratorium on New Leases. Suspended awards of new leases of oyster grounds pending completion of new survey of state oyster grounds.



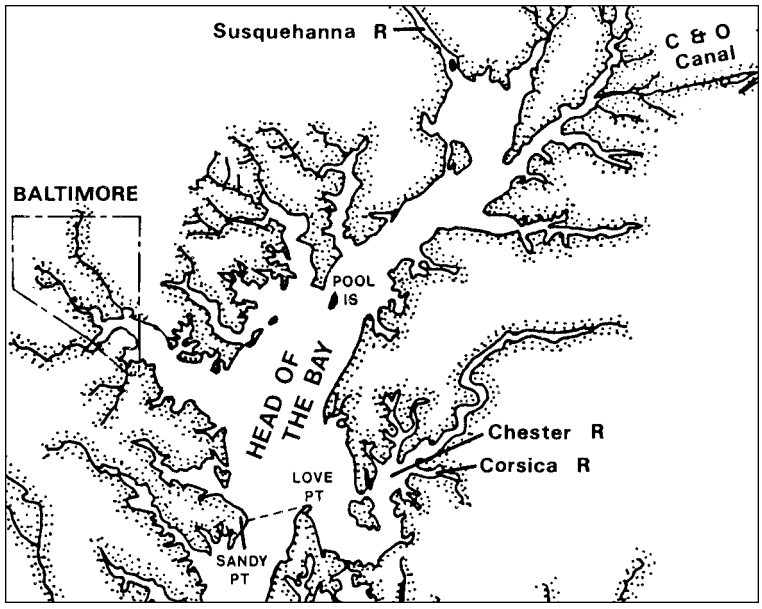
at the end of the old year and extends into the new. The time line refers to the new year (for example, 1961 denotes the 1960-1961 harvest period). Important events in the history of managment in Maryland are noted. (After Grave 1912, modified)

lated concentrations. These patterns have since been modified by harvesting practices. Dredging has tended to expand beds by dragging shell onto barren ground where it has served as a base for new spat settlement. Thus beds in many locations (e.g., Choptank River, Tangier Sound) grew greatly in area in the early days of dredging.

As part of the effort to understand the oyster and its fishery, we briefly describe Maryland's Chesapeake Bay oyster grounds as they are grouped into a series of locations. Historical changes are noted. Reference to recent spat settlement success, including the 1980 situation, involves personal communications from Dr. G. Krantz of Horn Point Environmental Laboratories. Page 112 provides a map of Maryland's portion of Chesapeake Bay.

Head of the Bay, Including Chester River

This area is located north of an imaginary line drawn from Sandy Point on the western shore to Love Point on the east. In the past, it yielded many small oysters which were used extensively by Baltimore canners (Grave 1912). The region is subject to irregular fresh-water flooding by Susquehanna River runoff. Some of the most extensive flooding in this region had devastating impacts on the oyster resource in 1928 (Truitt 1929) and 1936, 1943, 1945, and 1946 (Beaven 1947).



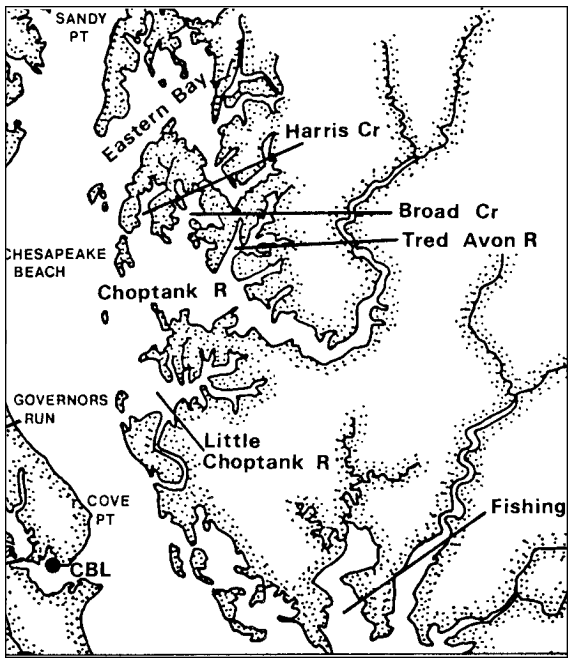
Stevenson (1894) commented that oysters used to be abundant as far north as "Pool" Island, with some even found at the mouth of the Susquehanna River. He attributed their disappearance to changes in freshwater inflow caused by more intense cultivation of farmland, timber harvesting, and ditching, with attendant rapid runoff. By 1912, the area of oyster grounds had been decreased by fishing activities (Grave 1912). Poor or irregular spat settlement did not allow for suitable recovery from fishing. The normal low salinity regime probably inhibited feeding at times, resulting in small oysters and in poor spawning and spat settlement success; accumulation of oysters in this region was always slow at best (Engle 1948). Sieling (1950a) also commented on the poor spat settlement of the region.

Grave (1912) noted that the Chester River contained oysters extending from about the six-foot depth contour to the edge of the deep water channel. The beds occupied a width of about one-third mile (0.5 km) from the river mouth up

to the Corsica River. Thereafter the width decreased to about one-quarter to one-eighth mile (0.4-0.2 km). Oysters extended upriver about 25 miles (40 km) from Love Point, with few breaks in the distribution. Many bars extended for some distance upon very soft mud bottoms as lumps rather than as continuous populations. Engle noted in 1948 that the setting in Chester River was insufficient to keep the oyster grounds stocked by natural means. Few of the natural bars appeared to be workable in 1980, with no spat noted on the four oyster beds surveyed by Dr. Krantz in 1980. Indeed, no spat were noted by Dr. Krantz in the rest of the Head of the Bay environment in 1980. Two large oyster beds at the mouth of the river have been silted over (H. Seliger, Johns Hopkins University, personal communication). This is a characteristic of overfished, unproductive oyster beds (Winslow 1881).

Eastern Bay

Grave (1912) noted that this region had numerous contiguous oyster bars. The most productive bars were generally in areas of good water circulation; poorly stocked grounds were found in areas of poor circulation. Over time, setting has been consistent and heavy in the area, so shelling has been performed in the past (approx. 2000 bu/acre annually) to provide substrate for spat settlement and growth to seed size for transplantation (Engle 1948). Sieling (1950a) felt that Eastern Bay may have been potentially the largest seed area in the state. For example, on shell plantings in 1947, there were 2000 spat per bushel; in 1948, there were 776 (Sieling 1950a). Millhill Bar was set aside in about 1941 as 150 acres of originally barren bottom which then received annual cultch plantings (Engle 1956). If set exceeded 500 spat per bushel (about one spat/shell) the seed was transplanted to growing grounds next spring. Interestingly, on four bars from 1946 to 1954, spat settlement intensity increased from east to west in eight of the nine seasons (Engle 1956). This pattern was generally repeated in the high 1980 set (Krantz, personal communication). The cause of this pattern is not clear.



Choptank River and Little Choptank

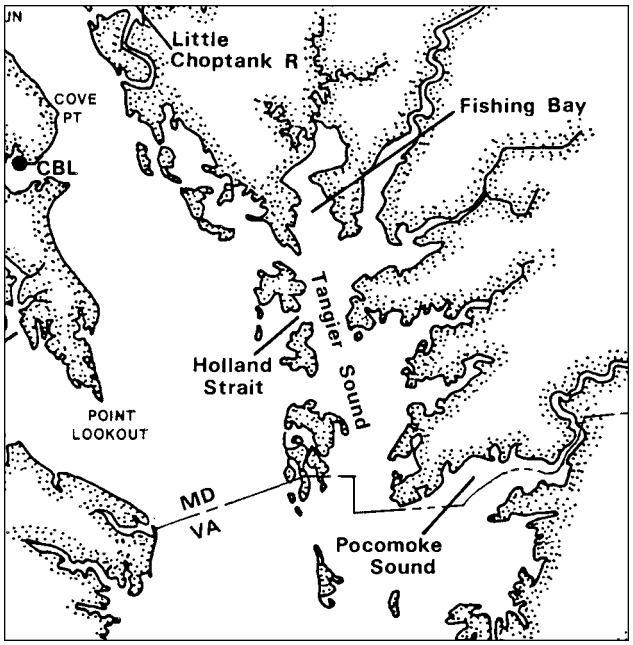
Choptank River oysters were so attractive to the consumer and so famous as to be known on the market as “Choptanks” (Stevenson 1894), just as there were “Kettle Bottoms,” “Parker Moores,” and “Chincoteagues.” The bottom of the river was mainly “hard.” Dredging had been performed in the river since 1870 and oysters more or less covered the bottom from shore to shore (Grave 1912), although they accumulated in separate “lumps” in the muddy mid-river channels. Grave (1912) attributed the general continuity of the grounds to the effects of dredging.

In Broad Creek and Harris Creek, some natural beds were so overstocked that the oysters were stunted (Grave 1912), a situation still true today. These oysters were then used for planting. Grave (1912) noted that the proportion of the total bottom area in these two creeks that was covered with oysters was unusually large, although he provided no data to support this statement. On Great Bar, Broad Creek, a square yard of bottom contained an average of 36 oysters below the 2.5 in (64 cm) market size and 12 above, for a total of about 394 bushels per acre (212 bushels of seed and 182 bushels of market oysters). Some Harris Creek grounds were apparently even more prolific.

In 1948, Engle was still able to include the lower Choptank and some of its tributaries in the category of locations with setting adequate to allow for natural restocking of the fished bars.

Tangier Sound and Fishing Bay

This area was surveyed by Winslow a century ago (1882) when it was being fished intensively and declining in yield. Stevenson (1894) noted a decrease in average oyster size over the size available 20 years earlier. Grave (1912) said that conditions on natural bars in this region gradually improved as one moved north from the Maryland-Virginia line. He attributed failure of the lower grounds to be replenished naturally to the excessive removal of cultch. Illegal out-of-season dredging of shell and seed oysters for sale to Virginia planters occurred here. He recommended private culture as a means of preventing this activity.



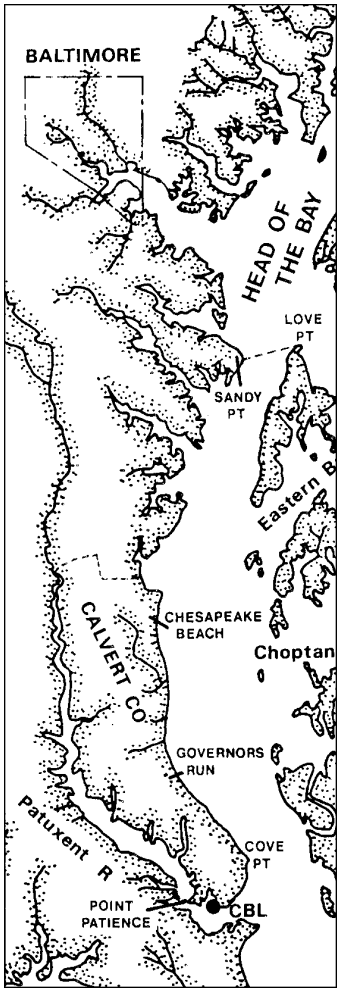
By 1948, Holland Straits had become the site of a state seed area receiving about 2000 bushels of cultch per acre (Engle 1948). Engle indicated that Fishing Bay was a region where setting was adequate to restock fished grounds. Sieling (1950a) warned that too much broodstock was being removed from this area, with depressed spat settlement resulting.

This area, and the following, were badly affected by the diseases MSX and *Perkinsus marinus* ("Dermo") in the 1960's.

Pocomoke Sound

This area was also surveyed by Winslow (1882). The oyster-producing bottoms were a mix of sand and mud (sticky and hard) with patches of hard sand, gravel, clay, and soft black mud. Clams were abundant in the soft mud (Grave 1912). Grave noted that since Winslow's survey, more than 5800 acres of ground had been over-fished to exhaustion. It appeared that reefs in this area did not become naturally restocked even if left alone. Many became silted

over and unfished until even the names were lost from memory. Still, in 1950 Sieling could declare it a self-sustaining area (although a shadow of its former self) with over 300 spat per bushel on natural cultch in 1947 and about 200 per bushel in 1948. It too was ravaged by disease in the 1960's and became a center for disease studies (Farley 1975).



Western Shore

This area includes the "Bay-shore grounds" or Bay bars of Stevenson (1894). In 1894 the oyster bars were almost continuous along the shore, extending in width to one and one-half miles (2.4 km) offshore in some areas. Oysters from Anne Arundel shore to Point Lookout were large and plump, and among the finest in Maryland; however, their abundance fluctuated widely (Stevenson 1894). On the other hand, Grave (1912) reported that Bay oysters off Calvert County were of inferior quality and that the Bay grounds had been dredged to the point of barrenness. The 1935 report of the State Planning Commission noted that the area between Cove Point and Chesapeake Beach had once produced fine oysters. However, a survey in November 1934 yielded the following figures for a series of test dredges over a three-eighths to one-half mile (0.6-0.8 km) distance:

> Governors Run - 2-11 large oysters per haul.
> Flag Pond - 12-21 oysters of mixed size.
> Daddy Dare's Wharf - 20-37 oysters of mixed size.

The surveyors noted that three to four bushels of oysters would have been taken from a productive ground over those same haul lengths. Further, Chesapeake Biological Laboratory scientists estimated the area to be capable of producing one and three-quarter million bushels per year (State Planning Commission 1935). Engle (1948) reported that large portions of the western shore did not have sufficient setting to keep the bars stocked by natural means. Beaven (1950) indicated that setting was very poor on the upper western shore (and in the major tributaries except near their mouths). Because earlier workers did not describe spat settlement, it is not clear if poor sets have always been prevalent on the western shore. However, these once productive grounds probably had self-sustaining sets because of the presence of plentiful brood stock and cultch.

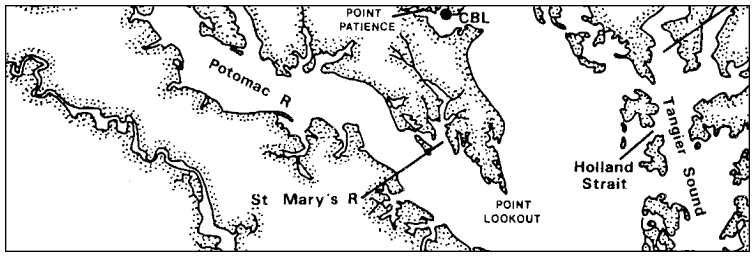
Patuxent River

In 1894, oyster reefs in this river extended 24 miles (39 km) from the mouth upstream to the southern border of "Prince George" County, having apparently extended even farther 25 years earlier (Stevenson 1894). Even in 1894, to a greater extent than elsewhere in Maryland, the Patuxent was the site of "laying down," or holding oysters to grow and await favorable markets. Grave (1912) noted that oysters from above Point Patience were superior to those below. In this deepest region of central Chesapeake Bay, oysters thrived even at 120-130 ft (37-40 m), with dense stocks in the hole near Point Patience. Grave (1912) noted that during one year of the 1906-1912 survey of the Board of Shell Fish Commissioners, there were few, if any, places along the Atlantic coast where oys-

ter food was more abundant than in this river (no data given). He attributed this to the presence of widespread muddy bottoms and organic material transported downstream from the extensive marl beds. The Patuxent has the reputation of being an area of good growth but poor settlement (Engle 1948, Sieling 1950a), so Grave's (1912) observations are important and the subject needs further investigation (see section on Feeding and Nutrition).

Potomac River, Including St. Mary's River

The largest oysters in Maryland ("Kettle Bottoms") were once fished from the Potomac (Stevenson 1894). In his 1912 report, Grave did not mention anything about the spat settlement in St. Mary's River (nor elsewhere in the Bay for that matter). However, in the past it has been intensive and consistent (Engle 1948, 1956, Sieling 1950a) with the result that a state seed area was established in this Potomac tributary. Sieling (1950a) noted the abundance of adult oysters in the river which did not grow to a large size, presumably because of overcrowding. (This was and is also true of Broad Creek and Harris Creek (p. 118) and the James River (Andrews 1951), all good setting areas.) Unfortunately, in recent years, spat settlement success in St. Mary's River has been poor, as it has been elsewhere in the Potomac, except near the river mouth (Davis et al. 1976). This low setting success has hampered rehabilitation efforts. It appears that oyster abundance depends on the rare heavy set which may occur only every 10-15 years (Davis et al. 1976).



REHABILITATION MEASURES

As noted in the section on the historical background of Maryland's oyster fishery, Chesapeake Bay oyster stocks are not the only ones to have become depleted. Oyster populations in New England declined greatly by the early 1800's (Ingersoll 1881, Sweet 1941). Thereafter, in states from New Jersey north, a system of private cultivation was encouraged, with consequent revival of the industry (Sweet 1941, Christy 1964). In addition, various rehabilitation measures have been undertaken in different regions of North America (Galtsoff 1943, Engle 1945b, Nelson 1950b, Pollard 1973, Whitefield 1973, Little and Quick 1976, MacKenzie 1977a). It is worth noting that no region on the Atlantic or Gulf Coast of the United States appears to have managed its eastern oyster resource so well that rehabilitation has been unnecessary. Frequently the resource has been overexploited greatly before any remedial measures have been taken.

Oyster populations from Chesapeake Bay south were less rapidly depleted than those in the northeast, to a large extent (at least initially) because of a greater resource base, fewer people living in the area, and less pollution. However, overfishing and disease led inexorably to population decline. In Maryland, Grave (1912) indicated that Pocomoke Sound's depleted oyster

grounds had not recovered quickly when left alone after there were too few oysters to maintain commercial interest. He felt that so much shell had been removed that inadequate amounts of cultch remained. Thus, active rehabilitation measures were necessary to enhance recovery of the oyster resource. That continues to be true today.

Much of the information necessary for satisfactory management of Maryland's oyster resource had been accumulated by about 1912 (see the section on Historical Background). Winslow (1881, 1882, 1884) had described the deterioration of the extensive and prolific oyster beds in Tangier and Pocomoke Sounds, attributing much of the decline to unregulated overfishing. The oyster industry had been thoroughly reviewed by Ingersoll (1881) and Stevenson (1894). The biology of the oyster had been subjected to extensive study by scientifically trained investigators (Brooks et al. 1884, Brooks 1905, Grave 1912). Although many aspects of oyster biology remained to be explained, the essential core of information for enlightened management was there. Unfortunately, as Wallace (1952) indicated in his critique of biological research on oysters, political considerations, rather than limited knowledge, have frequently contributed to declines in fisheries in North America and elsewhere (see also Adams 1968). Socio-political considerations have strongly affected management decisions in Maryland. Therefore, it is important that our available biological insights be marshalled to support appropriate management actions.

In contemplating management practices to be applied to Chesapeake Bay, it would appear sensible to consider the Bay from the same perspective that a farmer would apply to management of his land or farm animals. He would need to know the carrying capacity of the farmland, the nutrients available and nutrients required, where the good soil and poor soil was located, the yields to be expected from one soil versus another, or from one food supply versus another, reproductive capacity and health needs of the crops or stock, etc. If he were seeking to reclaim marginal farmland, the obvious tactic would be to start with the best section, clear it of weeds, fertilize it, and carefully nurture it until it was good farmland. Then he could move on to the less suitable land. It would be a waste of resources (unless they were not limited) to take a scatter-shot approach, diluting the effort and the return and perhaps misusing the good land at the same time.

Similarly with the Bay, one needs to know where good growing and good seed areas are located. These then must be tended and protected. The fact that a once reliable spatting region like St. Mary's River has apparently become an area of limited spatfall is disturbing. Such regions are the buffers needed to provide seed resources required for gradual upgrading of other regions, and seed is the limiting resource in public or private oyster harvesting in the Bay.

Similarly, we would wonder at the farmer who harvested his plants or animals before they were fullgrown, or who destroyed the soil or the rangeland in the process. That is what has happened in the Bay and no rehabilitation activity will be really successful until destructive practices are curtailed.

We can take as an instructive example the efforts at rehabilitation of the Long Island Sound oyster resource which have recently been described by MacKenzie (1981). As a result of an extensive study of the area from 1966 to 1972, MacKenzie concluded that oysters in Long Island Sound had the potential of covering the bottom of the Sound in a few years under optimal environmental conditions. This potential was due to early oyster maturity (by the second year), high fecundity of the parents, reasonably widespread setting success, and good post-setting survival under field culture. Limiting factors included low temperatures, lack of clean shell cultch for setting, a suite of predators and competitors, and presence of silt. MacKenzie found oyster survival to be high on cultivated beds because predators, competitors, and suffocation by silt could be controlled to a large degree by oyster farmers. MacKenzie felt that few oysters in the Sound would survive without such bed culture.

Such culture has been increased in Long Island Sound since 1966 (MacKenzie 1981). Oyster growers spread shells every year on setting beds. They controlled major predators like starfish and oyster drills by use of quicklime (starfish) and harvesting by suction dredge (drills). Growers avoided oyster mortalities from suffocation by silt by transplanting seed in March-April rather than in May-June as had once been the practice. This apparently lifts oysters above the winter-deposited silt before temperatures are warm enough to increase metabolism with its attendant respiratory and water pumping demand. As a result of these culturing activities, by 1972 (when MacKenzie's study ended), oyster yield in Connecticut had increased 85-fold over the 1966 yield. Off New Haven alone, production rose from 10 million oysters in 1966 to one billion oysters in 1972. Although MacKenzie had no further data for Connecticut yield after 1972, he did show that production in New York increased from 46 metric tons of oyster meat in 1967 to 956 metric tons in 1975. Thus, this study demonstrates the excellent effects of careful cultivation of private oyster grounds through use of simple measures such as annual provision of clean cultch at the right time and control of predators and of smothering by silt. To an extent, some similar measures are being taken by the state in Maryland's Chesapeake Bay. However, private culture could enhance this by allowing for more careful attention to specific areas by those with a financial investment in the success of the private ground.

Management Recommendations Since 1884

Various investigators and resource managers working in Chesapeake Bay published conclusions concerning appropriate management strategies. We will now describe their findings and recommendations developed over the past century. Some major points have been made again and again, and we hope that their reiteration in our report will help convince readers of the utility of these long-recommended actions.

Brooks et al. (1884) visited 59 oyster bars, made 326 examinations, measured and counted all the oysters upon 120,958 yd^2 (101 km^2) of oyster bottom, and concluded that the average density of oysters was one oyster per 4.2 yd^2 (3.5 m^2). This was a decline from the average of 1 per 2.3 yds^2 (1.9 m2) found by

Winslow in 1879 (Winslow 1884). They recommended annual surveying and marking of oyster grounds by the Oyster Police (as they were then known). They advocated that oyster beds should be closed where and when necessary to allow for rehabilitation and growth, and that the opening or closing of areas be decided upon by trained experts.

In his "popular treatise" on the oyster based on the earlier work of the Oyster Commission, Brooks (1905) advanced reasons for declining spat set: scarcity of mature oysters to furnish spawn; wanton destruction of large numbers of spat by watermen ignoring culling laws; and lack of clean shell on beds as cultch. (Note that Waugh (1972) found for *Ostrea edulis* in England that the number of spat setting per unit area was related to available shell area and was limited by the number of available larvae).

Grave (1910) expressed the opinion that Maryland localities differed greatly in the quantities of oyster food available, with different diatom species being found in different areas. He declared that oyster beds in sluggish waters were most easily injured by overfishing whereas those in swifter moving water recovered quickly, presumably because the currents cleansed the cultch of sediment. He suggested that those prolific oyster bars with an overabundance of stunted oysters of less than market size be designated as seed oyster bars. Oyster planters could purchase this seed and the cull law need not apply to them. The areas he singled out for this treatment were found in the Head of the Bay, Broad Creek, Harris Creek, and Tar Bay. After 1916, the Conservation Commission of Maryland did set aside choice locations as "Reserve Areas" for experimentation in transplantation.

Grave (1912) made a number of additional recommendations. He noted that in order to obtain spat, fresh cultch should be strewn on somewhat elevated bottom washed with strong currents at certain tidal stages. The freshness of the cultch would prevent formation on the shell of material unattractive to pediveligers as they crawled on the shell surfaces. The currents would keep the cultch clean. One bushel of shell would cover 20-25 ft^2 (1.8-2.3 m^2) of bottom with a one-shell-thick layer. An acre could be covered with 1700 bushels of shell but 2500 bushels per acre were recommended on good spatting grounds provided the set were moved to growing grounds and spread more thinly within the year. Apparently, experiments to determine suitable methods of planting shells had been performed, including placing them in rows or ridges across and parallel to currents. Grave concluded that broadcasting shell was more satisfactory and economical than planting in piles (considering the difficulty for larvae to penetrate the piles or ridges to settle on the interior shells).

In 1921, Truitt lamented the shifting of oyster shell and small oysters to shell piles on shore. Oyster shell was in demand for lime, road material and chicken grit, a situation deplored earlier by Brooks (1905). In addition, apparently the entry of motorized boats into the fishery tended to eliminate sailboats which used oyster shell as ballast. In the past, this ballast had been dumped onto the grounds as the catch was brought on board the sailboats. With the decline in sailboat

numbers, shell was not being returned to the grounds. Truitt recommended the return of shells systematically and abundantly according to an informed design based on knowledge of prime setting areas and of factors such as survival, growth and "fattening" for each proposed area to be shelled.

Truitt (1929) demonstrated the importance of shell as a settlement substrate by comparing spat settlement thereon with other material such as pebbles, cinders, coal lumps, glass, brickbats, and twigs or chips of various trees. Oyster shell was settled upon by about twice as many spat as was glass. The remaining materials had very few spat. Thus, oyster shell was the obvious choice as cultch.

In 1931, Truitt expanded upon his recommendations, urging shell planting in suitable places and noting deficiencies in selecting planting sites. It appeared that no attention was being paid to:

> "1. whether or not there is brood stock present to assure reproduction,
>
> 2. whether, once set, the young survive,
>
> 3. whether the areas selected are, essentially, breeding (setting) grounds or growing and fattening grounds,
>
> 4. whether plantings should be made on the basis of expediency as to season or at the time young (larvae) oysters are in the water and at what concentrations, and
>
> 5. whether salinity differences in the several regions affect growth and survival."

In general, shell distribution was highly dependent on the desires of local watermen. No scientific information was collected to any extent nor was it given attention if it was (Truitt 1931). Today, local committees of watermen advise the management agency as to shell distribution, and, in a number of instances, shell is placed in biologically unsuitable areas (personal observations).

Beaven (1945) outlined Maryland's oyster problem succinctly, indicating that the essentials of successful oyster culture included:

Stable bottom with good circulation of water containing adequate food

Suitable quantities of brood stock for spawning and larval production

Adequate supplies of clean cultch

Spat that are not so crowded as to prevent good growth

Pest- and predator- (and disease-) free conditions

Harvesting at the right time when the oysters are optimal for marketing

Beaven (1945) emphasized that the natural bars in Maryland should be studied on a more or less individual basis, due to their great variation in suitability for settlement, growth, etc. He indicated that we need to know the abundance of natural brood stock now available in the Bay, the numbers of brood oysters needed per acre for optimal spat production in a given locality, the extent of larval dispersion, and the best position of brood oysters in relation to the cultch. What concentration of cultch is optimal? Should cultch be distributed randomly and widely, or in windrows, or in some other configuration (see Grave 1912)? What levels of spat mortality occur in different localities? These questions asked in 1945 are still unanswered for the most part. In a related vein, evaluating the decline of the European oyster industry, Korringa (1946) noted that in the Dutch Oosterschelde, at least 10 million oysters were needed if enough spat were to be produced in an average summer. Such insight resulted from years of intensive study. No such information is available for Chesapeake Bay.

With regard to shell planting, it may be important to add a certain number of adult oysters to the shell after it has been laid on the bottom. Quantitative study of such practice has apparently not been made for C. virginica, but Knight-Jones (1951) provided some insight for *O. edulis*. When a shelled patch was stocked with oysters, nearly three times as many spat were recorded from it as from a shelled patch that had not been stocked with adult oysters. Similarly, there were always more spat on densely stocked grounds, usually about two times as many as were found on neighboring grounds with fewer oysters. Knight-Jones attributed this to the tendency of oyster spat to settle gregariously in the presence of adults and recommended that reclamation of derelict ground include the relaying of older oysters. Crassostrea *virginica* also demonstrates gregarious setting behavior (Hidu 1969, Hidu et al. 1978) so that Knight-Jones' work is worthy of repetition in the field with the eastern oyster.

Galtsoff (1943) provided a valuable statement of principles of oyster management for increased production. This paper should still be consulted for sound information on management and cultural practices. He warned against uninformed and indiscriminate planting of oyster shell and described some instances of careless management. For example, in different geographic regions, shell was planted in areas with no record of good spat settlement (this happens in Maryland), or where it was rapidly fouled. In some places, shells were dumped in large piles in the mistaken hope that tides and currents would distribute them. In Florida, *Ostrea equestris* was thought to be year-old C. virginica and was transplanted as seed by the thousands of bushels. Obviously, it is important to understand the dynamics of the local environment and to plant shells at the proper time in the proper configuration and in an appropriate location.

Galtsoff (1943) also discussed private oyster cultivation and management of public grounds. He concluded that natural oyster beds cannot produce as many oysters as can cultivated bottoms. The natural population is a mix of ages which may interfere with one another. Spat and seed on the adults may compete for food and oxygen. Harvesting, culling, and processing all can cause mortality of spat. A well-cultivated bed can harbor a population of single-age oysters in an appropriate concentration to utilize ambient food, thus fattening quickly. The population need not be disturbed by dredging until it is to be harvested as a group. The bottom can then be replanted with spat, a process which Galtsoff showed is more advantageous than the planting of 2-3 year old seed (he expected a return of one bushel of oysters per bushel of seed compared to 4-7 bushels of oysters per bushel of spat).

Galtsoff (1943) recommended that badly depleted grounds be rehabilitated by planting, and that planted grounds should be closed to fishing until oysters reach market size. When the ground is opened, all oysters should be removed to prepare the ground for the next planting. A distinction should be made between setting and growing grounds and no shells should be planted on the latter except to reinforce the bottom if necessary. Grounds should be rotated for harvesting depending on the time needed by the oysters to grow to market size. He stated that the cost of such a program should be borne by those who benefit economically from it, i.e., the harvesters and packers. As Alford (1973) pointed out, the Maryland oyster program is very heavily subsidized. Galtsoff (1943) showed how an appropriate assessment per bushel of oysters could be implemented. He recommended a system of checking records that was established in Louisiana. We believe that appropriate and effective mechanisms suitable for local conditions in Maryland should be developed.

As Galtsoff (1943) indicated, any program of management requires thorough knowledge of local grounds and an understanding of the behavior of oysters in each area. He reiterated this in his 1945 note on rehabilitation of Chesapeake Bay oyster resources (Galtsoff 1945). In a move in this direction, the Maryland Commission on the Conservation of Natural Resources (1948) provided a thorough survey of the Maryland oyster resource. They noted that in good seed areas, one bushel of shells would catch enough spat to yield about three-quarters of a bushel of seed the next year at 600-1000 seed oysters per bushel. They claimed that about 3000 bushels of shell were needed to plant one acre of seed area and that 2250 bushels of seed should result. This in turn should yield 2250-6750 bushels of mature oysters when planted in a growing area at a density of 500 bushels of seed per acre.

We can conclude from these reports that the haphazard placement of cultch or seed is wasteful, just as the indiscriminate spreading of seed by a farmer over his farm (roads, ditches, barnyard, and woodlot as well as ploughed fields) would be a waste. The oyster grounds should be as carefully studied as farmland would be. The requirements of the oyster crop should be as well known as are the requirements of agricultural crops.

With regard to such generalizations as can be made about Chesapeake Bay oyster grounds, Engle (1948) pointed out that there was (1) a wide range of intensity of setting from one location to another, (2) a tendency for more regularity in setting from one year to another in certain areas, (3) a tendency for more regular and heavier setting on the Eastern Shore, and (4) a tendency for heavier setting at the mouths of rivers and down-Bay than upstream or in the Head of the Bay region. Three categories of regions could be established. One included areas with consistent heavy setting. A second comprised areas with adequate setting when cultch was added. The third included areas in which setting was insufficient to replace harvestable stock. Areas in the first category (Eastern Bay, Holland Straits in Tangier Sound, St. Mary's River) had been developed as seed areas on which 2000 bushels of shell per acre were placed yearly. Locations in the second category included Fishing Bay, Tangier Sound, and Choptank River including its lower tributaries. Planting of cultch could be practiced here if money and shell were sufficient. The third region included much of the western shore, the Patuxent River and the Chester River. Here the planting of cultch would probably be a waste of time, shell, and money until the better regions of the Bay had been carefully cultivated and more regions had been made self-sustaining. When that had occurred, perhaps the regions of poor setting could be treated to improve settlement.

A report to the General Assembly of Maryland made similar points (Chesapeake Biological Laboratory 1953). Natural oyster bars are the sites most favorable for oyster growth because they have been established by natural processes over the centuries. Overfishing, removal of natural cultch, and heavier siltation due to clearing of land had combined to smother many natural beds under layers of mud. Yet water conditions over oyster grounds in 1953 appeared to be as favorable for oyster survival, growth, and quality as they had been 70 years earlier. (We believe that this is probably still true for large areas of oyster grounds today, especially on the Eastern Shore; however an extensive survey of water quality to determine this is very desirable).

The 1953 report also noted three categories of natural oyster grounds. Again there were the seed areas (often shallow and semi-enclosed bodies of water) in which settlement was usually excellent but in which growth was poor due to crowding. The seed oysters should be harvested and moved elsewhere to grow. Then there were self-sustaining bars with suitable setting to replace harvested oysters (e.g., Eastern Shore tributaries). These could continue to produce well if small oysters and sufficient shells were returned to the bottom and if overharvesting was prevented. The third category included growing bars where set was poor but growth was excellent (the Bay proper and the larger tributaries). For this latter category, it was felt that strong currents favored oyster growth but acted to disperse larvae. Such bars should be seeded regularly to maximize production.

The 1953 report noted that the above categories were an attempt to impose clear-cut distinctions on a fluid situation. Patterns of growth and setting in the Bay are dynamic and changeable. Thus, management strategies should also be flexible and would require extensive carefully collected and up-to-date informa-

tion to be most effective. They would require large expenditures of time and money to have any impact and the 1953 report urged the expansion of private farming to help with this.

Finally, it seems reasonable to end this review of management recommendations with those made in 1966 (Quittmeyer 1966) by a knowledgeable team of consultants (an oyster biologist, two business administration professors, a sociologist, an economist, and a political scientist) to the Seafood Advisory Committee of Wye Institute (see also section on Private Culture and Oyster Farming). This team considered the Maryland oyster industry with care and their recommendations are clear, comprehensive, and seem to be consistent with available knowledge. In the recommendations, listed below as they appeared in the 1966 report, references to "Department of Chesapeake Bay Affairs" have been replaced by "Tidewater Administration" of the Department of Natural Resources. Similarly, "Natural Resources Institute of the University of Maryland" has been replaced by "Center for Environmental and Estuarine Studies" or "Center." Expertise regarding oyster biology is now shared by workers at Chesapeake Biological Laboratory and Horn Point Environmental Laboratories, both in the Center. Seed oysters may no longer be readily available from St. Mary's River, as that region has deteriorated since 1966

> "With awareness of the attitudes of watermen in Maryland, from a biological standpoint the following steps can be recommended on the oyster fishery:
>
> a. Continue the state-operated shell planting and seed-oyster operation.The scale of these operations is already large and can provide quantities of seed oysters.
>
> b. Give the Tidewater Administration full authority to determine, designate and use seed areas regardless of location, county lines, and local sentiment.
>
> c. Authorize the Tidewater Administration to dispose of seed oysters by sale or transplanting to areas of their choosing. This would provide a beginning to a self-sustaining industry.
>
> d. Open all public grounds to oystermen of the State. Tradition and public opinion notwithstanding, public oyster beds should not be opened for marketing before 1 October each year. This will tend to insure quality to the consumer and good yields to the producer.
>
> e. Impose a uniform tax on all marketed

oysters, which would at least pay for the cost of seed production and transplantation.

f. Encourage private planting by removing restrictive laws on renting barren bottom and by selling seed oysters by competitive bids. The Tidewater Administration with advice from the Center for Environmental and Estuarine Studies should have wide authority to determine utilization of bottoms.

g. Explore the possibility of rehabilitating deep Bay beds, particularly on the Western Shore of the lower Bay, by renting for 10 or 20 years at competitive bids, large tracts of 1,000 acres or more of good public bottom for modern management. Rentals of no less than $100 per acre per year should be expected. Seed oysters should be made available and no restrictions made on source or type of management, except to meet public health standards.

h. Grant authority to the Tidewater Administration to determine during the impending survey of public grounds those which are productive or which can be made so and open all marginal bottoms to private leasing.

i. Authorize the State to sell or plant shells for private companies at cost on unused or inferior rented bottoms in seed areas. Initiation of private seed production will provide some insurance against spatfall failures and help stabilize seed production.

j. Re-examine and determine policy in regard to dredging of buried shells for shell-planting programs. Establish criteria for determining whether a bottom is more properly used to grow oysters or

supply buried shell. A deep conflict between use of existing shell deposits as a source of cultch and potential use as beds for growing oysters is arising because most shell deposits underlie recently depleted productive bottoms. The demand for buried shell may cause irreparable harm.

k. Provide the Center with expanded capabilities to pursue their research and advisory responsibilities to the Tidewater Administration in its many management decisions, monitoring of setting, and ecological research.

l. Encourage watermen to become participants in a more diversified system by executing the planting and transplanting with modern equipment—light dredges if needed, etc.—for the state.

m. Re-evaluate the Potomac River Compact seeking to rectify the political settlement which defies effective management. The river has extensive high-quality oyster-growing bottoms but lacks seed oysters. These could be obtained from tributaries such as St. Mary's River and Great Wicomico River. Neither Virginia nor Maryland has shown positive attitudes toward the Potomac oyster fishery.

n. Convince the people of Maryland and Virginia that a management system for Chesapeake Bay with very few limitations between states would provide the most effective and flexible fisheries industry to the benefit of all residents of the region."

Scientific Management

It is appropriate to comment on the serious inadequacy of information available in Maryland for scientific management of the sort applied to shellfish stocks elsewhere. A very useful introduction to the problems of estimation of population dynamics and its application to management of shellfish stocks is provided by Hancock (1979) in a paper presented to a shellfish management symposium (other useful papers appear in that same symposium). His paper considers assumptions of various fishery models, their application to various fisheries, and some of the associated pitfalls. Methods of managing fisheries are briefly considered (unrestricted fishery, management by specific regulations, management by effort limitation, management by catch quota). He notes the shortcomings and uncertainties of managing shellfish stocks. Hancock's experience is firsthand, deriving from his work with cockles (*Cardium edule*), a commercial bivalve fished in the United Kingdom (Hancock 1965, 1967). He built on his studies of this species to provide generalized insights into population parameters and their interrelationships (e.g., between stock and recruitment) for exploited marine bivalves in general (Hancock 1973, Hancock and Simpson 1962). His insights are applicable to oyster management.

Managing oyster populations successfully requires information concerning oyster abundances on the grounds, annual magnitude of recruitment (spat set and survival), natural mortality and fishing mortality, growth, and age at first maturity. These estimates are not all easily obtained. Growth and age at first maturity can be determined fairly well, but variations with location in the Bay need to be taken into account. Fishing mortality can be estimated from landings, which should include details of catch-per-unit effort and of location of the fishing effort (to aid in management of specific regions where necessary). Magnitude of spat settlement is presently being assessed yearly in the Bay. Natural mortality estimates are more difficult to make but can be derived with some effort. It would be helpful to understand the dispersal of larvae from one region to another.

Given this information, suitable management decisions concerning opening or closing areas to fishing, catch limitations, length and timing of season, placement of seed and cultch, etc. could be made and defended vigorously. Introduction of such a program, coupled with an increase in rental of Bay bottom for private culture, might proceed slowly but deliberately and become more refined over a few years.

For an example of the application of biological knowledge and catch information to modelling an oyster fishery, we can turn to the *Ostrea lutaria* fishery in Foveaux Strait, New Zealand. Allen (1979) was able to make use of the extensive body of knowledge that had been collected concerning the species' life history, including information on spawning and recruitment, growth, and natural mortality. He coupled this with information on fishing mortality and distribution of fishing effort. The result was a yield model for the fishery. Although the estimates of the various parameters involved were not accurate enough to provide estimates of optimal catch levels from year to year, the model was used to exam-

ine the relative advantages of fixed and varying annual catch quotas. A variable quota was found to provide the highest average catch under the model's assumptions. It also provided a good level of protection against catastrophes which might result from overfishing a low-level population. Allen (1979) discussed the various shortcomings of his model, but none were incapable of being overcome. Presumably, the New Zealand model is now being tested and refined.

Fishery models are valuable tools to managers of shellfisheries and finfisheries around the world. In Chesapeake Bay, they would help provide rational bases for proposing and implementing various management strategies that would protect and enhance the oyster resource, to the benefit of all concerned. Power (1970) provided a broad review of legislation affecting the Maryland oyster industry. As others have done, he noted the fact that wise management of Maryland's oyster resource has been hindered by legislative responses to the concerns of watermen. He urged that the management agency be given broad authority to manage the fishery. The resultant range of choice necessary for effective management and the freedom from outdated laws and from having to deal with a cumbersome legislative process would permit bold initiatives. The appropriate mix between public and private oyster grounds could be attained. There would be greater freedom to explore advantageous Maryland-Virginia cooperation in oyster management.

We feel Power's conclusions are correct. If high production is the proper objective of management, there is no evidence that it will be best achieved by retaining controlling decisions in the legislative branch of government. There is much evidence that a biological resource can best be managed by trained biologists whose decisions are based on research findings, field sampling, and continuous interaction with experienced watermen, rather than on politically expedient factors.

Biological Aspects of the Oyster Cull Law in Maryland

The following report to a Meeting of the Advisory Committee to Tidewater Fisheries on December 6, 1951, is included because it covers a number of interesting matters and because of the late Mr. Beaven's extensive experience with the biology of Maryland oysters.

Biological Aspects of the Oyster Cull Law in Maryland
by G. Francis Beaven
(Reported to Meeting of Advisory Committee to Tidewater Fisheries)
(December 6, 1951)

"The aim of any cull law is to insure the retention of sufficient juveniles in a natural population to replace the adults which are cropped or eliminated by natural causes. The effective operation of such a measure is essential on any oyster bottom which is to continue in production entirely or largely through the results of natural repopulation.

"The optimum size at which an oyster or other animal is taken is partly determined by the point where increments of future growth to the total crop become offset by losses due to the increased mortality among the older individuals. The market value at a given size and the ease of handling and processing are other factors to be considered in establishing the most profitable size at which the oysters should be taken. In an industry such as the poultry industry it frequently is more profitable to market the crop as broilers and replace the stock with a new crop than to carry the animals on to maturity. The same principle may at times be applied to oysters.

"Since rate of growth, rate of mortality, marketability and other factors are quite variable over the areas where oysters are grown, it is difficult to establish the best size at which a minimum limit should be set. For this reason cull laws have not been uniform everywhere and contention arises as to the wisdom of the limitations which have been established.

"The present Maryland law requires that all oysters less than three inches in length shall be returned to the beds upon which they grew while harvesting operations are in progress. It is true that in most instances the crop would produce better returns if the three inch oysters were permitted to remain on the bottom and attain a larger size. At times very young and thin shelled oysters at three inches in length are practically worthless for shucking. On the other hand, in some areas the single round deep cupped oysters which occur may contain considerably larger meats at 2 1/2 inches than do many much longer oysters growing under crowded conditions. Hence the establishment of the three inch limit represents something of a compromise.

"The rate of growth of Maryland oysters often has been given as one inch per year. This figure is a very broad approximation. Occasional spat on planted shells under exceptionally favorable growth conditions in Maryland have been found to slightly exceed three inches in length at the end of the initial growing season when the oysters are less than six months old. Oysters known to be less than eighteen months old similarly have been found at times to exceed six inches in length. In certain seed areas oysters fail to reach three inches after many seasons of growth and only a small proportion ever reach market size. Furthermore, the rate of growth is much more rapid when oysters are young and decreases greatly with increasing age. Typically, however, most Maryland oysters on good growing bottom will have reached three inches in length when they are three years old.

"The established three inch cull law under Maryland conditions serves to ensure that oysters typically too small for shucking are returned to the bars where they may be expected to continue rapid growth without undue mortality. Since the proportion of undersize oysters in the oystermen's catch increases as he continues removal of the market sized individuals the point eventually is reached where it is not profitable for him to continue harvesting even though a number of large oysters still are present. This tends to ensure future well balanced populations with sufficient brood stock for new generations. In those areas where environmental conditions consistently favor a rate of natural reproduction suffi-

ciently high to replace the oysters harvested, the strict enforcement of the three inch cull law has served to maintain production on a self-sustaining basis. With continued vigorous enforcement of this law, and the presence of adequate cultch, continued yields at minimum rehabilitation costs can be expected. It should be pointed out, however, that much of Maryland's bottoms do not receive sufficient set of young oysters to repopulate the bars under normal harvesting practices even though the cull law is enforced. Production on such bottoms can be maintained by bringing in seed oysters from areas where setting is high.

"Some years ago Dr. Thurlow Nelson of New Jersey pointed out a condition under which enforcement of a cull law may be detrimental. It is a known fact that rate of individual growth among oysters may vary quite widely. Among an even aged set some individuals will grow rapidly and produce giants while some will grow slowly and produce runts. It is probable that the offspring of the fast growers will contain a high proportion of similar fast growers and that the offspring of runts will contain a high proportion of runts. Under conditions where all have an equal chance to mature the practice of removing the fast growers and putting back the runts may finally result in the development of a slow growing population of runts on the bar. Such a condition is reported to have occurred in Europe. According to Dr. Korringa of Holland, the oyster growers there practice a very intensive method of cultivation. Seed are produced on tile and transplanted many times so that all of the set have an equal opportunity to grow. When the age of harvest is reached the Dutch growers carefully go over their plantings and remove all of the small slow growing individuals for sale first. As long as an oyster shows vigorous growth it is returned to the beds so that in the end only the fastest growers and largest oysters are left and these are used for brood stock on the seed beds before they are finally marketed. Over the years these planters have developed oysters which grow more rapidly and attain a larger size than do oysters of the same species grown in France where the practice has been to harvest all oysters as soon as they reach market size with runts remaining indefinitely on the beds.

"Under Maryland conditions, where setting has remained high enough to maintain natural production and especially in the areas where seed is produced, it is likely that natural competition through crowding serves to eliminate most runts and that the fastest growers have the best opportunity of reaching maturity. Thus far there is no indication of an adverse effect of the cull law upon oyster growth in Maryland. The present practice of transplanting seed from thickly populated areas to bars where natural reproduction does not maintain sufficient populations should serve to eliminate the runts which might tend to develop there naturally. Variations of growth among oysters on different bars in Maryland and of oysters from different sources when planted on the same bar are being studied by the Department of Research and Education and by agencies elsewhere. If superior races of oysters should be discovered they can be introduced for brood purposes. Thus far the oysters produced in Maryland seed areas have been found to grow best under Maryland conditions. Checks should continue to be made on the

growth rate in isolated self maintaining areas to determine whether any tendency towards developing slow growing varieties may occur.

"While enforcement of the cull law thus appears highly desirable on Maryland's natural rocks there are two weaknesses in the law as written which are apparent. The term "all oysters" under three inches may be understood to include every oyster which has attached. Many of the younger oysters are too small to be recognized except by a trained person using special techniques. On a self-sustaining bar there must be quite an excess of spat to offset natural mortality. During early fall a bar of this type in good condition should have one or more spat ranging down below one inch in length attached to every large oyster. These are too small to be knocked off without killing them. If the large oysters are returned to the bottom with the spat on them then it is not possible to harvest any others at all from the bar which is manifestly absurd. Until recent years few watermen or inspectors recognized spat below one inch in size when culling oysters. This practice is sound but leaves open the question as to whether or not the cull law is really being complied with. There are practical objections to making exceptions of small oysters say under one inch in length. It might be that the provision to cull out all visible small oysters should remain in the law but that the provision to throw back large oysters with small ones attached which cannot be separated without killing them should be dropped. It is doubtful that many large oysters are ever returned to the bottom under the existing law for it would be practically impossible to prove that a young oyster had been killed in removing it from a large one when only the large ones are left at inspection. The inspector, of course, would still count as illegal any large oyster bearing a small one which could be knocked off without killing it. Some such revision may be desirable in view of the recent more widespread recognition of small spat by both oystermen and inspectors.

"The second weakness of the cull law is its application to privately planted beds. In many cases such beds are on bottoms which are not dependent upon natural set for their production. Seed produced in high setting areas is transplanted to the beds and grown to market size. Unlike production on natural rocks the new crops are not dependent upon the small oysters and shell culled off, but upon replanting with seed of known count in such concentration that a good crop can be produced. When such a planter is forced to cull his crop then he does not want the small oysters and shell put back on the ground from which he is harvesting them, for their presence there interferes with complete harvesting of the large oysters and it is desirable to have the ground cleaned up as completely as possible before replanting. He may choose to cull out the small oysters for replanting on another bed if their value as seed will offset the cost of the operation. In many instances the undersize oysters and shells are few and the cost of culling would greatly exceed the value of the small oysters as seed. To cull such stock adds greatly to the planter's cost of production. Hence it is to his advantage to let any undersize oysters and shell go on to his shell pile and thence back to seed beds for further seed production. In this manner he can produce more oysters per year which is the goal of any management procedure. Not all planters operate in the

manner described for some are fortunate enough to have bottoms which may produce in a manner similar to the self sustaining natural rocks. However, the application of the cull law to planters who operate on a crop rotation basis serves to limit his production rather than increase it."

PRIVATE CULTURE AND OYSTER FARMING

Bottom Rental

Current harvesting practices for oysters in Maryland's Chesapeake Bay may be placed in the anthropological category of hunting and gathering. Oyster fisheries which thrive elsewhere—in Europe and Japan (Korringa 1976), in Long Island Sound (MacKenzie 1981)—represent the more advanced category of farming. For nearly a century, scientists and informed managers have urged the state of Maryland to open areas of the Bay to private oyster farming; yet the acreage of oyster ground under lease now is minimal: 651 lease holders control about 9,000 acres of bottom (Jensen 1981). This limited area amounts to three percent of the 279,000 acres of oyster ground reserved for public or private use (Jensen 1981). The small proportion is somewhat ironic; in 1830, Maryland followed New Jersey (1820) and Rhode Island (1827) and became one of the first states to recognize private cultivation of oysters when it passed a law permitting one-acre sites for that purpose (Stevenson 1894).

In 1905, Brooks pointed out that demand had outrun the natural supply of oysters. He noted that some harvesting and processing activities added to the depletion of the fishery and suggested that oyster farming could alleviate these problems. For example, spat and seed oysters still attached to market oysters ended up on shell piles outside shucking houses, their death inevitable. A planting industry would find such attached oysters suitable as seed. They would be sold to the planter rather than to the shucking house. Where once the full-grown oyster was the economic prize and the attached small oysters were of no commercial value, now the attached oysters could be of more value than the large oysters and cull laws would be unnecessary. Again, Brooks indicated that the rampant violation of culling laws of his time could be avoided if the harvested shell, spat, and seed could be sold to planters. Similarly, if a demand for oyster shell by oyster planters who would use it as cultch arose, the loss of this valuable resource could be stemmed.

After his extensive six-year survey of Maryland's oyster grounds, Yates (1913) felt very optimistic:

> "It now seems not only reasonable but probable that within the next generation the citizens of Maryland will be leasing and cultivating a probable 100,000 and a possible 300,000 acres of so-called "barren bottoms" where oysters do not now grow in commercial quantities; that the

> more than 200,000 acres of natural oyster bars now reserved for the use of the oystermen as a result of the Maryland Oyster Survey will be so conserved and developed that they will produce as they have done before ore, twice the amount they now yield; and that the oyster industry of Maryland will then be based on an annual production of 20,000,000 bushels of oysters where now it is barely 5,000,000..."

Yates was wrong, not because the Bay was becoming less capable of yielding such quantities of oysters but because sociological and political factors lead to mismanagement and the discounting of biological realities. Dr. R. V. Truitt, the former director of Chesapeake Biological Laboratory, consistently pointed out the potential productivity of the Bay, with its oyster catch in the past having surpassed the beef production of the states surrounding the Bay (Nichol 1937). He felt that farming could have led to the level of productivity aspired to by Yates, for the reasons alluded to by Brooks (1905).

Economists have also been interested in private culture as a rational way of increasing oyster yield. Fairbanks (1932) presented an extensive discussion on the subject, tracing its history in Maryland and making recommendations that it be pursued vigorously. Similarly, Wheatley et al. (1959) suggested that oyster productivity in Virginia's York River could be increased by renting additional ground. Abrahamson (1961) discussed the economic aspects of markets for middle Atlantic oysters.

Wharton (1963) briefly described the natural history of the oyster, harvesting and marketing activities, and oyster laws and their enforcement. He concluded that a history of lack of concern for conservation measures had led to the oyster decline, coupled with the effects of inadequate law enforcement, unhelpful watermen's attitudes, and increased demand that came with improved transportation facilities and packaging techniques. Over time, he noted, Bay-area politicians had dictated oystering policy in compliance with the watermen's wishes. He felt that the state's newly initiated intensive rehabilitation program might help increase production on public beds, but he found it restrictive and costly, requiring controls and higher taxes. The biggest problem, however, was the state's deaf ear to numerous recommendations to allow greater private cultivation.

In a thorough analysis of the oyster fishery in Maryland, Christy (1964) discussed the common property approach to natural resources in general— its effects on the resource, its economic consequences, and its associated public costs. He then dealt with the supply and demand for oysters, before considering the characteristics of Maryland's industry. He considered alternative management strategies and suggested the institution of "exclusive use" rights. This would eliminate the problems of congestion on or overfishing of good areas. Oyster beds would produce economic rent and there would be an economically proper allocation of capital and labor resources. Innovative technology would be encouraged and the

public would not to have to bear the costs of cultivation and management. Oyster production could be adjusted with respect to demand. To achieve this goal in the face of opposition by oystermen, he suggested the imposition of gradual restrictions on the number of producers by using direct license limitation and monetary disincentives.

In an informative presentation, Glude (1966) suggested that three criteria be employed to evaluate successful management of commercial fisheries: (1) that the resource be harvested at a profit; (2) that the resource be maintained at a level which produces the maximum sustained economic yield; (3) that each participant in the fishery be provided the opportunity to obtain an adequate share of the harvest. Using these criteria, he determined that management of the oyster fishery in Washington State was successful whereas management of the Maryland oyster fishery was not. The public grounds in Maryland are under heavy fishing pressure, so individual incentive to practice conservation is weak. The catch is restricted only by allowing use of inefficient harvesting methods. Development of private oyster farming has been hindered. Efforts to improve management and the fishery have been hampered by opposition from the fishing industry. Thus the limitations to improved production are social and political. Glude quoted his "Great Law of Fishing" by stating that "Fisheries that are unlimited become unprofitable." He concluded that the situation could be changed only by "courageous experimentation to develop improved management techniques, and a well-planned system of public education."

In 1966, the Seafood Advisory Committee of Wye Institute received a report on the Chesapeake Bay fisheries of Maryland from an independent research group of consultants (Quittmeyer 1966; see also section on Rehabilitation Measures). Based on the extensive study performed by the research group, the Seafood Advisory Committee strongly recommended a system of private culture of all oyster grounds except seed areas. The grounds should be apportioned into tracts of a size sufficient to attract private capital and management. Great flexibility in managing such grounds should be allowed to the farmers. The leasing program should be phased in gradually to avoid disruption to self-employment of individual watermen. The interests of these individuals should be recognized and respected but the greater interest of the Maryland taxpayer who subsidizes the oyster industry must also be recognized. The management agency should have the freedom to classify oyster grounds as "seed," "self-sustaining," and "growing grounds" and would be allowed to restrict entry to the fishery. The scarce and vital seed areas (mostly on the Eastern Shore) should be designated and used only for that purpose. Access to the common resource should be limited to those seriously desiring to make a living from its harvest and efficiently equipped to make that harvest and help repay the cost of repletion. These actions, coupled with increased rehabilitation of grounds, would result in more oysters per unit of effort, raising the income of watermen. If the recommendations in the report were followed, the committee predicted a doubling of production in five years. The recommendations have thus far not been followed.

Again, Maryland's situation was analyzed by Alford (1973). He discussed oyster bars as a common property resource and described the resulting overexploitation arising from a lack of conservation incentives. He reviewed private oyster culture in the Bay and the restrictive Maryland laws concerning private bottom rental, and described the political influence of Maryland watermen on management efforts. Despite this, in 1965, the private oyster grounds, which then comprised 16% of the oyster-producing bottom of Chesapeake Bay, produced 42% of the total catch. He claimed that another 176,000 acres of cultured bottom in Maryland could provide 10 million pounds of oyster meat if the beds produced as well as those in Virginia did. He noted that between 1960 and 1966, the state of Maryland spent $7 million on oyster propagation, while the industry generated $400,000 from taxes and license fees. In another paper, Alford (1975) put forth a suggestion for interstate cooperation in the oyster industry. He discussed the oyster fishery in general and emphasized the special problems associated with the division of the Bay between Maryland and Virginia. He suggested a variety of mechanisms for increasing inter-state cooperation in order to bolster productivity. This cooperation would include allowing Virginia planters to rent bottom in Maryland waters, and would allow Marylanders access to the (then rich) seed beds of the James River.

Agnello and Donnelley reported on economic and legal factors affecting the oyster industry of the mid-Atlantic (1975a, b). They discussed the impact of three forces (economic, biological, legal) in the decline of the middle Atlantic oyster industry (1975a). A supply and demand model of the oyster industry was developed and the authors concluded that common property characteristics of the industry have harmed the industry's progress. Evidence of overfishing exists in common property states, with sub-optimal exploitation of the oyster resource. This is especially true in Chesapeake Bay states which the authors compared with Delaware Bay states where private culture is more common. They noted (1975b) that allowing for a mix of private and common property rights would result in higher ex-vessel prices and more stable intraseasonal price movements.

The ability of oyster grounds to yield increased harvests under even the most elementary of culture conditions is described by MacKenzie (1981) for Long Island Sound. Because growers began providing more clean shell cultch, kept removing two dominant predators from oyster beds, and took steps to prevent smothering by silt, yield in Connecticut increased 85 times from 1966 to 1972.

Part of the problem associated with common property resources appears to involve the fact that no one who participates in the fishery has any incentive to reduce his catch or cultivate the grounds, since there is no guarantee that other participants would do the same. This dilemma has been referred to as the "tragedy of the commons" by Hardin (1968), and this analysis has been applied to the Maryland oyster industry by Power (1970 — however, see Godwin and Shepard, 1979, for another perspective on the "tragedy of the commons").

Sometimes, pursuit of the common resource can be counterproductive to the common good and leave those dependent on the resource fearful for their stability. In late 1980, for example, a Maryland waterman told the Easton *Star-Democrat* newspaper that divers (as a new harvesting technique) were cleaning the bottom of oysters, leaving few for spawning. Faced with this dilemma, the watermen felt little recourse:

> "But if everyone else is doing it, then I'm going to put a diver on my boat, too. What else can I do? As long as the oyster business is being ruined anyway, I've got to get what I can, there's no other way."

It is understandable yet disheartening to note that this watermen's view of and response to the problem are not unique. Indeed, as the section on Historical Background suggests, watermen and their representatives remain unconvinced of the destructive power of overfishing or of the usefulness of private culture as an alternative way to bolster oyster-bed productivity. The very subject of rental of oyster ground has traditionally been an emotional one: though he did not mention the state, Galtsoff (1958b) reported being physically threatened after a small town meeting where he advocated private oyster leasing.

Maryland enjoys a unique situation because Chesapeake Bay has been a prolific producer of oysters. Its lower salinity habitats preclude most diseases, pests, and predators that deplete oyster grounds in higher salinities. Yet the industry is a shadow of what it was —and what it might be. Commenting on the problems of getting scientific insights incorporated into social action, Bowman (1940) used the Maryland oyster industry as an example. He cited the large amount of scientific material collected on the oyster and Brooks' recommendations concerning the management of the industry. He said that the legislators had ignored all these data and recommendations, preferring to consult "practical" oystermen. He described the results as a failure.

There appear to be three main reasons for watermen's resistance to private development of Maryland oyster grounds. Two have been voiced for some time (Commission of Tidewater Fisheries 1948), but the third appears to be more recent.

The first objection is that privately cultivated oysters will increase the harvest so much as to depress the market, bringing down the price of publicly harvested oysters. The 1948 Commission noted that farmed oysters from the Bay proper (it did not then recommend leasing tributary grounds) would be larger animals, and thus not directly competitive with standard oysters from the tributaries. It also noted that Maryland once marketed an annual production of 12-15 million bushels to an American population half the size of that in 1948; proper marketing, it said, should be able to sell any increase from private cultivation.

The second objection stems from the fear of encroachment by big business and the possibility that the traditional, individualistic way of life of the people who work on the water will be endangered. If, as a matter of social policy, it appears important to maintain productive tonging bars, or to encourage dredging by sailboat, or to maintain a "tidewater way of life," suitable legislation could be enacted to sustain these things, while at the same time encouraging private cultivation. The economic advantage that would accrue to tidewater communities from private cultivation—increased supply and demand for oysters, year-round work opportunities, the circulation of more money within the communities—as outlined in earlier references, appears to be substantial.

The third, and apparently more recent, argument is that a potential major bottleneck in increasing oyster production lies with actual processing of the catch rather than with harvesting. Some watermen have claimed that the lack of shuckers and processing machinery will "back up" the distribution of the supply, and overload the present processing capacity. But this may be a chicken-before-the egg complaint. Presumably, any increase in private farming would result in slowly increasing oyster yield. That in turn would stimulate more intensive research into shucking and processing machines. Oysters are basically solid meat within a hinged calcium-carbonate box. Yet crab processors now use a machine which picks meat out of many shell compartments in a crab body. Processing blue crab meat seems more difficult than removing oyster meat in that the meat lies within these various compartments and the shell breaks easily. We expect that the major problem of opening oyster shells will be solved, especially if a growing supply and growing demand-encouraged by better marketing and production-can be counted on by food processors.

Oyster Aquaculture in Maryland

Farming oysters has been underway in a number of nations for many years, with excellent results (Korringa 1941, 1976). For example, around 1860 France started to study methods of improving spat collection and began leasing oyster grounds. Many European countries and some areas of the United States followed suit. In Holland in the late 1800's, the oyster grounds were withdrawn from the free fishery and private culture began; this led to an unexpected revival of the oyster industry there. Not all problems were solved, and some regions continued to decline.

In most instances, oyster farming has followed the decline of natural oyster populations. Thus, although Maryland watermen have resisted the concept of renting oyster grounds for nearly a century, it would seem inevitable that a system allowing for rational utilization of the Bay's oyster growing potential must eventually prevail. As noted earlier, Dr. R. V. Truitt, former director of Chesapeake Biological Laboratory and a long-term investigator of oyster biology in the Bay, was fond of comparing the Bay's oyster producing potential with the production of dressed beef from terrestrial farms. For example, in his foreword to a report by Nichol on the oyster-packing industry of Baltimore (Nichol 1937), Truitt noted that the oyster yield (as he wrote) had averaged about two million

bushels over the past few years, compared with a yield of 15 million bushels in the previous century. The difference of 13 million bushels in terms of shucked meat was equivalent to a herd of 160,000 head of large steers, each dressing 600 pounds including meat and bone. Truitt noted that this quantity of beef exceeded that produced on Maryland's farms at the time. Thus, the decline in oyster production was greater than Maryland's beef production, yet the potential productivity of the Bay with regard to oyster production was not being tapped. The same situation exists today. Even though pollution has undoubtedly affected a greater proportion of Bay waters than in Truitt's day, one would expect the Bay to be able to sustain a greater harvest than it presently does if management and harvesting practices were changed to take advantage of what we know about oyster biology.

Bottom Culture

Should farming of oysters be encouraged in Maryland, it could take two directions. The first is the rental of Bay bottom (preferably good areas rather than the marginal grounds now available) to entrepreneurs who would undertake to cultivate it to produce maximum yield, just as a farmer cultivates his land. And, just like the farmer, the oyster grower would need to apply principles common to animal husbandry or plant production. For such activities, the oyster farmer would need to understand the fertility of his grounds. He would have to assess the food supply available for seed oysters and adults if he hoped to rear seed to market size. If he decided to depend on natural set to provide him with seed (a riskier proposition), he would need to understand the past history of the region with regard to dependability of set. Presumably, the state would have delineated those areas of the Bay that had dependable set and those that were good for fattening and growth. Once natural set or purchased seed were in place, the farmer would have to monitor for pests and disease organisms (fortunately a lesser problem in most of Maryland's waters than in higher salinity areas of the Bay). Because of capital and (especially) labor costs, it might be necessary to automate systems for cultivating the bottom, eliminating pests, evaluating oyster growth and condition, and harvesting each year's crop. Presumably, good husbandry practices would include complete harvest of all oysters from the bottom at the appropriate time, followed by reconditioning of the bottom as necessary. Further, a system of rotation of "cropland" might be necessary as it is on land. The carrying capacity of the grounds (i.e., number of oysters optimal for good growth per hectare) would need to be determined. In other words, a thorough knowledge of local grounds and of the behavior of oysters in each locality would be required. Such information should be readily available if correct management principles were being followed, for how can we manage what we do not understand? The absence of such information might discourage individuals from undertaking oyster farming; it would certainly slow down such an undertaking. But eventually a core of information would accumulate as more and more people became involved in oyster farming. The general subject of molluscan farming is explored further by Loosanoff (1972).

So far we have been speaking of on-bottom culture. Off-bottom culture of oysters often results in greater yields, fewer pest problems, and easier harvesting.

However, it also is beset with legal difficulties and it can be very labor intensive. Little exploration of this topic has occurred for Maryland's waters (Shaw 1966a, 1969, 1970, 1972; Shaw and Merrill 1966) but it appears that off-bottom culture in Maryland might be made commercially feasible, although more detailed economic analyses are necessary. A more general summary of the subject of oyster culture from rafts in east coast estuaries is provided by Aprill and Maurer (1976). More recently, Walker and Gates (1981) reported on an innovative approach to string oyster culture in Narragansett Bay, using saltmarsh ponds with artificially prolonged tidal flows. Economically, the internal rate-of-return ranged from 6.8% to 26.3%, with room for improvement.

Aquaculture or Seed Culture

The second direction possible in oyster farming is the employment of aquaculture techniques to spawn and rear seed which can then be placed in the Bay to grow to market size or which can be sold to other oyster farmers. The lack of seed in Chesapeake Bay is a major problem facing resource managers. Aquaculture technology is well advanced and several books are available for general use (e.g., Walne 1974, Korringa 1976), and a number of regional "hatchery manuals" have been produced (e.g., Pacific oyster - Breese and Malouf 1975; New Zealand oysters - Curtin 1979).

With regard to Chesapeake Bay, Dupuy et al. (1977) have produced a detailed, useful manual for rearing oyster larvae in hatcheries. In Maryland, Hidu et al. (1969) reported on a series of trial experiments in the low salinity (10-20 ppt) area of Solomons. They considered conditioning and spawning of adults, rearing of larvae, and handling of spat, and made numerous recommendations, concluding that commercial hatcheries appeared to be biologically feasible in the Chesapeake Bay area.

Some of the conclusions and recommendations of Hidu et al. (1969) can be summarized as follows:

1. *Conditioning and Spawning.* Low salinity stocks of Chesapeake Bay oysters can be conditioned starting in February by placement in running Bay water (0.5 L min^{-1} per dozen oysters) at 24-26°C. Parallel brood-stocks can be established at two-week intervals. Visual inspection of gonads of selected oysters would indicate success of this regime. Four or five weeks after conditioning started, spawning can be attempted. In late spring or summer, field stock can be collected and held at 20-22°C for a week before spawning is attempted. Spawnable oysters can be held in late fall through winter at 20-22°C in running water.

2. *Larval Rearing.* The technical details of culturing fertilized eggs and larvae, of changing water and feeding larvae, etc., need not be repeated here. Essentially, scrupulous cleanliness is required, a suitable temperature regime is necessary for good growth of larvae but not bacteria,

screening of larvae for size is necessary for selection of rapid growers, and sufficient food and antibiotics are needed for larval growth and control of bacteria.

3. *Handling of Spat*. Young spat (a few days to a few weeks old) need protection from predators (crabs, drills, flatworms) in the field. (For example, Krantz and Chamberlin (1978) studied blue crab predation on cultchless oyster spat. From an examination of broken oyster shell taken from field plots and of shells destroyed by blue crabs in laboratory tanks, they concluded that high mortalities (79-99%) of spat (size range 6 mm-25 mm) occurring within one month of planting in the field were probably attributable to blue crab predation.) Spat undoubtedly must be held in a hatchery or outdoor troughs (usually a costly action) until they reach a size sufficient to resist attack by predators or should be placed in the field in cooler months when predators are less active or are absent.

In addition to biological considerations, economic factors involved in hatchery operations must be carefully considered. A pilot-scale hatchery operation has been underway at Horn Point Environmental Laboratories to provide insight into labor, energy, and capital costs for such a commercial scale facility. Unfortunately the hatchery was built by the state in an area which was declared to be less than optimal by oyster biologists who were consulted (salinities are lower than those found at better sites in Maryland's Chesapeake Bay). In spite of its sub-optimal location, operation of the hatchery has yielded some information on manpower and operational requirements (Lipschultz and Krantz 1978). Labor was the major cost component, although the study year (1976) was one in which energy costs were much less than they are at present. The data need updating, but the model is a useful first step in the important project of estimating costs of hatchery activity. It is encouraging that a number of commercial oyster hatcheries (albeit small ones) have operated in Maryland for a number of years.

Some recent papers on West Coast aquaculture practices by Lannan (1980a,b,c) and Lannan et al. (1980) provide excellent examples of the sort of information that is needed in Maryland concerning broodstock management of C. virginica for hatchery use. These papers consider larval survival of *C. gigas* in hatcheries and attempt to optimize such survival by various biologically sound practices such as broodstock conditioning and selected mating. Lannan (1980a) found substantial variation in larval survival. The variation was due to genetic and non-genetic factors. The non-genetic factors appeared to be subtle environmental differences in the rearing systems. Genetic influences involved regulation of gametogenesis and timing of spawning. Lannan et al. (1980) showed that, to achieve maximum larval survival, gametes needed to be released at a certain optimal stage. Time-course conditioning trials revealed an optimum conditioning interval during which the proportion of viable gametes is at a maximum. Matings which occurred before or after this optimum interval resulted in reduced gamete viability. This was reflected in reduced setting success.

Clockwise from top: Oyster cultivation in trays by an individual waterman. Young oysters in raceways at a research-oriented, pilot-scaled hatchery at Horn Point Environmental Laboratories. Setting-tables containing spat and cultch in the State-run oyster hatchery at Deal Island.

Careful observation could determine if such optimum intervals exist for C. virginica If they do, one would need to know the annual gonadal cycle of one's brood stock to take advantage of them. Then one would choose the appropriate conditioning regime, including temperature. Finally, the optimum conditioning interval at the chosen temperature would have to be determined empirically, depending upon the season. In addition, the suitability of various parental lines would need to be determined (Lannan 1980b). It may be that some lines reach optimal spawning condition at a period that is different from other lines. The mating of lines reaching optimal spawning condition at the same general time period would produce better larval survival and spat settlement than would the mating of lines not in synchrony.

Finally, the legal aspects of closed-cycle aquaculture have been examined by Bockrath and Wheeler (1975). They discuss potential problems with such systems in Maryland which may result from the wording of Maryland legislation that was developed before such aquacultural systems were envisaged. The principal problems include vagueness in the wording of some statutes regulating the natural fishery, apparent inhospitality to corporate investment in fishery resource activity, and the lack of any reference to such systems in the laws which deal with private oyster culture. The authors conclude that entirely new statutes are needed if Maryland wishes to encourage closed-system mariculture development.

A Glutted Market

We have referred to the concern of watermen and processors that the potential exists for markets to become glutted if oyster production rises above present levels. They appear to feel that increased supply of oysters will outstrip demand, resulting in depressed prices.

Though economists can provide better detailed analysis of this potential, we can take note that past demand for oysters was much greater than it is now. For example, Nichol (1937) pointed out that theater-goers in Baltimore once ended their evening with oyster stew in oyster parlors, and that oyster suppers were an elite form of hospitality, especially at Thanksgiving and Christmas. Engle (1966) commented that he recollected having oysters as a family meal at least once a week, and that they traditionally appeared in the dressing of holiday fowl and as oyster stew on Easter morning. Yet, as the population increased, oyster production and consumption decreased, leading to the loss of the tradition of eating oysters at home or as aperitifs when dining out. Bryan (1949) noted that in 1912, per capita consumption was five times what it was in 1949; when the U.S. population was half that of 1949, Maryland sold seven times the number of oysters in the 1949 harvest at a profit.

It seems reasonable to conclude that scarcities and resultant high prices lead to the loss of the habit of eating oysters. This would seem to hurt industry more than the "problem" of having plenty of oysters available at moderate prices. Suitable marketing strategies should be able to expand demand for such a nourishing food as oysters, especially if prices were moderate and competitive with

other meat sources. New methods of preparing oysters might also serve to attract potential customers who would otherwise refuse to eat oysters in their more traditional raw or stewed form.

SPATFALL PREDICTION

Each spring in Maryland's portion of Chesapeake Bay, the Department of Natural Resources pays contractors to have large quantities of oyster shell dumped overboard at different locations (Outten 1980). This shell serves as cultch for oyster larvae which require hard surfaces when they settle to begin their benthic existence. Since Maryland's most recent program of shell and seed planting began, 120 million bushels of shell and seed have been handled at a cost of about $24 million (Outten 1980). The cost of planting an acre of bottom with shell varies from $550 to $700 (Outten 1980).

Some of the shell ("fresh") is purchased from oyster packers, who are under no obligation to sell to the state. Obviously, not all of the fresh shell which is removed from the Bay annually in the oyster harvest is returned, since oysters are exported in-shell. Additional use is made of "dredge" or "fossil" shell mined from deposits located in the muddy bottom of the Bay. These finite resources will eventually run low because dredged shells are an exhaustible resource (Outten 1980) and the amount of fresh shell returned to the Bay is less than the amount harvested. Given the cost to the state and the continued depletion of shell resources, it is important that the cultch be used carefully in order to get the maximum return (in spat settlement) for the money expended.

The importance of cultch material has long been understood by oyster farmers and biologists. In 1855 in Connecticut, shells for catching spat were deployed on the northern shore of Long Island Sound (Galtsoff et al. 1930). Brooks (1905) remarked that part of the reason for a decline in the oyster resource in Chesapeake Bay was the absence of enough clean shell on beds as cultch. He advocated an end to the use of shells from shucking houses as road-building and lime-production material; they should be returned to the Bay as cultch. Galtsoff et al. (1930) claimed that reasons for the decline in the annual crop of oysters on the U.S. East Coast included the failure to return sufficient quantities of shell to the oyster beds. In Europe, planting of oyster shell as cultch material had been practiced for decades (Korringa 1941).

It has also been common knowledge that placement of the cultch in the water must be timed carefully. If the cultch is placed too early-before the larvae are ready to settle—it may become fouled by bacterial slimes which are unattractive or repellent to larvae, or by invertebrates which compete for setting space with or prey upon the mature oyster larvae (Nelson 1908, Sieling 1951, Manning 1953, Beaven 1955, Engle 1956, Wisely et al. 1978, Steinberg and Kennedy 1979). Indeed, Korringa (1941) claimed that, after about 12 days, cultch becomes unsuitable for settling by larvae of the European oyster, *Ostrea edulis*. However, no such time limit for cultch in Maryland's Chesapeake Bay has

been determined (Sieling 1951, Manning 1953, Beaven 1955, Engle 1956). Obviously, if cultch is placed too late to catch the peak or peaks of larval settlement, the money involved in its placement will have been wasted and the planted shell may become so fouled that, when the next year's settlement period occurs, the shell may only be minimally attractive.

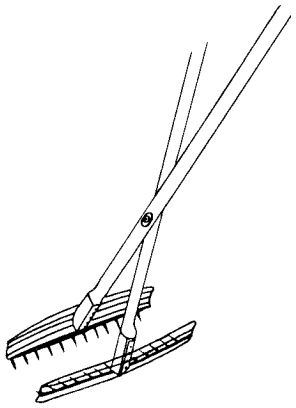
The period of main oyster settlement in any region is notoriously variable, which means that the placement of shell according to the convenience of human suppliers or management personnel may result in placement too early or too late in the season. For example, as part of Sea Grant-supported research in the summers of 1977 to 1979, one of us (VSK) monitored the periods of spat settlement in two tributaries of the Choptank River, i.e., Broad Creek and Tred Avon River (Kennedy 1980). In Broad Creek, two peaks of settlement occurred in 1977, in late July and late August. In 1978, a small peak of settlement occurred in early August. In 1979 there were two peaks again, this time in mid-June and early July, with few spat being found thereafter. In Tred Avon River in 1977, spat numbers were very low until a small peak of settlement occurred in late September which was later than settlement occurred in Broad Creek. In 1978, almost no spat were noted on plates in Tred Avon River during the period of study. There were three peaks of abundance in 1979 (late May, mid-June, early July), after which settlement was negligible. From this information it is obvious that, if cultch was planted in these areas in June as a matter of economic and logistical convenience, it would have arrived "too early" in 1977 and 1978 in both tributaries. It would have been "on time" in 1979, although it would have missed the first peak of spat settlement in Tred Avon River. Thus, it would seem desirable to have a method of predicting the proper time to place the cultch.

This is not a new insight. In 1874, Winslow (based on his work in North Carolina and Connecticut) stated "...thousands of dollars could be saved annually by the oystermen if they would determine with any approximate accuracy the date when attachment of the young oysters would occur." (quoted by Korringa 1941). In New Jersey, J. Nelson (1909) tried to predict the probable date of setting of C. virginica by studying the stages of development of larvae in the water. His son, T. C. Nelson (1917), stated that it was possible to predict setting time in New Jersey waters within two days of the event. The French initiated such studies in the 1920's, followed by the Dutch in the 1930's (Korringa 1941). In Holland, Dutch oyster farmers paid close attention to the studies and predictions of the government supported biologists when preparing to place spat collectors in the field (Korringa 1941). The application of such predictive techniques has spread to western Canada ("...In British Columbia no cultch is exposed before a forecast predicts a spatfall of commercial intensity." Quayle and Terhune 1967b, p. 1); Japan (Wisely et al. 1978); New Zealand (Dinamani and Lenz 1977); and the northwestern U.S. (Lindsay et al. 1959).

In all these areas, hydrographic conditions and aspects of larval activity and distribution tend to differ. For example, in British Columbia 95% of the oyster larvae (*C. gigas*) occur between the surface and a depth of 10 ft (3 m) (Quayle

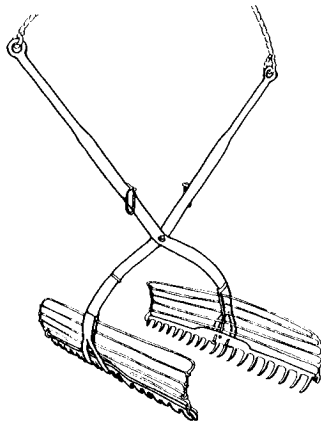
and Terhune 1967a), unlike the situation with C. virginica in Barnegat Bay and Delaware Bay (Nelson 1953,1955, Kunkle 1957). In the state of Washington, setting of *C. gigas* larvae and the predictability of setting vary with the presence of a stable, warm surface layer of water (Westley 1968). The variability of hydrographic conditions and larval distribution in other regions has been discussed by Korringa (1941).

It is, therefore, not a foregone conclusion that one can predict spat settlement details wherever one might choose to do so. In the state of Washington, it is considered necessary to (a) measure hydrographic conditions; (b) determine when spawning occurs; (c) observe distribution and abundance of larvae; (d) follow progress of larval groups in plankton; (e) make setting predictions by using present findings and comparing them with past data; and (f) evaluate predictions by observations on eventual distribution and abundance of set (Lindsay et al. 1959). The possibility of transference of this predictive ability to Chesapeake Bay has not been demonstrated.



Oyster tongs

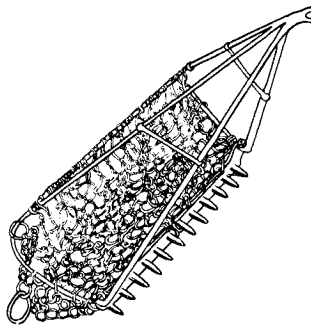
If the state of Maryland finds it increasingly important to conserve money and shell in its planting program, as we believe it undoubtedly will, it will be important to know when to place the cultch for maximum benefit. This is no more or no less than what is done elsewhere. Second, if private farming of oyster bottom increases in the state, as we believe it must if the industry is to thrive, then oyster farmers in Maryland will be no less in need of predictions for collecting commercial quantities of spat than are their compatriots elsewhere around the world. Indeed, given the logistical difficulty Maryland would face in stockpiling shell and placing it overboard in a limited period of time, it is clear that the most efficient system would involve a large number of individual oyster farmers who would see that their own smaller holdings were shelled at the right time.



Patent tongs

FISHING GEAR

The commercial oyster fishery in Chesapeake Bay relies upon fishing gear which has not changed, or has changed very little except for the use of patent tongs, in more than sixty years (See Figure 6). The origins of at least one gear type, hand tongs, can be traced back to the traditional gear used in fisheries on the west coast of England and imported by the early colonists (Carey 1970). The three main methods used on the public oyster grounds of the Bay are dredging, patent tonging, and hand tonging. Both Churchill (1920) and Sieling (1950b) have written excellent reviews of these fishing methods and gear, the latter containing especially good drawings and photographs. These types of gear vary in efficiency, the oyster dredge being the most efficient device of the three (Sieling 1950b; Maryland Board of Natural Resources 1953). However, all three of these fishing methods are less efficient and more labor-intensive than other methods involving use of escalator and hydraulic dredges (NOAA, Office of Fisheries Development, 1977a,b). A mechanical escalator harvester, developed from a conventional Maryland soft clam dredge, can harvest 500 bushels of oysters an hour while being operated by only two people (Haven et al. 1979).



Oyster dredge

Tonging oysters before 1919.

Dredging oysters from a skipjack in 1980.

Tonging oysters in 1980.

Figure 6.

The more efficient methods, while frequently illegal or restricted on public grounds for conservation reasons (Sieling 1950b), can often be used by growers on private or leased oyster grounds in other states (NOAA, Off. Fish. Dev., 1977b). Oyster farmers on the Pacific Northwest and Long Island Sound use large, barge-mounted dredges which effectively harvest oyster beds. Some hydraulic dredges can yield an average of 1,400 bushels per day per man (NOAA, Off. Fish. Dev., 1977a). In addition, studies at Willapa Bay on the West Coast are continually seeking to improve oyster cultivation methods by developing new methods or techniques, or new uses for existing equipment. For example, the use of the traditional English pasture harrow on oyster beds has been found to increase spat settlement, control fouling growth, and prepare the oysters for harvesting (Sayce and Larson 1966).

In a recent paper, Haven (1981) described modern gear that can increase harvest efficiency; the gear included automatic culling machines, mechanized seed planters, and oyster harvesters.

DREDGING IN OYSTER CULTIVATION

Ingersoll (1881) considered the advantages and disadvantages of dredging as a management or cultivation practice. The consensus among those who had studied the subject was that, if properly conducted at the right time and in the right place, dredging was a beneficial practice. Undisturbed oyster bars tended to become consolidated into a rigid structure which was hard to work. Dredging broke up the "rock" and scattered the oysters over a wider area, thus extending the bar. The provision of greater area allowed for better oyster growth and may have provided greater surface area for spat settlement.

Winslow (1881, 1882) concurred with these observations. By the time of his survey, the oyster grounds in Tangier and Pocomoke Sounds had doubled in area from the original compact vertical configuration because of dredging. Given moderate fishing effort before the Civil War, the beds were continually improving (Ingersoll 1881). However, after the Civil War, dredging increased in intensity, resulting in a depletion of about 80% in Pocomoke Sound and 66% in Tangier Sound (Ingersoll 1881).

Because of such depletion, many claimed that the dredgers were responsible for killing and crushing young oysters. However, Brooks (1905) disputed this claim and noted that private leaseholders who farmed oysters in Connecticut used much larger dredges than were used in Maryland, apparently with benefit to their oyster beds. Brooks presented his own observations that, although dredges may break or kill small oysters, the number was limited and probably of little significance. Because the spat are attached flat on the substrate, he thought they thereby avoided being damaged. As they grow they project more and more above the substrate but by then their structural strength should have increased.

The subject of using dredging as a cultivation tool was explored in some detail on *Ostrea edulis* beds in England by Waugh (1972) with conclusions contrary to those of Brooks (1905). In England, it was the practice to use harrows to turn shells over to kill epifauna and expose clean surfaces for spat settlement. Over a number of years, Waugh performed a variety of field experiments using harrows. He found that, while oyster condition on harrowed beds was not affected, growth was significantly less compared with that on control beds. He cautioned against harrowing without care on stocked grounds because of the shell damage that might ensue. Shell damage results in slowed growth. On grounds that had been shelled, harrowing did not appear to result in increased recruitment. There seemed to be no increased mortality because of harrowing.

Waugh's (1972) work appears to be the most extensive reported. Its transferability to the situation with Crassostrea *virginica* is not clear. Our impression is that American oysters tend to have stronger shells than do flat oysters, thus they may be subject to less mechanical damage from dredging or bagless dredging. The subject needs further careful experimentation in Chesapeake Bay. Note that the pasture harrow has been used in Washington state with the result that settlement of *C. gigas* larvae has been enhanced (Sayce and Larson 1966).