Maryland's Oyster Redevelopment Program - Sanctuaries and Harvest Reserves

Final Report

Prepared by

Philip W. Jones and Brian J. Rothschild

September 21, 2009

INTRODUCTION

Oyster bars in Maryland fall into one of three management categories - sanctuaries, managed reserves and traditional harvest areas. Maryland's sanctuary program was created in the early 1990s. The principal goal of the sanctuary program is to attempt to enhance the ecological services of oysters in a given area through closure of the commercial fishery. Some sanctuaries have been treated with shell and seed plantings while other areas are closed to harvest and no specific enhancements are undertaken.

Managed reserves are located in low salinity, low disease areas where natural recruitment is usually very low. In the managed reserve program, specific oyster bars are closed to harvest, sites are prepared by reclaiming shell and the area is reseeded with hatchery oysters. Reserves are managed to provide both ecological and economic benefits[1].

Traditional harvest areas are managed primarily through a set of laws and regulations that establish season length, daily catch limits, allowable gear types and a minimum size limit. Traditional harvest bars have historically been managed for their economic benefits. Management objectives in traditional harvest areas have been pursued primarily through habitat rehabilitation, enhancement, and seed planting. Our report on management of traditional harvest areas is in progress and will be provided at a later date.

In this report, background on Maryland's sanctuary and harvest reserve programs is presented and recommendations for future restoration activities are made.

I. Sanctuaries

Provisions of the 1994 Chesapeake Bay Program Oyster Management Plan (OMP) resulted in the establishment of a network of oyster sanctuaries throughout Chesapeake Bay and its tributaries. The OMP presented guidelines for sanctuary development in three salinity zones - 5 to12 ppt, 12 to14 ppt and > 14 ppt. The primary objective of creating sanctuaries in low salinity waters (5-12 ppt) was to promote the ecological value of oysters. Survival of juveniles and adults in this region is high compared to survival in other salinity zones. However, because natural recruitment is often low in fresher portions of the 5-12 ppt zone, supplementing wild spat production with hatchery seed may be necessary at some sites in order to maintain stocks. Sanctuaries in 12-14 ppt were selected to provide both ecological benefits and to serve as a source of brood stock. Oyster bars in this region of Chesapeake Bay generally have good survivorship and recruitment and do not normally require additions of shell or seed to remain productive. Higher salinity areas (> 14 ppt) were included in the program to foster potential development of older disease resistant oysters and to provide a source of brood stock.

---

[1] Maryland Department of Natural Resources, Fisheries Service. 2005. Preliminary economic evaluation of Maryland's oyster reserve harvest program. Tawes State Office Bldg., 580 Taylor Avenue Annapolis Maryland

Over the long term, these areas should not normally require treatment with shell or seed aside from an occasional shell planting to improve spatset.

The State of Maryland began development of the Sanctuary Program with bars which were already closed to harvest (e.g. bars nears Cambridge and Oxford Lab) and added additional areas to the program over time (Table 1). There are currently 31 sanctuary sites in the Maryland portion of Chesapeake Bay and five sites in the mainstem of the Potomac River (Figure 1).

Progress in achieving key OMP objectives of Maryland's Sanctuary Program was evaluated by Tarnowski (2005)[2] based on an analysis of the subset of Maryland sanctuaries sampled in the DNR Fall Survey. The sanctuaries included in the analysis are presented in Figure 1 and Table 2. As noted in his report, the Sanctuary Program evaluation includes data collected over a four-year drought (1999-2002) followed by two consecutive years of abnormally high freshwater inflow. These conditions resulted in a prolonged period of historically high disease related oyster mortality which clearly influenced the results and conclusions reported in the study. The study found that under these environmental conditions, regardless of the degree of habitat rehabilitation (through addition of shell) or population enhancement (through additions of seed oysters), many of the sanctuary populations tended to look like nearby natural populations in relatively short periods of time. However, there were some exceptions where sanctuary biomass increased significantly over the study period. Tarnowski (2005)[3] concluded that the program was not achieving stated OMP objectives primarily because environmental conditions, not fishing, appears to be the foremost controlling factor in oyster recruitment, disease, and mortality and therefore is the overwhelming determinant of sanctuary success.

MDNR has also been monitoring three power dredge sanctuaries in southern Maryland both during the Fall Survey and with additional patent tong sampling. All three sites have benefited from two shell plantings each and subsequent good spatsets which, in combination with good survivorship over the past six years, has resulted in a significant increase in the number of market oysters[4].

In 2007 a patent tong survey was undertaken to estimate density and special extent of oyster population planted by the Oyster Recovery Partnership (ORP) on five sanctuaries (Strong Bay, Shoal Creek II, States Bank, Lake Ogleton and Ulmstead)[5]. Most estimates of abundance were less than 5% of the number planted which was lower than anticipated given an expected 50% initial mortality rate and annual natural mortality rate of 15%. The author concluded that the lower than expected survival may have been due to factors related to planting techniques, higher than expected initial mortality, the quality of the

[2] Tarnowski, M. 2005. An evaluation of the Maryland oyster sanctuaries monitored by the MDNR shellfish program's fall oyster survey. Maryland Department of Natural Resources. Fisheries Service.
[3] Ibid.
[4] Tarnowski, M., Personal communication.
[5] Paynter, K. 2008. 2007 sanctuary assessments. A report to the U.S. Army Corps of Engineers Baltimore District.

shell base that seed were planted on, or illegal harvest. (Note that site specific information on spat survival plus data on natural mortality of juveniles and adults will need to be routinely collected in order to adequately evaluate site specific oyster restoration progress.)

There is widespread agreement that Maryland's Sanctuary Program, as originally designed, has not resulted in significant increases in the abundance of oysters throughout the Maryland portion of Chesapeake Bay. In addition to environmental factors and illegal harvest, lack of success of the program has been attributed to several other factors including: (1) placement of sanctuaries in suboptimal areas (those where natural mortality has historically been high and areas of low quality or unsuitable habitat); (2) inadequate scope of the program (too small to expect significant increases in abundance) and (3) insufficient levels of funding/effort to restore substrate and enhance stocks. [Note that the extent to which placement of sanctuaries in suboptimal habitat contributed to the lack of success of the sanctuary program may require additional evaluation. Most sanctuaries were improved with shell plantings – often more than once – in addition to some seed plantings (Table 2). Also, it should be noted that even though high disease areas were considered suboptimal for restoration, there is a consensus in the scientific community that such locations are desirable for long-term development of disease tolerance.]

Lack of success in restoring native oysters led to the preparation of a draft Environmental Impact Statement (EIS) for Oyster restoration in Chesapeake Bay[6]. The EIS evaluated the risks and benefits associated with introducing a non-native oyster into Chesapeake Bay and the potential for native oyster restoration through an examination of several management alternatives. A preferred alternative has been identified in the EIS. It does not include the use of non-native oysters to restore stocks in Chesapeake Bay. Instead, oyster management activities in Chesapeake Bay will focus exclusively on native oysters.

In Maryland, the foundation of the oyster management program will include: (1) enhancing efforts to increase the abundance of native oysters through habitat restoration and use of hatchery produced oyster seed; (2) providing more protection to the stock by reducing fishing mortality and (3) expanding aquaculture of native oysters. A key element of recovery is an expansion of the State's oyster restoration program. This expansion will involve increased enhancement efforts on some of the existing sanctuaries and an expansion of the geographic scope of oyster restoration activities. In the next two sections of this document, information is presented which can be used to facilitate expansion of restoration of oyster stocks in Maryland waters of Chesapeake Bay.

[6] U.S. Army Corps of Engineers. 2008. Draft Programmatic environmental impact statement for oyster restoration in Chesapeake Bay including the use of a native and/or nonnative Oyster. U.S. Army Corps of Engineers, 803 Front Street, Norfolk, VA 23510.

II. Candidate Bars for Expanded Oyster Restoration

Rothschild (2009)[7] analyzed DNR fall survey data to identify the most productive oyster bars in Maryland. Determination of the most productive or "best bars" was based on the abundance of market oysters at sites sampled in the Maryland DNR fall survey from 1996 - 2007. The "best bars" in a given year were those with sites in the top 10% (> 70 market oysters per bushel) of all sites sampled. These results are presented in Table 12 of his report.

Data in the Rothschild (2009) report for bars with market oyster abundance in the top 10% of all bars surveyed in four or more years over the study period (1996-2007) plus information on bar size, legal fishing gears, and salinity zone from other sources is presented in Table 3. The location of these bars is presented in Figure 2. Several important points can be drawn from these data:

- many of the "best bars" are not currently in Maryland's sanctuary program;
- 13 of the 18 best bars have never been treated with seed and have not been treated with dredged shell (which enhances spat settlement for approximately 4 years after being planted) since the 1980's or mid -1990's;
- Bruffs Island in the Wye River, Deep Neck in Broad Creek and Cason in the Little Choptank have never been planted with seed or shell yet appear to have maintained high levels of productivity over time;
- 12 of the 18 best bars are located in a relatively small geographic area that includes Eastern Bay, and Miles, Wye, Lower Choptank and Little Choptank Rivers;
- Point Lookout, which is a sanctuary, is the only "best bar" south of the Little Choptank River.

Time series of catch/tow of market oysters on "best bars" which have never been treated with natural or hatchery seed and have not been treated with dredged shell since the 1980's or mid-1990s are presented in Figures 3a – 3c. Oyster abundance declined significantly on all best bars in the early 2000s as a result of disease related mortality and subsequently increased through 2004 – 2006 in all areas for which data are available except for Cedar Island. In 2007 market oyster abundance declined on Kent Point, Eastern Bay and Broad Creek oyster bars and continued to increase at Harris Creek and Little Choptank sites.

In an attempt to expand the geographic range of potential sites for the Redevelopment Program, the definition of a "best bar" was relaxed to include bars in the Rothchild (2009) report that were in the top 10% three years over the study period (Table 4). This resulted in the addition of 19 "best bars" but only two additional areas - Wicomico River (eastern shore) and St Mary's River. With the exception of sites in the Chester and South Rivers and Grapevine Cove in the Little Choptank, bars that were in the top 10% three years over the study period either have not been planted in seed or shell in recent years or have never been subject too enhancement activities.

[7] Rothschild, B., 2009. Indicative Analysis of the Fall Oyster Survey in Maryland waters of Chesapeake Bay. Draft report to the Maryland Department of Natural Resources.

The results of relaxing the definition of a "best bar" to include sampling sites with 2 years in which market oyster abundance was in the top 10% of all sites sampled are presented in Table 5. Additional sites were added to several of the river/areas previously identified as potential best bars and the geographic range of candidate area/rivers was expanded to include the Upper Bay, Calvert shore, and the Honga, Wicomico (western shore), Patuxent and Potomac Rivers. It is important to note that unlike the majority of candidate best bars with market oyster abundance in the top 10% in three or more years (Tables 3-4) many of the bars in the top 10% in two years of the study period (Table 5) were treated with seed. Treatment with seed most likely contributed to the relatively high numbers of market oysters at these sites in subsequent years. It is also important to note that unprecedented spat production in the Wye and Miles Rivers and Eastern Bay in 1997 is most likely related to the high abundance of market oysters in those areas in 1999 and 2000.

III. Candidate Rivers/Areas for Expanded Oyster Restoration

Two approaches were used to identify potential river/areas for inclusion into Maryland's Oyster Redevelopment Program. One approach was based on recruitment success and the other on production of market oysters per acre of oyster habitat.

Recruitment data from the DNR fall survey was used to examine the relationship between reproductive success at the river/region level and the occurrence of "best bars" in three or more years in the 1996-2007 fall survey market oyster time series (see Tables 3-4). Two indices of recruitment success were used in this evaluation. One is based on spatfall data collected from 53 key spat monitoring bars sampled in the fall survey over the period 1985 -2007[8]. The other is based on spatfall counts for all sites sampled in the fall survey each year over the period 1996-2007[9]. For both indices, data for a given site was grouped into one of 23 rivers/regions presented in Table 2 in the 2007 DNR fall survey report. River/region specific indices were calculated as the average number of spat/bushel at all selected sites in the river/region over the time series. Data for the 23 areas was ranked from the highest to lowest average number of spat/bushel (Table 6). Comparing data from either of the two recruitment indices to rivers/areas which support "best bars" that have not recently or have never been treated (Eastern Bay, Miles River, Wye River, Broad Creek, Harris Creek, Little Choptank, Wicomico River (eastern shore) and St. Mary's River) indicates that, with the exception of Wicomico River, there is a good correlation between the two sources of information. (Wicomico River (eastern shore) ranked among the lowest recruitment areas). That is, rivers with untreated or not recently treated "best bars" have above average reproductive success. Assuming that spatfall estimates determined from fall survey data are representative of spatfall in a given river/area, this

[8] Tarnowski, M. [Ed.] 2008. Maryland Oyster Population - Status Report 2007 Fall Survey. Maryland Department of Natural Resources Shellfish Program and Cooperative Oxford Laboratory MDNR Publication.
[9] Data sources ftp://dnrftp.dnr.state.md.us/public/outgoing/fish/Oysters/ and ftp://dnrftp.dnr.state.md.us/Public/Outgoing/Fish/Oysters/Other/MDNR Annual Fall Survey

evaluation suggests that the following areas – in the order of highest to lowest average rank - Miles River, St. Mary's River, Broad Creek, Little Choptank, Eastern Bay, Harris Creek and Wye River may be the most appropriate candidates for large scale restoration activities.

The effect of extremely strong recruitment in the mid-Bay region in 1997 on the rank of candidate rivers/areas and on the above conclusions was examined by excluding results of the 1997 fall survey from the spatfall analysis. Among candidate areas this change had the most significant effect on the ranking of Miles River, Wye River and Eastern Bay (Table 7). Excluding 1997 spatfall data resulted in the following ranking (highest to lowest) of potential candidate areas/rivers which support best bars - St. Mary's River, Broad Creek, Little Choptank River, Harris Creek, Miles River, Eastern Bay and Wye Rivers.

Estimates of production of market oysters among rivers/regions were also examined as a means of identifying potential river/areas for inclusion into Maryland's Oyster Redevelopment Program. In this evaluation, production was estimated as the average reported harvest within a river/region from 1985-2008 divided by the oyster bar acreage within that river/region. Acreage estimates were based on the modified Maryland Bay Bottom Survey (MBBS)[10]. (Note that this evaluation requires numerous assumptions including the following: oyster harvesters accurately report the location of their harvest; F is the same among regions and the relative reporting rate of commercial fishermen is the same Baywide). Production estimates are presented in Table 8. Note that because of the way the harvest data were reported, production estimates are presented for St Mary's River and Smith Creek combined and for Nanticoke and Wicomico Rivers combined. Eastern Bay, Broad Creek and St. Mary's River (and Smith Creek) were the most productive areas followed by Choptank River, Harris Creek, Wye River, Little Choptank River, Chester River and Miles River. Overall, there appears to be is a good correlation between the location of "best bars" and the most productive rivers/areas. (Note that the two exceptions are Middle Bay - which is composed of a very large geographic area- and Wicomico River.)

A summary of production estimates and spat fall rankings described above is presented by river/area in Table 9. Overall, rivers with "best bars" " three or more years over the 1996 - 2007 time series that have never been treated or have not been treated in recent years ranked highest in production and spatfall when data for all years is included in the two recruitment time series (key bars and all bars). However, when spatfall data for 1997 is excluded from the two time series, estimates of recruitment success declined significantly in Eastern Bay, Miles River and Wye River.

[10]Greenhawk, K. 2005. Development of a potential habitat layer for Chesapeake Bay oyster bottom. Maryland Department of Natural Resources. Oxford Cooperative Laboratory; Smith, G., D. Bruce, E.Roach, A. Hansen, R. Newell and A. McManus. 2005. Assessment of recent habitat conditions of eastern oyster *Crassostrea virginica* bars in mesohaline Chesapeake Bay. North American Journal of Fisheries Management 25:1569-1590.

Based on estimates of production and on the four time series of recruitment presented in Table 9, it appears that Broad Creek, St. Mary's River and Harris Creek are the best candidate areas for large scale restoration. In addition to supporting "best bars", production and spatfall rankings are high in these three areas and estimates of recruitment success were not lowered significantly when recruitment data for 1997 was excluded from the analysis. Eastern Bay, Wye River, Little Choptank and Miles River also appear to be good candidate areas. They also support "best bars" which have not been treated with seed or shell in recent years. However, they differ from the three areas identified above in that spat fall rankings are significantly lower when the dominant 1997 year class is removed from the recruitment analysis.

IV. Managed Reserves

The principal objectives of the managed reserve program are to enhance ecological services associated with increased oyster abundance and to provide economic benefits to commercial fishermen through harvest of reserve oysters. A detailed history of the managed reserve program was prepared by DNR Fisheries Service[11] and is briefly summarized as follows. In the managed reserve program, oyster bars in low salinity areas are closed to harvest, sites are prepared by reclaiming silt covered shell and shell plantings and the area is seeded with hatchery oysters. Site preparation included removal of as many of the diseased oysters as practical, planting shell to improve substrate if needed and planting disease free hatchery seed. Monitoring of all sites are conducted to estimate survival, growth and disease prevalence and intensity. Sites are reopened periodically to harvest when predetermined size structure criteria of oysters on the reserve bar are met. Only hand tongs and diving (less efficient gear types) are permitted during harvesting of the Reserve oysters.

The first reserve sites were established in Maryland in 1997 and the program was expanded in 2000 to create larger reserves (Figure 1). One element of the 2000 expansion of the program was the designation of the Chester, Choptank, and Patuxent Rivers as priority areas in which to establish reserves. Reserve sites are managed through a steering committee which is responsible for recommending to the Department the dates for opening and closing the fishery, the daily catch limit, the minimum size limit and the limit on total removals. Opening managed reserves to fishing requires DNR approval and generally only occurs when 50% or more of the oysters on the site are 4 inches or larger in size. Over 17,500 bushels of oysters have been harvested in the reserve program to date[12].

Maryland's Oyster Reserve Program is administered by the Oyster Recovery Partnership (ORP). The ORP also oversees planting of hatchery seed on oyster sanctuaries and open harvest areas. To date, ORP and its partners have planted over 2 billion hatchery seed Of these, about 700 million were planted on 17 reserves, 600 million were planted on 35

---

[11] Maryland Department of Natural Resources, Fisheries Service. 2005. Op cit..
[12] S. Abel, ORP, Personal Communication.

sanctuaries sites and over 300 million were planted on 37 open harvest areas[13] (Tables 10 – 11).

Evaluation of the reserve program is limited to a 2005 Maryland DNR analysis of costs to produce oysters harvested from three reserves established in 2001 and fished in 2004 (Emory Hollow and Blunts in the Chester River and Bolingbroke Sands in the Choptank River)[14], the first year the bars were opened. Costs included estimates for hatchery spat, bar rehabilitation, shell planting, seed production and planting, monitoring and staff time. Production cost estimates for the total expected harvest over time (12,000 bushels) for the three bars ranged from $29 -$58 per bushel depending on values used for spat costs and whether site preparation costs were included. Average dockside value of oysters used in the report was $23 per bushel. No attempt was made to estimate the value of ecosystem services resulting from increased oyster abundance and biomass on the three bars.

Although final production costs for the three reserve bars used in the DNR analysis have not been previously estimated, the minimum cost using DNR estimates would be in the range of $20 - $40 per bushel if all of the reserve harvest to date (17,500 bushels) was taken from the three bars used in the original DNR analysis - Emery Hollow, Blunts and Bolingbroke Sands. Based on reported oysters legally harvested, this estimate indicates that the production cost per bushel of oysters in the reserve program is equivalent to or higher than the ex-vessel price per bushel of oysters harvested in the program. (Note that illegal harvesting, which has been reported to have may have been significant, has also occurred on these bars.) Obviously, increasing the harvest of reserve oysters would reduce costs but may not be compatible with managed reserve ecosystem enhancement objectives.

The 17,500 bushel reserve harvest is about 3% of the harvest of the wild stock in Maryland (477,000 bushels) over a comparable time period (fall 2004 – winter 2009). At an ex-vessel price of $30 per bushel, the total dockside value of the reserve harvest is about $525,000. Averaged over the life of the project to date, this is equal to about $105,000 per year. Even without considering production costs, the economic benefits of harvesting oysters from managed reserves are very limited compared to the value of the wild fishery. When production costs are considered, it does not appear that economic benefits alone can be used to justify the practice of harvesting oysters from reserves. Future changes being considered by ORP may result in an outcome where the reserve harvest program may become economically viable[15]. (Note that the Oyster Advisory Commission in its 2008 report recommended that within the next five years, the areas currently designated within the Managed Reserve Program be integrated into Industry Managed Areas or into Aquaculture Enterprise Zones. The intent of this change is that these areas would eventually be funded solely by private funds.)

[13] https://www.oysterrecovery.org/Content/ContentDisplay.aspx?ContentID=49
[14] Maryland Department of Natural Resources, Fisheries Service. 2005. op cit.
[15] S Abel, ORP, Personal Communication.

V. Factors to consider in Designing a Restoration Program for oysters

This section of the report, the literature associated with some important elements of oyster restoration is summarized.

Establishing criteria for evaluating success of restoration projects – Performance criteria for success of individual restoration projects has not yet been standardized and for some projects has been completely lacking. There are issues associated with oyster reef restoration for conservation and ecosystem services. These include a lack of large-scale restoration projects to test the effectiveness of oyster restoration for the purposes of ecosystem services and lack of long term scientific monitoring to evaluate project success[16]. These shortcomings have contributed to the difficulty of measuring progress of restoration projects and have also led to a general agreement that more uniform performance measures and indicators are needed.

Development of performance-based metrics as well as project-specific success criteria to evaluate individual projects is an objective of the NOAA Chesapeake Bay Office. Metrics being considered include:

1. oyster population status (oyster abundance, biomass, density, distribution, size, survival, recruitment, disease),
2. physical/chemical conditions (substrate characterization, water quality—especially dissolved oxygen, sedimentation rates, hydrodynamics),
3. ecological benefits (fish species diversity, abundance of key taxa, diversity of benthic infaunal and epifaunal communities), and
4. economic benefits (harvested amounts, dockside value, number of watermen benefiting).[17]

Ecosystem benefits - The habitat value of undisturbed oyster reef habitat in the mesohline portion of Chesapeake Bay was recently assessed by Rodney and Paynter[18]. In this study, benthic marcofauna assemblages were sampled at four sanctuaries (one each in the Severn, Patuxent, Chester and Choptank Rivers) and four adjacent unrestored plots located outside the sanctuaries. Restored reefs were closed to harvest, treated with fresh shell and topped with a layer of shell that was seeded with live juvenile oysters. Restored reefs were three to five years old at the time of sampling and had high densities (mean of 173 oysters m^2) of adult oysters. Non-restored reefs were 0.16 - 0.8 km from restored sites and were located on the same historical oyster bars. Non-restored reefs were not treated with shell or seed and typically contained dead oyster shells buried beneath up to several centimeters of silt.

---

[16]Eastern Oyster Biological Review Team. 2007. Status review of the eastern oyster (*Crassostrea virginica*). Report to the National Marine Fisheries Service, Northeast Regional Office. February 16, 2007. 105 pp.

[17] National Oceanic and Atmospheric Administration (NOAA). 2007. NOAA Report to the Chairman, Committee on Appropriations, U.S. Senate. June 2007.

[18] Rodney, W.S. and K. T. Paynter. 2006. Comparisons of marcofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland. Journal of Experimental Marine Biology and Ecology 335 (2006) 39–51

Key findings of the Rodney and Paynter[19] study are as follows: (1) densities of macrofauna, epifauna and sessile macrofauna were significantly higher on restored than unrestored reefs; (2) three out of the five dominant taxonomic groups were much more abundant on restored plots - mean amphipod density was 20 times higher on restored plots and densities of xanthid crabs and demersal fish were both four times greater on restored plots; and (3) two out of four functional feeding groups: suspension feeders and carnivore/ omnivores, were more abundant on restored plots. The authors concluded that since reef macrofauna include many important fish prey species, oyster reef restoration may have the potential to augment fish production by increasing fish prey densities and fish foraging efficiency.

This conclusion is consistent with a study by Peterson et al (2003)[20] in which enhancement of fish production resulting from restored oyster habitat is estimated. Important assumptions in the study were that: (1) any species exhibiting greatly enhanced abundance of recruits on reefs, relative to nearby unstructured sedimentary habitats, is limited in recruitment by oyster reef area; and (2) new reefs may enhance fish production by providing spatial refuges from predation and alleviating food limitation through producing reef-associated prey resources. The results of available empirical, quantitative studies from the southeast USA were synthesized in this study to estimate the magnitude of density enhancement for each species of fish and mobile crustacean on oyster reefs relative to unstructured sedimentary habitat. Species were classified in one of three groups: (1) species showing no numerical association with reefs; (2) species whose recruitment was habitat-limited based on nearly exclusive association of recruits with oyster reefs instead of mud/sand habitat, and on life-history information indicating obligate association with structural features of benthic habitat and (3) species not limited in recruitment by reef habitat but whose growth and survival was limited by reef-associated resources, as judged by significant augmentation of abundance on oyster reefs as opposed to mud/sand habitats.

The authors used information on these species to calculate the average augmentation of abundance per unit reef area by species and by age class. They reported that 10 m^2 of restored oyster reef in the southeast United States is expected to yield an additional 2.6 kg yr^{-1} of production of fish and large mobile crustaceans for the functional lifetime of the reef. A reef lasting 20 to 30 yr would be expected to augment fish and large mobile crustacean production by a cumulative amount of 38 to 50 kg 10 m^{-2}, discounted to present-day value. By 100 yr, an asymptote of ca. 80 kg 10 m^{-2} is approached. The authors reported that the calculations used to compute the estimates assume that oyster reef habitat now limits production of reef-associated fish and crustaceans in the southeast United States and that this assumption seems reasonable based on the tight associations of so many fishes with reef-dependent prey, and the depletion of reef habitat over the past century.

---

[19] Ibid/

[20] Peterson C., J. Grabowski and S. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation. Marine Ecology Progress Series Vol. 264: 249–264

Reef design – One important element in rebuilding reefs is creating textured habitat that provides some protection to spat from predation and serves as refuge for reef associated species. Experiments conducted on shellbased reefs and experimental reefs constructed of other material demonstrate that adequate space within the interstices of a reef is necessary to achieve even modest survival of new oyster recruits. There is clear evidence that interstitial space, to a depth of at least 15 cm, is important in enhancing the survival of new oyster recruits[21].

Another important consideration in reef design is reef height. It has been widely reported that three-dimensional reefs are essential for oyster reproductive success, for protection from predators and to create habitat for other organisms[22]. Oysters set, survive and grow faster on three dimensional reefs and are less susceptible to predation, disease and extended bottom-water hypoxia/anoxia events than oysters on beds near or on the bottom[23,24].

Maryland's reef restoration program involved constructing both high and low relief reefs[25]. High relief reef construction involved creating man-made shell piles and rehabilitating natural underwater hills by planting shell. Shell piles varied from 30 to over 100 feet long and ranged in height from about 4 to over 8 feet. Lower relief reefs were created by spreading shell about 4 inches thick on existing natural reefs. The trade off between high and low relief reefs was that for the cost of about 1 acre of man-made piles, approximately 8 acres of natural oyster bottom can be shelled.

Efforts to restore oysters through creation of three-dimensional reefs in Chesapeake Bay have to date, met with limited success. The Virginia Marine Resources Commission (VMRC) has been involved in construction of more than 70 three-dimensional reefs since 1993. Oysters initially grew rapidly on these reefs, but succumbed to disease within two to four years[26]. The status of 24 three-dimensional reefs constructed in the Virginia portion of Chesapeake Bay through 2007 was recently evaluated. It was reported that none of the reefs showed a long term increase in oyster abundance - recruitment tended to be highest within the first few years after reef construction and adding brood stock to

---

[21] Luckenbach, M. 2000. Oyster reef habitat. Abstract [In] Chesapeake Bay Program. 2000 Oyster restoration workshop proceedings and agreement statements. CBP/TRS 238-00.
[22] Chesapeake Research Consortium. 1999. Chesapeake Bay oyster restoration: consensus of a meeting of scientific experts. Virginia Institute of Marine Science. Wachapreague, VA
[23] Hargis, W. and D. Haven. 1999. Chesapeake Oyster Reefs, Their Importance, Destruction and Guidelines for Restoring Them. [In] Oyster Reef Habitat Restoration: A synopsis and Synthesis of Approaches Edited by M. W. Luckenbach, R. Mann and J. A. Wesson • 1999 • Virginia Institute of Marine Science Press , Gloucester Point, VA.
[24] Lenihan, H. S. and C. H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecol. Appl 8:128–140.
[25] Judy, C. 2000. Oyster restoration in Maryland. Abstract. [In] Chesapeake Bay Program. 2000 Oyster restoration workshop proceedings and agreement statements. CBP/TRS 238-00.
[26] U.S. Army Corps of Engineers. 2008. Draft Programmatic environmental impact statement for oyster restoration in Chesapeake Bay including the use of a native and/or nonnative Oyster. U.S. Army Corps of Engineers, 803 Front Street, Norfolk, VA 23510

reefs did not significantly alter these patterns[27]. The lack of success in creating viable three-dimensional reefs has been attributed to salinity related disease epizootics; a lack of recruitment; competition for substrate by other benthic organisms; loss of substrate through burial and decline in substrate quality through actions of other organisms[28].

The USACE is currently involved in native oyster restoration activities in the Virginia portion of Chesapeake Bay using three dimensional reefs[29]. In 2004, nine reef complexes currently covering approximately 87 acres were established in the Great Wicomico River as permanent sanctuaries. High relief reef (HRR), low relief reef (LRR) and unrestored bottom (UNB) were the main elements of each of the nine complexes. Height above the river bottom was 10– 18 inches for HRR and 3–5 inches for LRR, prior to reef settlement of 1-2 inches. In 2007, 85 one-square-meter plots, allocated randomly across the three treatments in the nine reef complexes were sampled with patent tong and video surveys. Findings of the study three years after reef construction are presented as follows:

1. HRR reefs (30 acres or 34% of the restored area) supported 67 % of the oysters (adults juveniles and spat) and LRR (57.3 acres) supported 32 %. UNB (107.4 acres) supported only 1%.
2. Mean number of oysters per m^2 was four times higher on HRR (1026.7 ± 51.5 SE) than on LRR (250.4 ± 32.3 SE) and 171 times higher than UNB (6.0 ± 1.5 SE);
3. Mean size (shell length) of oysters in HRR (47.3 mm ± 1.2 SE) was 15 % larger than LRR (41.0 mm ± 1.1 SE). This difference was primarily due to the larger adults on HRR than on LRR;
4. The key mechanism mediating abundance was height above the river bottom. Oyster density rose linearly from just over 200 oysters per m^2 when a reef was 10 % high relief to over 1000 oysters per m^2 when a reef was 90 % high relief;
5. Spat density was a positive parabolic function of adult density, with a peak at an adult density of 850 oysters per m^2. In addition, variance in juvenile recruitment was lower on HRR (CV = 43 %) than on LRR (CV = 129 %);
6. HRR always had sufficient shell accretion for reef persistence (6-16 l per m^2); accretion on LRR was usually less than 4 l per m^2. Historically, accretion rates exceeding 5 l per m^2 characterized successful native oyster reefs.
7. The native oyster metapopulation on the restored reef system meets established criteria for sustainability presented in Powers et al.(in press): (1) it is comprised of multiple year classes at high abundance; (2) it is composed of young and old adults that have survived disease challenge; (3) the reefs are accreting at a rate that will provide settlement habitat for future generations; and (4) it receives sufficient wild spat settlement and recruitment to sustain the populations over the long term.

[27] Southworth, M., R. Mann, J. M. Harding & J. A. Wesson.. 2008. Multiyear recruitment patterns of oysters (*Crassostrea virginica*) on constructed reefs in the Chesapeake Bay. J. Shellfish Res.
[28] Mann, R. and E. Powell. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. Journal of Shellfish Research, Vol. 26, No. 4, 905–917.
[29] Schulte, D., R. Burke and R. Lipcius, 2009. Unprecedented Restoration of a Native Oyster Metapopulation in the Great Wicomico River, Chesapeake Bay, VIMS Special Report in Applied Marine Science and Ocean Engineering, No. 409

The authors reported that the Great Wicomico River restoration project differed from prior restoration efforts in Chesapeake Bay by building oyster reefs of high vertical relief at a broad spatial scale in large sanctuaries protected from fishery exploitation, and in locations characterized by high recruitment. Typical restored sanctuaries prior to the GWR project amounted to 1% or less of an estuary's original oyster reef extent. The GWR reef network encompasses approximately 40 % of the original oyster reef extent within a hydrodynamically restricted system. Significant vertical relief and reef persistence were accomplished by building a substantial portion of the reef system as high as 18 inches (HRR) in contrast to the traditional 3-5 inch (LRR), which typically does not promote reef persistence more than ca. five years. The authors concluded that the ephemeral nature of LRR has proven to be one of the main contributors to the decline in native oyster habitat wherever they are used. They also concluded that although disease-related mortality will impact the oysters on these reefs, the recent development of disease tolerance in oysters on sanctuary reefs of lower Chesapeake Bay bodes well for the long-term persistence of the GWR native metapopulation. (Note that the USACE also constructed approximately 60 acres of subtidal "high-relief" oyster shell reefs in 2007 and 2008 throughout the Lynnhaven River in 2007 and 2008. Monitoring of these reefs is to start in spring 2009.)[30]

In North Carolina, a three-dimensional reef study was conducted to evaluate whether mortality of oysters on natural oyster reefs varies with water depth (3 m vs. 6 m) and whether bottom-water hypoxia/anoxia and reduction in reef height through fishery disturbance interact to enhance mortality of oysters[31]. The authors reported that during stratification of the water column in summer, oxygen depletion near the bottom at 6 m caused mass mortality of oysters and other species associated with the reef, while oysters elevated into the surface layer by sufficient reef height or by location in shallow water survived. Authors concluded that the interaction of reef habitat degradation through fishery disturbance and extended bottom-water hypoxia/anoxia caused the pattern of oyster mortality observed on natural reefs and influenced the abundance and distribution of fish and invertebrate species that utilized the habitat.

In Alabama, eight oyster reefs (625 m^2 each) were constructed in each of three different areas of Mobile Bay[32]. Four reefs in each area were high relief (≥1.0 m vertical relief) and four were low relief (0.1–0.2 m). Sampling occurred over approximately two years. The authors concluded that:

1. Oyster recruitment and abundance varied by location and was higher on high relief than low relief reefs.
2. The pattern of higher recruitment of oysters at high relief reefs suggests that in locations where oyster mortality is high or larval supply is low, high relief reefs are an important design element in successful reef restoration.

---

30 Burke R., and R. Lipcius. 2009 Alternative Ecosystem-Based Restoration Approaches with Native Oyster Metapopulations in Chesapeake Bay: Lynnhaven River System Alternative Substrate Experiment. Final Report. Virginia Institute of Marine Science, The College of William and Mary.

31 Lenihan, H. S. and C. H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecol. Appl 8:128–140.

32 Gregalis K., S. Powers and K. Heck. 2008. Restoration of Oyster Reefs along a Bio-physical Gradient in Mobile Bay, Alabama. Journal of Shellfish Research 27(5):1163-1169. 2008.

3. It is unlikely that the high relief reefs would produce a 10-fold difference (the difference in costs between high and low relief reefs) in oyster abundance as compared with low relief reefs.
4. In terms of oyster survival, abundance, and reef longevity, high relief reefs are more likely to show benefits with future sampling.
5. It is plausible that longer term monitoring of the reefs may find a more substantial benefit of vertical reef elevation as a result of greater resiliency to fishing disturbance or decreased frequency of anoxic and hypoxic events.

Costs of reef construction - In the Mobile Bay study described above, all reefs were 625 m^2. The low relief reefs (0.1–0.2 m) were composed of a limestone marl base covered by oyster shell (48 m3) and cost $2,068 per reef to construct ($13,400 per acre). The high relief reefs (≥1.0 m) were composed of a concrete rubble or limestone marl base (434 m^3) and a top layer of oyster shell (140 m^3) and cost $18,600 - 20,292 each to construct ($120,000 - $131,000 per acre).

As reported in the EIS, estimated costs for standard habitat rehabilitation (which is not defined in the EIS) range from about $6,436 per acre in Maryland to about $2,249 per acre in Virginia and the Potomac River. Cost per acre for three-dimensional reefs constructed in Virginia ranged from about $100,000 to $150,000 per acre. The USACE reefs - which have more height off the bottom than in standard replenishment programs but less height than three dimensional reefs - cost about $59,000 per acre including construction, seeding, and monitoring.

Availability of materials for reef construction - Fossil oyster shell has been the primary reef material used in oyster restoration and repletion in Chesapeake Bay. Maryland has planted approximately 180 million bushels of fossil shells since the repletion program began in 1960[33]. For several reasons, obtaining permits to continue the fossil shell program became increasingly difficult over time and in 2006 Maryland DNR made the decision not to apply for a renewal of the required permits. To date, an acceptable substitute for large scale restoration activities has not been found. New approaches which have potential for restoration include cleaning exposed shell on natural bars and extracting previously planted and shallow buried shells.

Disease resistance in wild Chesapeake Bay oysters – Disease experts at a 2007 Oyster Management Plan (OMP) meeting[34] made the following points relative to natural disease resistance in Chesapeake Bay oysters:

1. Natural Virginia oysters clearly appear to harbor some MSX resistance. No equivalent data are available for Maryland.
2. Data from Virginia suggest that populations from dermo-enzootic waters are relatively resistant, characterized by prevalences and intensities of Perkinsus marinus

---

[33] Judy, C. 2000. Status of shell supply for reef restoration and environmental impacts of dredging. Abstract. [In] Chesapeake Bay Program. 2000 Oyster restoration workshop proceedings and agreement statements. CBP/TRS 238-00.
[34] Chesapeake Bay Program. 2007.Oyster Management Plan Meeting Relating to Oyster Disease Issues Potomac River Fisheries Commission, Colonial Beach, VA.

(and H. nelsoni) infection, and overall mortality, more similar to domesticated disease-resistant lines than to naïve controls. (Although not referenced on the workshop report, the data are from a study by Encomico et al. 2005[35]).

3. Large oysters exist in Virginia and Delaware Bay populations that remain healthy despite intense disease pressure. A disproportionate reproductive contribution from such "resistant" oysters—assuming such is heritable— may underlie development of P. marinus resistance in wild populations. These findings may not apply to Maryland waters, where dermo disease is normally less prevalent, and thus where selective pressure is lighter.

Three studies to assess Dermo resistance in wild Chesapeake Bay oysters have been published in recent years. In one of these studies, disease resistance in seven oyster "populations" - three from Chesapeake Bay (Tangier Sound, lower Rappahannock River and Choptank River), three from the Gulf of Mexico (Grande Terre, Oyster Bayou and Hackberry Bay) and CROSBreed oysters was evaluated[36]. Spat from each of the seven groups were held at field sites in the Rappahannock and Yeocomico Rivers. Based on variation in survival and Dermo infection after one year of growth, further studies were carried out on Rappahannock, Tangier Sound, Oyster Bayou and CROSBRED samples. At the end of the study of these four groups, mortality at the Rappahannock site was 100% for the Oyster Bayou and Rappahannock oyster samples and roughly 60% for Tangier Sound and CROSBreed samples. At the Yeocomico site, mortality was about 80% for the Rappahannock sample, 40% for Oyster Bayou and 10-20% for Tangier Sound and CROSBreeds. Based on these results, the authors concluded that Tangier oysters are resistant to dermo and that the resistance is comparable to CROSBreed oysters.

A comparative study of growth, Dermo disease resistance, and survival of nine groups of oysters cultivated in floating trays in Piankatank River (low salinity), Mobjack Bay (moderate salinity) and Lynnhaven Bay (high salinity) Virginia was recently reported in the literature[37]. In this study, five regional strains (upper Chesapeake Bay, North Carolina, South Carolina, Louisiana and Louisiana triploids and four hybrid strains (Chesapeake Bay oysters mated with NC, SC, LA and Texas (TX) oysters) were held in floating rafts at each of the three study sites. At each site, patterns of growth and incidence of Dermo infection were similar. However, mortality trends for the Chesapeake Bay strain and the four hybrid strains were accelerated compared to the other groups. North Carolina, South Carolina and with a lesser degree of certainty the Louisiana diploid strains demonstrated reduced levels of mortality when challenged by Dermo than the Chesapeake strain and Chesapeake hybrid strains. The authors concluded that the results show promise for cultivating North Carolina, South Carolina and possibly Louisiana stains in higher salinity regions of Chesapeake Bay.

---

[35] Encomico et al. 2005. Performance of "natural dermo-resistant" oyster stocks – survival, disease, growth, condition and energy reserves. Journal of Shellfisheries Research. Jan. 2005.
[36] Encomico et al. 2005. Op cit.
[37] Brown, B.L., A. Butt, D. Meritt and K. T. Paynter. 2005. Evaluation of resistance to Dermo in eastern oyster strains tested in Chesapeake Bay. Aquaculture Research 36, 1544 – 1554.

In a related study, growth, Dermo infection intensity and survival of North Carolina (collected at Cape Lookout) and Chesapeake Bay oysters (collected near Annapolis) were evaluated under standard tray culture conditions at Wye River, Maryland; Mobjack Bay, Virginia; Pamlico River, NC and Bogue Banks, NC[38]. Dermo infection prevalence reached 100% in all groups of oysters held at all high- and moderate-salinity sites and under these conditions, the CB strains ceased to grow and mortality reached 100%. Growth continued in the NC strain and mortality was 37-40%. At the low-salinity site in North Carolina, Dermo infection persisted at low weighted prevalence throughout the latter portion of the culture period but was not associated with mortality of either strain.

The Role of Domesticated Disease Resistant Oysters in Restoration – A study to determine the contribution to recruitment of 18.5 million cultchless DEBY oysters seeded from 2002 to 2006 in the Great Wicomico, Lynnhaven, York, and Elizabeth Rivers was recently published[39]. Locally recruited spat were collected from 2002-2006 to determine if reproduction by the transplanted DEBY oysters produced detectable contributions to subsequent recruitment. This determination was made by examining the frequency of a mitochondrial haplotype that occurs at high frequencies in DEBY oysters but is rare in wild Chesapeake Bay oysters. The estimated frequency of this haplotype in locally recruited oysters averaged 1.4% compared with the average frequencies found in the hatchery produced DEBY oysters of 35.9% and wild oysters of 1.2% oysters. The authors reported that they were unable to detect a significant DEBY contribution to wild-produced spat. They hypothesized that contributions to recruitment by DEBY oysters was low for three primary reasons:

1. Predation could have decimated the deployed oysters before they could reproduce.
2. Initial census numbers of wild oysters may have been underestimated and too few DEBYs were deployed to expect an observable contribution.
3. DEBYs have low fitness under natural conditions caused by aquaculture selection.

Two workshops held in 2007 provide guidance on the role of domesticated disease resistant oysters in oyster restoration and management. Participants at a 2007 workshop entitled *Revisiting Genetic Considerations for Hatchery-Based Restoration of Oyster Reefs* reported that the absence of documented evidence that planting domesticated oysters has yielded improved survival or higher subsequent recruitment is a compelling argument against the use of domesticated oysters in future restoration activities. Participants at this meeting also concluded that the development of alternative strains of the Eastern oyster for use in restoration should not be pursued and that preserving and enhancing local wild stocks that exhibit some level of natural disease resistance would be a preferred means of encouraging the development of disease resistance.

---

[38] Brown, B. A. Butt, S. Shelton, D. Meritt and K. Paynter. 2005. Resistance of Dermo in eastern oysters, Crassostrea virginica(Gmelin), of North Carolina but not Chesapeake Bay Heritage. Aquaculture Research, 36 1391-1399

[39] Carlsson, J, R. Carnegie, J. Cordes, M. Hare, A. Leggett, and K. Reece. 2008. Evaluating Recruitment Contribution of a Selectively Bred Aquaculture Line of the Oyster, Crassostrea virginica used in Restoration Efforts. Journal of Shellfish Research 27(5):1117-1124.

Disease experts at a 2007 Oyster Management Plan (OMP) meeting[40] also agreed that there is no compelling argument for use of domesticated oysters in ecological oyster restoration (genetic issues aside). There was also a consensus at the OMP meeting that domesticated disease-resistant lines are acceptable for use in purely commercial restoration (i.e., repletion, harvest reserves) and recommended for use in aquaculture.

<u>*Disease management recommendations*</u> - *OMP Disease Management Workshop*[41] - In addition to recommendations presented in the *Disease resistance in wild Chesapeake Bay oysters section* of this document, oyster disease experts at the 2007 Oyster Management Plan Workshop put forward several recommendations for managing oyster disease in Chesapeake Bay. These are presented as follows:

1. Transplanting infected natural seed is not advisable in general, however parasite dispersal associated with the movement of lightly infected oysters may be relatively insignificant against a larger backdrop of natural parasite dispersal and transmission.
2. If infected oysters must be transplanted for repletion purposes, they should be transplanted at small size to areas characterized by similar or higher disease levels.
3. The efficacy of bar cleaning is questionable because of the 20% of oysters that are typically left behind by cleaning efforts. An indirect negative impact of bar cleaning is the indiscriminate removal of healthy, potentially resistant animals that are ideal broodstocks for restoration. (Since 2008, the practice of bar cleaning is no longer being conducted by ORP.)
4. The role of hatchery production with respect to oyster conservation and ecological restoration should be limited to amplification of natural stocks (i.e., supportive breeding). Production of domesticated oyster lines for repletion or commercial restoration is appropriate.
5. Restoration should begin with leaving natural oyster populations alone, creating sanctuaries and enforcing harvest moratoria to allow populations a chance to naturally expand, and disease resistance to evolve.
6. Selection of sanctuaries should include consideration of oyster dispersal patterns, and metapopulation structure; setting aside existing productive reefs; and protection from poaching is a major problem.
7. Benefits of natural oyster sanctuaries include: (a) presumptively disease-resistant broodstock will be given more opportunity to spawn; (b) they are important repositories for natural genetic diversity; (c) sites in 5-12 ppt can be expected to generate ecological benefits, with intermittent oyster spawning however offspring are likely to be susceptible to both MSX and dermo diseases and (d) sites in >14ppt will promote the development of natural disease resistance

[40]Chesapeake Bay Program. 2007. Op cit.
[41] Chesapeake Bay Program. 2007. Op cit.

Reef Restoration - specific recommendations from Hargis and Haven (1999)[42]

1. The most rapid and least costly recovery of reefs can be obtained by using reefs that retain significant (some) vertical relief and shell volume, have living young and adult oysters upon them and are known to "catch" spat. Fishery closure, adequately enforced, is all that is required.
2. Recovery of such active reefs could be hastened by judicial addition of oyster shell to the core, *i.e*. by "lifting" some of the living veneer off and replacing it after core enhancement, or replacing the displaced veneer by addition of living oysters from elsewhere.
3. A light "dusting" of clean oyster shells (*i.e.* 2,000 bushels per acre) over the living veneer of Hard Oyster Reefs each year will enhance set and survival in succeeding years. Of the various restorative techniques offered here and below, this is the best since it causes the least destruction to the oysters already living in the veneer.
4. Recovery to former (or new) conditions and dimensions can be enhanced by adding new core materials, preferably clean oyster shells, to immediately adjacent hard bottoms, thus extending the basal extent of these reefs. Some of the living oysters in the veneer could be gently transferred to these areas.
5. On sites with significant quantities of living oysters (*i.e*. 500 to 1,000 bushels per acre) in the "veneer" some of the living oysters could be tonged or gently dredged and moved to other areas or stockpiled overboard nearby for replacement in the veneer of the reef being restored. Moving living oysters, which might have to be done twice should this course be decided upon, is usually destructive of the oysters being moved as well as those left behind. Perhaps the best strategy in such a situation is to add only small quantities of shells and/or seed, but to do so each year for a number of years.
6. Where appreciable quantities of living oysters are lacking on existing reefs, reef rebuilding should take place on the "footprints" of Hard Oyster Rock.
7. Some "experimental" reefs should be rebuilt or established in waters with depths of 1.8-2.4 m (5.9-7.9 ft) at M.L.W. (or greater if funds permit) and should extend upward into the intertidal. This will permit determination of the differences between setting and survival (and of levels of disease and predation) at one vertical level versus another.
8. Rebuild some depleted reefs in strategic locations by reshelling to a depth of about 1 foot (30 cm). This will raise the bed slightly above the surrounding bottom and enhance setting and allow comparing results between activities numbers 5 & 6. This technique should be effective in areas of low sedimentation rates and on reefs with low disease and predator levels.
9. Where oyster shells are limited in availability, reefs with greater vertical height and volume might be built with "cores" of alternative materials and topped with a veneer of clean oyster shell at least 15 cm (6.0 in.) thick. (Setting occurs on shell

[42] Hargis, W. and D. Haven. 1999. Chesapeake Oyster Reefs, Their Importance, Destruction and Guidelines for Restoring Them. [In] Oyster Reef Habitat Restoration: A synopsis and Synthesis of Approaches Edited by M. W. Luckenbach, R. Mann and J. A. Wesson • 1999 • Virginia Institute of Marine Science Press , Gloucester Point, VA.

surfaces several inches or more beneath the outer layer of shells.) The veneer also can be "seeded" with living oysters taken from similar sites to speed rebuilding.

VI. Next Steps

The following are activities which should be undertaken prior to finalizing an expanded oyster restoration program:

- Establish program goals;
- Develop short list of candidate sites (includes describing restoration activities to date);
- Determine physical and biological characteristics of candidate bars;
- Determine bar or area specific restoration objectives and restoration plan including costs and manpower requirements;
- Design monitoring program to measure progress towards achieving objectives; and
- Scale activities to available funding and manpower.

Implementation of expanded oyster restoration program activities should include studies that will allow improvements in our understanding of the relationship of factors such as reef location and configuration and oyster production. In addition to measurements of the physical and biological characteristics of reefs, important elements of monitoring in these studies should be collection of data which allow estimation of recruitment, age specific estimates of abundance, growth, natural mortality and disease mortality.

Table 1. Summary information for existing Maryland Oyster Sanctuary Program sites. (From Tarnowski, M. 2005. An evaluation of the Maryland oyster sanctuaries monitored by the MDNR shellfish program's fall oyster survey. MDNR, Fisheries Service, Tawes State Office Building, 580 Taylor Avenue, Annapolis, MD 21401)

Location	Sanctuary Name	Total Acres	Effective Date
Upper Western Shore	Fort Carroll	20	10/1/1995
	Severn River	6,719	10/30/1998
	South River	1,909	9/4/2000
	Herring Bay	5	7/9/2004
	Gales Lump	50	8/30/2002
Calvert Shore	Plum Point	5,870	11/1/1999
Patuxent River	Pt. Patience		N/A
	Neal Addition	7	9/14/2001
	Elbow/Teague (NOB 13-2)	57	9/14/2001
	Kitts Marsh	28	6/30/2003
	Paul J. Bailey (Trent Hall)	10	8/20/2003
Chester River	Strong Bay	207	6/12/2003
	Ringgold	116	9/14/2001
	ORA Zone A	4,586	5/20/1996
Eastern Bay Area	Mill Hill	296	9/30/2000
	Miles River	84	10/22/1979
Choptank River	Cook Point	17	9/14/2001
	Howell Point	6	9/14/2001
	Ora Zone A	4,567	5/20/1996
	Horn Point Lab	10	7/1/1986
	Cambridge	1,755	11/26/1937
	Oxford Lab	38	6/1/1961
	La Trappe Creek		10/11/2002
Nanticoke River	Roaring Point	10	7/9/2004
Lower Bay	Dorchester PD	100	11/1/1999
	Somerset PD	100	11/1/1999
	St. Mary's PD	100	11/1/1999
	SW Middleground	17	9/14/2001
	Kitts Creek	1,056	9/14/2001
	Poplar Island	7	6/27/2003
	Piney Point AC	10	
	TOTAL ACRES	**27,757**	

Table 2. Sanctuaries and reserves monitored in the Maryland DNR fall survey.

Location	Sanctuary Name	Plantings[1]		
		seed	dredged shell	fresh shell
Upper Western Shore	Chinks Pt	99,07	98	
	Alms House			97
Chester River	Strong Bay	03,05	02,05	
	Ringgold	07	87	97
Eastern Bay	Mill Hill		88	
Mid-Bay East	Poplar Island		03	
Choptank River	Cook Point		90,97.06	
	Green Marsh	03	02	
	Shoal Creek	99,01	98	
Patuxent River	Neal Addition	99	99	
	Paul J. Bailey (Trent Hall)	02		
Tangier Sound	Piney Island East Add. 1		00,02	
Lower Bay East	Northwest Middle Ground		00,02,06	
Lower Bay West	Point Lookout		01,05	
Pocomoke Sound	Kitt's Creek East	98,99,00		
Potomac River	Heron Island			96
	Bluff Point Lumps			

[1]Information on site specific planting activities for MDNR fall survey sites sampled in the Severn and South Rivers are available at: ftp://dnrftp.dnr.state.md.us/Public/Outgoing/Fish/Oysters/Other/MDNR Annual Fall Survey

Table 3. Maryland oyster bars with market oyster counts at a given site in the top 10% (counts of 70 or more) of all bars surveyed in **four or more years** over the period 1996 - 2007. With the exceptions of the historic area of each bar, legal fishing gears and salinity codes, data in this Table were taken from: Rothschild, B., 2009. Indicative Analysis of the Fall Oyster Survey in Maryland waters of Chesapeake Bay. Draft report to the Maryland Department of Natural Resources.

	River/area	Bar name	Yates survey acres[1]	Years sampled	Plantings			Years in top 10%	Legal fishing gears[4]	Salinity code[5]
					Seed	Dredged shell	Fresh shell			
Chester R.	Upper Chester	Old Field	652	96-02	93,97,98,00	97		97,99,00,01	HT	1
	Lower Chester	Blunts[2]	378	02-05	01,04	01		02,03,04,05	HT, Di	1
Severn R.	Severn	Chinks Pt[3]	251	99-07	99,07	98		00,01,03-06	closed	1
South R.	South	Thunder & L	48	96-07	96,00,07			00-02,04,05	HT	1
Mid-Bay	Kent Shore	Kent Point	445	96-07		95		98,99,05,06	Di, PT, SD	2
Eastern Bay	Eastern Bay	Cedar Island	428	96-07		90		99,00,01,04	HT	2
	Eastern Bay	Ringold M.	241	96-07		87		99,00,05,06	HT	2
Miles R.	Miles	Coffee	583	96-07	98	90,96,98		99,00,04,06	HT, Di	1
Wye R.	Wye	Bruffs Island	112	96-07	-	-	-	99,00,05,06	HT	1
Choptank R.	Broad Creek	Deep Neck	513	96-07	-	-	-	96-98,00,06	HT	1
		Royston	1313	96-03		88		96-98,00	HT,PD	1
		Willeys Is. Flats	295	96-07		89		97,98,06,07	HT	1
	Harris Creek	Tilghman wharf	760	96-07		84		96-00,01	HT, PD	1
L. Choptank	L. Choptank	Cason	205	96-07	-	-	-	96-98,00	HT	1
		Susquehanna	191	96-07		87		96,98,99,07	HT	1
		Town Point	87	97-01		89		97,98,99,00	HT	1
		Town Point		96-07		89,02		96,98,00,07	HT	1
Lower Bay	St. Mary's Shore	Point Lookout [3]	1323	01-07		01		03-07	closed	2

[1]Smith, G. 1997. Maryland's Historic Oyster Bottom. A Geographical Representation of the Traditional Named Oyster Bars. Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory, Oxford, MD.
[2] Reserve
[3]Sanctuary
[4]HT = hand tongs, Di = diving, PT = patent tongs, SD = sail dredge, PD = Power dredge
[5]code 1=5-11 ppt; 2=12-14 ppt; 3 = 15-18ppt (Bars are assigned a salinity code based on average summer salinity over the period 1990 -1999 as presented in Figure 2 in Tarnowski, M. 2005. An evaluation of the Maryland oyster sanctuaries monitored by the MDNR shellfish program's fall oyster survey. MDNR, Fisheries Service, Tawes State Office Building, 580 Taylor Avenue, Annapolis, MD 21401

Table 4. Maryland oyster bars with market oyster counts at a given site in the top 10% (counts of 70 or more) of all bars surveyed in **three years** over the period 1996 - 2007. With the exceptions of the historic area of each bar, planting data and salinity codes, data in this Table were taken from: Rothschild, B., 2009. Indicative Analysis of the Fall Oyster Survey in Maryland waters of Chesapeake Bay. Draft report to the Maryland Department of Natural Resources.

Region	River/area	Bar name	Yates survey acres[1]	Years sampled	Plantings			Years in top 10%	Legal fishing gears[2]	Salinity code[5]
					Seed	Dredged shell	Fresh shell			
Chester R.	Upper Chester	Durdin	305	96-07	96,98			96,97,00	HT, Di	1
Chester R.	Lower Chester	Love Point	2160	96-07	98	94		99,00,05	SD, Di	1
South R.	South River	Purdy Flats	36	96-07	03			05,06,07	HT	1
Miles R.	Miles River	Ash Craft	55	96-07	-	-	-	99,00,06	HT	1
		Herring Island	214	96-07		89,98		00,05,06	HT, Di[3]	1
		West End	345	96-07		00		04,05,06	HT	1
		Wild Ground	223	96-07		99		99,05,06	HT	1
Wye R.	Wye River	Mills	93	96-07	-	-	-	99,00,05	HT, Di	1
Choptank R.	Broad Creek	Brown Bar	216	96-07		89		98,00,07	HT	1
		Mulberry Pt	130	97-07		00		98,05,06	HT	1
		Great Bar	496	96-07		90		97,98,06	HT,PD	1
	Harris Creek	Eagle Point	154	96-99		87		96,97,98	HT, PD[4]	1
		Little Neck	41	96-07	-	-	-	96,97,99	HT	1
		Mill Point	214	96-07		99		96,97,98	HT	1
	Lower Choptank	Irish Creek	735	96-07		89		98,99,00	HT,PD	1
L. Choptank	L Choptank	Butterpot	81	96-07	-	-	-	96,98,00	HT	1
		Grapevine	38	96-07	01 or 02			96,98,00	HT	1
Wicomico R. E.	Wicomico East	Mt. Vernon W.	14	96-07	-	-	-	96,97,98	MDE restricted	1
Potomac	St. Mary's	Chicken Cock	140	96-07	-	-	-	96,97,98	HT,PD, Di	2

[1]Smith, G. 1997. Maryland's Historic Oyster Bottom. A Geographical Representation of the Traditional Named Oyster Bars. Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory, Oxford, MD.
[2] HT = hand tongs, Di = diving, PT = patent tongs, SD = sail dredge, PD = Power dredge.
[3]HT/Di line crosses bar, almost all of the bar is HTonly .
[4]HT/PD line crosses bar, mainly HT
[5]code 1=5-11 ppt; 2=12-14 ppt; 3 = 15-18ppt (Bars are assigned a salinity code based on average summer salinity over the period 1990 -1999 as presented inTarnowski, M. 2005. An evaluation of the Maryland oyster sanctuaries monitored by the MDNR shellfish program's fall oyster survey. MDNR, Fisheries Service, Tawes State Office Building, 580 Taylor Avenue, Annapolis, MD 21401)

Table 5. Maryland oyster bars with market oyster counts at a given site in the top 10% (counts of 70 or more) of all bars surveyed in **two years** over the period 1996 - 2007. With the exceptions of the historic area of each bar, planting data and salinity codes, data in this Table were taken from: Rothschild, B., 2009. Indicative Analysis of the Fall Oyster Survey in Maryland waters of Chesapeake Bay. Draft report to the Maryland Department of Natural Resources.

Region	**River/area**	**Bar name**	**Yates survey acres**[1]	**Years sampled**	**Plantings**			**Years top 10%**	**Bar code**	**Bar Id**
					Seed	**Dredged shell**	**Fresh shell**			
Upper Bay	Upper Bay	Hodges	295	96-07				00,05	UBEHO0	790
				96-07				99,00		791
				96-07				97,98		792
		Swan Point	3268	96-07	03,04			06,07	UBESP0	776.5
	Upper Anne A	9 Foot Knoll (ORP)[2]	242	04-07	02			05,06	UAANF0	804.7
		Mountain Point	1627	00-07	04			99,00	UAAMP0	799
Chester	Lower Chester	Buoy Rock[2]	323	96-07	97,98,00			99,00	LCHBR0	43
				96-07				03,05		46
		Flood Point	20	96-03	?			99,00	LCHFP0	39
		Strong Bay[2]	274	02-07	03	02		06,07	LCHSB0	51
		Wickes Beach	473	96-07	06			99,00	LCHWB0	60
		Bluff Point	443	96-07	99-02			99,00	UCHBL0	80
	Upper Chester	Boathouse	79	96-07	00-05	05		98,99	UCHBH0	111
		Cliff	115	96-07	?			99,00	UCHCBL0	102
		Drum Point	45	96-07	98-99			99,00	UCHDR0	113
		Ebb Point	118	96-07	00,01,03			96,97	UCHEB0	90
		Middleground	239	96-00				99,00	UCHCM0	77
		Piney Point	497	96-07	?			96,99	UCHPI0	66
South River	South River	Rock Point	12	96-07	02,07			02,05	SORRK0	671
		Swan Reef	249	96-07	?			05,06	SORSR0	669
Mid-Bay	Kent Shore	Brickhouse	37	96-07		89		05,06	KESBH0	408
	Lower Anne A.	Sandy Point	88	96-07	02,04,07			99,00	LAASN0	438
		Three Sisters	2606	96-07	01,04,07			04,06	LAATH0	419
				96-07				06,07		419.5
				96-07				03,05		424
Eastern Bay	Eastern Bay	Bald Eagle	278	96-07	98,00			99,00	EBNBE3	227
		Bodkin Shoals	1633	96-07	?			05,06	EBNBS0	194
		Bugby	1114	96-07	99,01			99,00	EBNBG0	195
		Hollicuts Noose	863	96-07	?			04,05	EBNNN0	185
		Mill Hill	356	96-07		88		00,01	EBNMH0	221
		Parsons Island	339	96-07		88		99,00	EBNPI0	216
				96-07				00,05		217
		Walter White	265	96-07				99,00	EBNWW0	239
				96-07				99,00		240
		Well Cove	149	96-07	98			99,00	EBNWC0	242
Miles River	Miles River	Persimmon tree	405	96-07		89,98		99,00	MIRPT0	483
		Turtleback	46	96-07		84		99,00	MIRTB0	482

[1]Smith, G. 1997. Maryland's Historic Oyster Bottom. A Geographical Representation of the Traditional Named Oyster Bars. Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory, Oxford, MD.

[2] Reserve

[3]Sanctuary

Table 5 (continued). Maryland oyster bars with market oyster counts at a given site in the top 10% (counts of 70 or more) of all bars surveyed in **two years** over the period 1996 - 2007. With the exceptions of the historic area of each bar, planting data and salinity codes, data in this Table were taken from: Rothschild, B., 2009. Indicative Analysis of the Fall Oyster Survey in Maryland waters of Chesapeake Bay. Draft report to the Maryland Department of Natural Resources.

Region	**River/area**	**Bar name**	**Yates survey acres**[1]	**Years sampled**	**Plantings**			**Years top 10%**	**Bar code**	**Bar Id**
					Seed	**Dredged shell**	**Fresh shell**			
Wye River	Wye River	Wye River Middle.	53	98-07			01	99,00	WYRWM0	888
Choptank	Harris Creek	Great Marsh	339	96-07		98,00		06,07	HACGM0	256
		Wild Cherry Tree	518	96-07		99,00,01		98,99	HACWC0	254
	Tred Avon	Louis Cove	208	97-07		97		99,00	TARLC0	763
	Lower Choptank	Lighthouse	719	96-07	99	97		99,00	LCRLI0	174
				96-07				99,00		177
	Middle Choptank	Sandy Hill	493	96-07	99			99,00	MCRSL0	134
	Upper Choptank	Mill Dam[2]	159	96-07	98,05			00,07	UCRMD0	137
		Shoal Creek	134	96-07	?	?		00,04	UCRSC0	124
Little Choptank	Little Choptank	Ragged Point	652	96-07		?		97,98	LTCRP0	317
		Tobacco Stick	209	97-00				99,00	LTCTS0	312
Lower Bay	Calvert Shore	Hog Island	493	96-07		87		04,05	LCSHI0	383
	Honga River	Lakes Cove	385	96-07		87		96,97	HORLC0	288
Patuxent R.	Upper Patuxent	Broad Neck	119	96-07	06			04,05	UPXBN0	556.3
Wicomico W.	Wicomico West	Bramleigh Cr.	320	96-07	99,00,03,0 4			06,07	WWRBC0	864
		Manahowic Cr.	186	96-07	99,00,04			96,97	WWRMC0	873
		Mills East	128	03-07	03			05,06	WWRME0	877
		Mills West	132	96-07				96,97	WWRMW0	874
		Mouth of River	108	96-07	04			04,05	WWRMR0	846
Potomac	Lower Potomac	St George Is.	221	96-07		?		06,07	LPRSG0	606
	St. Marys River	Cherryfield	266	96-07				96,97	LSMCH0	681
	St. Clements Is.	Heron Island	253	96-07				96,97	LPRSG0	627.5
	Upper Potomac	Gum	530	96-07	97,01 or 00, 03			06,07	UPRGU0	632
				96-07				99,02		635
		Pascahanna	98	96-07				98,00	UPRPA0	651
		Swan Point	755	96-07	03			99,00	UPRSP0	644
				96-07				05,07		645

[1]Smith, G. 1997. Maryland's Historic Oyster Bottom. A Geographical Representation of the Traditional Named Oyster Bars. Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory, Oxford, MD.

[2] Reserve

[3]Sanctuary

Table 6. Spatfall rankings in the Maryland portion of Chesapeake Bay by river/region. Rankings in the column labeled key spat bars are based on 53 "key" spat monitoring bars sampled over the period 1985 – 2007 and aggregated by regions reported in the 2007 DNR fall survey report. Rankings in the column labeled 1996-2007 are based on data collected at all sites sampled in the DNR fall survey and grouped into regions presented in the 2007 fall survey report. Regions in bold support "best bars" three or more years over the period 1996-2007 as determined in Rothschild 2009.

River/region	Rank (spat per bushel) where #1 is highest and #23 is lowest)	
	key spat bars 1985 – 2007[1]	all fall survey sites 1996 – 2007[2,3]
Miles	1	3
St. Mary's River	2	2
Broad Creek	3	6
Little Choptank	4	9
Eastern Bay	5	1
Honga River	6	12
Tangier Sound	7	4
Harris Creek	8	5
Potomac River	9	16
Manokin	10	7
Wye River	11	10
Pocomoke Sound	12	11
Lower Bay	13	8
Choptank	14	15
Fishing Bay	15	13
Tred Avon	16	14
Middle Bay[4]	17	20
Nanticoke	18	19
Patuxent River	19	18
St. Clements/Brenton Bay	20	22
Wicomico (eastern shore)	21	17
Chester	22	21
Upper Bay	23	23

[1]Rankings were determined from 53 "key" spat monitoring bars over the period 1985 – 2007. Data for specific bars were taken from: Tarnowski, M. 2005. An evaluation of the Maryland oyster sanctuaries monitored by the MDNR shellfish program's fall oyster survey. MDNR, Fisheries Service, Tawes State Office Building, 580 Taylor Avenue, Annapolis, MD.

[2]Data sources ftp://dnrftp.dnr.state.md.us/public/outgoing/fish/Oysters/ and ftp://dnrftp.dnr.state.md.us/Public/Outgoing/Fish/Oysters/Other/MDNR Annual Fall Survey.

[3] Does not include sites planted with seed in the year plantings were made.

[4] Includes data for Severn, South and Mid-shore. Best bars in these regions include Chinks (Severn), Thunder and Lightening (South) and Kent Point (Mid-shore).

Table 7. Spatfall rankings by region excluding data for 1997. Rankings in the column labeled key spat bars are based on 53 “key” spat monitoring bars sampled over the period 1985 - 1996 and 1998 – 2007 aggregated by region as reported in the 2007 DNR fall survey report. Rankings in the column labeled 1996 and 1998 - 2007 are based on data collected at all sites sampled in the DNR fall survey and grouped into regions presented in the 2007 fall survey report. Regions in bold support “best bars” three or more years over the period 1996-2007 as determined in Rothschild 2009.

Region	Rank (spat per bushel) where #1 is highest and #23 is lowest)	
	key spat bars 1985 – 1996 and 1998 - 2007[1]	All fall survey sites for 1996 and 1998 – 2007[2,3]
St. Mary's River	1	2
Broad Creek	2	7
Little Choptank	3	11
Honga River	4	6
Tangier Sound	5	1
Potomac River	6	13
Manokin	7	3
Harris Creek	8	8
Pocomoke Sound	9	5
Lower Bay	10	4
Choptank	11	16
Fishing Bay	12	10
Miles	13	9
Tred Avon	14	20
Eastern Bay	15	12
Middle Bay[4]	16	19
Nanticoke	17	17
Patuxent River	18	14
Wye River	19	18
St. Clements/Brenton Bay	20	22
Wicomico (eastern shore)	21	15
Chester	22	21
Upper Bay	23	23

[1]Rankings were determined from 53 “key” spat monitoring bars over the period 1985 – 2007. Data for specific bars were taken from: Tarnowski, M. 2005. An evaluation of the Maryland oyster sanctuaries monitored by the MDNR shellfish program’s fall oyster survey. MDNR, Fisheries Service, Tawes State Office Building, 580 Taylor Avenue, Annapolis, MD.

[2,]Data sources ftp://dnrftp.dnr.state.md.us/public/outgoing/fish/Oysters/ and ftp://dnrftp.dnr.state.md.us/Public/Outgoing/Fish/Oysters/Other/MDNR Annual Fall Survey.

[3] Does not include sites planted with seed in the year plantings were made.

[4] Includes data for Severn, South and Mid shore. Best bars in these regions include Chinks (Severn), Thunder and Lightening (South) and Kent Point (Mid-shore).

Table 8. Estimates of oyster production for the Maryland portion of Chesapeake Bay by river/region. For each region/tributary, production is expressed as the average the 1985-2006 reported harvest in bushels/acre of oyster habitat as determined from modified MBBS oyster bar area estimates. The reported harvest by area/region was taken from Tarnowski, M. (2009) and MBBS acreage was provided by K. Greenhawk, Maryland Department of Natural Resources, Fisheries Service (personal communication). Regions in bold support "best bars" three or more years over the period 1996-2007 as determined in Rothschild 2009.

Region/Tributary	Average harvest 1985-2008	Acres oyster habitat (modified MBBS)[1]	Average bushels/acre
Eastern Bay	38,319	1,293.70	29.6
Broad Cr.	14,619	503.38	29.0
St. Mary's R. and Smith Cr.	9,081	326.61	27.8
Choptank	70,397	3,845.16	18.3
Harris Cr.	9,966	596.6	16.7
Wye R.	2,681	174.36	15.4
Little Choptank R.	15,776	1,048.78	15.0
Chester R.	30,028	2,038.83	14.7
Miles R.	7,159	581.13	12.3
Fishing Bay	10,860	965.94	11.2
Wicomico R., St. Clement and Breton Bays	13,428	1,220.83	11.0
Manokin R.	4,337	690.85	6.3
Pocomoke Sound	2,691	577.01	4.7
Tangier sound	17,248	4,010.68	4.3
Patuxent R.	10,184	2,401.15	4.2
Honga R.	4,483	1,155.19	3.9
Middle Bay	19,699	5,463.64	3.6
Upper Bay	16,656	6,409.26	2.6
Nanticoke and **Wicomico R.**	7,978	3,265.72	2.4
Lower Bay	5,049	2,597.00	1.9

[1]Region/tributary specific estimates of oyster habitat were provided by Kelly Greenhawk, Oxford COL. Methods used to calculate bar specific habitat estimates are presented in Greenhawk, K. 2005. Development of a potential habitat layer for Chesapeake Bay oyster bottom. Maryland Department of Natural Resources. Oxford Cooperative Laboratory.

Table 9. Summary of production and spatfall estimates by rivers/areas in the Maryland portion of Chesapeake Bay. Regions in bold support "best bars" three or more years over the period 1996-2007 as determined in Rothschild 2009.

River/region	Production	spat counts - key spat bars – all years	spat counts - all fall survey sites – all years	spat counts - key spat bars – exclusive of 1997	spat counts - all fall survey sites – exclusive of 1997
Eastern Bay	1	5	1	15	12
Broad Creek	2	3	6	2	7
St. Mary's River[1]	3	2	2	1	2
Choptank River[2]	4	14	15	11	16
Harris Creek	5	8	5	8	8
Wye River	6	11	10	19	18
Little Choptank River	7	4	9	3	11
Chester River	8	22	21	22	21
Miles River	9	1	3	13	9
Fishing Bay	10	15	13	12	10
Wicomico R., St. Clements and Brenton Bays	11	20	22	20	22
Manokin River	12	10	7	7	3
Pocomoke Sound	13	12	11	9	5
Tangier Sound	14	7	4	5	1
Patuxent River	15	19	18	18	14
Honga River	16	6	12	4	6
Middle Bay[3]	17	17	20	16	19
Upper Bay	18	23	23	23	23
Nanticoke and **Wicomico Rivers**	19	18,21	19,17	17,21	17,15
Lower Bay	20	13	8	10	4
Tred Avon		16	14	14	20
Potomac		9	16	6	13

[1]Includes Smith Creek
[2] Includes Tred Avon
[3]Includes data for Severn, South and Mid shore. Best bars in these regions include Chinks (Severn), Thunder and Lightening (South) and Kent Point (Mid-shore).

Table 10. Summary of reserves, sanctuaries and open areas planted with hatchery seed by the Oyster Recovery Partnership since 1998.

	Number		
River/area	Reserves	Sanctuary sites	Open areas
Chester	10	3	7
Choptank	3	6	6
Corsica	-	2	-
Eastern Bay	1	4	-
Little Choptank	-	1	-
Magothy	-	3	2
Nanticoke	-	1	-
Patuxent	2	6	3
Potomac	-	1	5
Wicomico	-	-	3
Severn	-	3	4
Tangier	-	-	5
Upper bay	1	1	-
South River	-	4	2
Total	17	35	37

Table 11. Number of seed oysters (in millions) planted by area, bar and year over the period 1998 – 2008 by the Oyster Recovery Partnership[1].

River/area	Bar/area name	Year											
		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total
Chester	Blunts (Managed Reserve)				15.0	18.2	35.9	18.4	19.4			21.0	128.0
	Buoy Rock						1.0	3.1	11.7	13.2			29.0
	Emory Hollow (Managed Reserve)				5.0	0.7	1.0	5.1		9.6		22.7	44.1
	Old Field							6.7	9.9	32.5			49.1
	Ringgold (Sanctuary)						1.0						1.0
	Bluff								1.7	8.0			9.7
	Devils Playground (Managed Reserve)								20.6				20.6
	Durdins									22.5		6.4	28.9
	Drum Point (Managed Reserve)										2.3		2.3
	Hudson Bar (Managed Reserve)										19.1		19.1
	Willow Bottom (Managed Reserve)										7.7		7.7
	Boathouse (Managed Reserve)								12.5				12.5
	Piney Point										4.3	11.8	16.1
	Hickory Thicket (Sanctuary)									18.2	26.6	15.8	60.6
	Carpenters Island (Managed Reserve)									18.5		36.6	55.0
	Copper's Hill (Managed Reserve)										2.5	27.0	29.5
	Strongs Bay Sanctuary						19.8	1.8	50.3		10.1	26.0	108.0
	Side Shoal									1.0			1.0
	Spaniard Point (Managed Reserve)									49.2			49.2
	Wickes Beach									2.8			2.8
Choptank	Bolingbroke Sands (Managed Reserve)				15.0	14.9	41.2	5.3	4.4	30.2		32.0	143.0
	France Bar			18.5									18.5
	Howell Point (Sanctuary)			0.8	0.8								1.7
	Mill Dam (Managed Reserve)					13.5			2.8		9.0		25.3
	Oyster Shell Point Bar									9.8	3.5	16.6	29.9
	Cabin Creek (Sanctuary)											13.9	13.9
	Shoal Creek (Sanctuary)				3.5								3.5
	Shoal Creek II (Sanctuary)						14.3	6.7	6.9	4.0	18.9	25.3	76.1
	Sandy Hill				1.1								1.1
	Tred Avon		0.2										0.2
	Turtle Back									1.2			1.2
	Green Marsh (Sanctuary)						17.5					30.2	47.7
	State’s Bank (Sanctuary)						5.0	5.1	15.0		7.9	25.6	58.6
	The Black Buoy (Managed Reserve)							4.3	17.3	47.2			68.8
	Dixons Harvest Bar								2.8				2.8
Corsica	Possum Point (Sanctuary)								2.0	0.4		11.5	13.9
	Emory's Wharf (Sanctuary)								6.0	1.4		23.8	31.3
Eastern Bay	Bugby (Sanctuary)			6.0			6.0						12.0
	Mill Hill CBT (Sanctuary)			6.3	0.4	0.2	6.3					40.8	53.9
	Cox Neck (Managed Reserve)										8.7		8.7
	Horsehead (Sanctuary)					1.6						3.2	4.7
	Cabin Creek (Sanctuary)								0.5				0.5
Little Choptank	Susquehanna Sanct. Research Bar					3.3	2.3	0.9					6.5
Magothy	Chest Neck Point (Sanctuary)					1.3				2.3			3.6
	Black Bar											10.5	10.5
	Rock Point											4.7	4.7
	Ulmstead (Sanctuary)									2.7			2.7
	Duer Memorial (Sanctuary)									0.0			0.0

[1] https://www.oysterrecovery.org/Content/ContentDisplay.aspx?ContentID=49

Table 11 (continued). Number of seed oyster planted (in millions) by area, bar and year over the period 1998 – 2008 by the Oyster Recovery Partnership.

River/area	Bar/area name	Year											
		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total
Nanticoke	Roaring Point (Sanctuary)				1.4	2.1	2.2						5.7
Patuxent	Bailey (Sanctuary)					10.2	0.1						10.3
	Broadneck (Managed Reserve)				5.2		7.9	5.1		29.0			47.2
	Elbow (Sanctuary)					1.2							1.2
	Holland Point						0.1						0.1
	Holland Point (Managed Reserve)										4.9	19.4	24.3
	Peterson	0.0	1.2										1.3
	Neal's (Sanctuary)											10.2	10.2
	Helen's Creek										2.6	5.6	8.1
	Navy Rec Center (Sanctuary)								0.1				0.1
	Kitts Marsh (Sanctuary)							10.1					10.1
	Teague (Sanctuary)					1.2							1.2
Potomac	Neal's Sound					1.8							1.8
	Bonum Creek							3.2					3.2
	DO CO Buyback Site		0.0										0.0
	Swan Point						2.3						2.3
	Webster Field (Sanctuary)								0.0				0.0
	Morgantown					0.6	0.1						0.7
Wicomico	Buds Landing (Brown)							3.7					3.7
	Key Bar									2.4	3.4	6.8	12.6
	Wicomico								2.1				2.1
Severn	Weems Creek (Sanctuary)				1.6	1.9							3.5
	Chinks Point										4.3	11.5	15.8
	Tolly Point		7.2										7.2
	Old Fort	0.1											0.1
	USNA	1.5											1.5
	Lake Ogelton (Sanctuary)									7.1		33.4	40.4
	Severn (Sanctuary)								2.4				2.4
Tangier	Terrapin Sands			4.2			4.2						8.4
	Cod Harbor		0.7										0.7
	Smith Island		0.3										0.3
	SO CO Buyback Site		0.0										0.0
	Bishops Head	?	0.1										0.1
Upper Bay	Nine foot Knoll (Managed Reserve)					0.9						13.6	14.5
	Memorial Stadium (Sanctuary)					2.7	7.0						9.7
South	Glebe Bay (Sanctuary)				1.7				0.4				2.1
	Hurricane Hole (Sanctuary)								0.4				0.4
	Brewers									10.3	1.7		12.0
	Ferry Point (Sanctuary)	1.2								1.5	2.8		4.3
	Harness (Sanctuary)		0.0						0.5				0.5
	River Mouth				0.3								0.3
	Miscellaneous projects			2.5	3.0	0.2	6.4	0.8	1.8			19.0	33.7

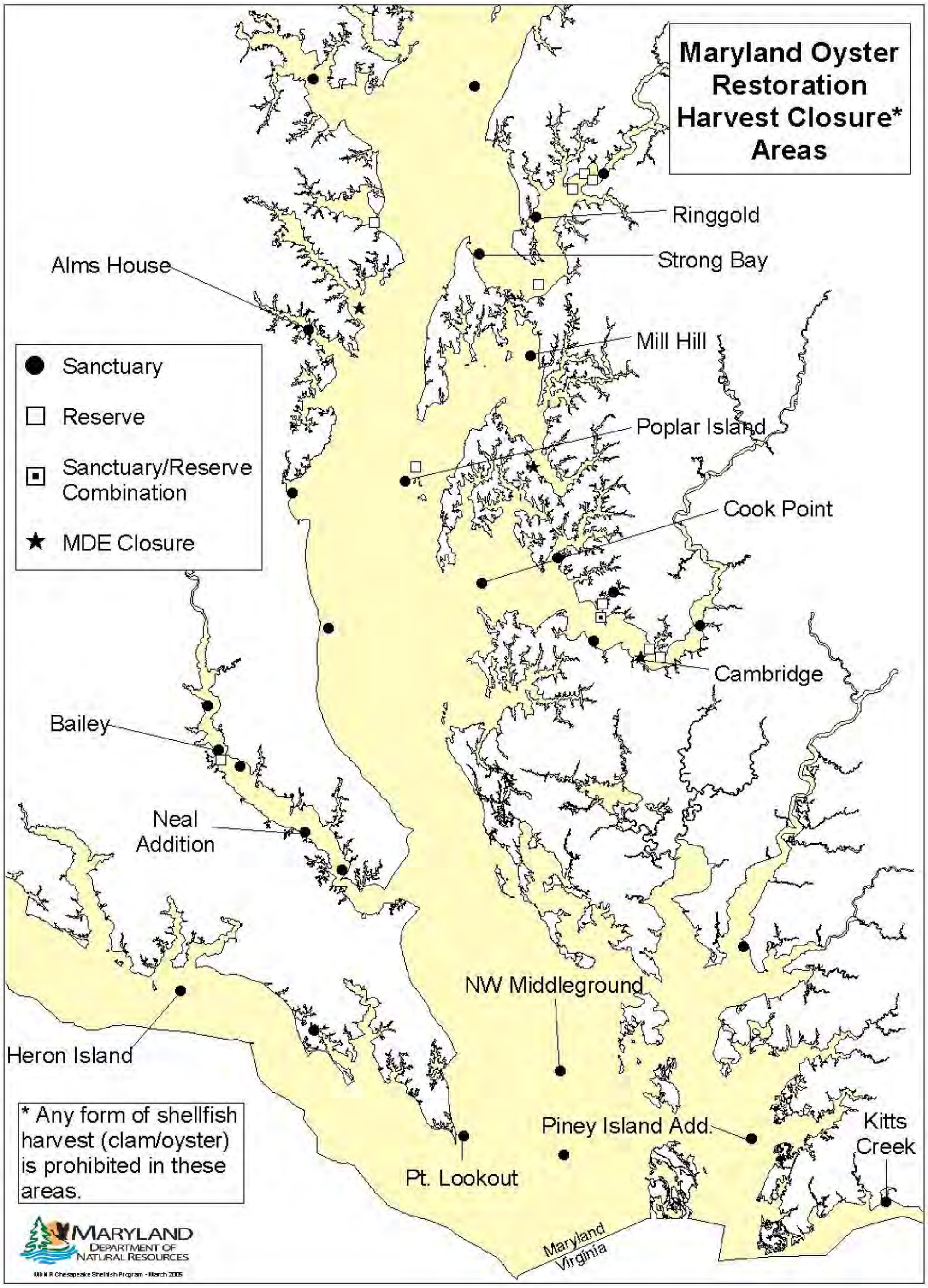

Figure 1. Location of all sanctuaries and harvest reserves in Maryland and the names and locations of sanctuaries sampled in the DNR fall survey

Figure 2. Location of 'best bars' with market oyster abundance in the top 10% of all bars surveyed in four or more years over the 1996-2007 study period (From Rothschild (2009).

Site #	Area	Latitude	Longitude		Site #.	Area	Latitude	Longitude
16	Broad Creek	38.69468	-76.23872		324	Little Choptank River	38.54338	-76.21283
29	Broad Creek	38.74052	-76.24490		325	Little Choptank River	38.54625	-76.21908
36	Broad Creek.	38.75610	-76.23625		309	Little Choptank River	38.53237	-76.24312
41	Lower Chester	38.98905	-76.19717		374	Low Bay West	38.04668	-76.30888
88	Upper Chester	39.08558	- 76.16473		407	Mid Bay East	38.86087	-76.38350
218	Eastern Bay	38.90357	-76.30642		658	Severn River	38.96515	-76.46153
231	Eastern Bay	38.92253	-76.28583		676	South River	38.93442	-76.51768
259	Harris Creek	38.70403	-76.31557		192	Miles River	38.86728	-76.22053
295	Little Choptank River	38.51470	-76.26446		882	Wye River	38.86028	-76.19412

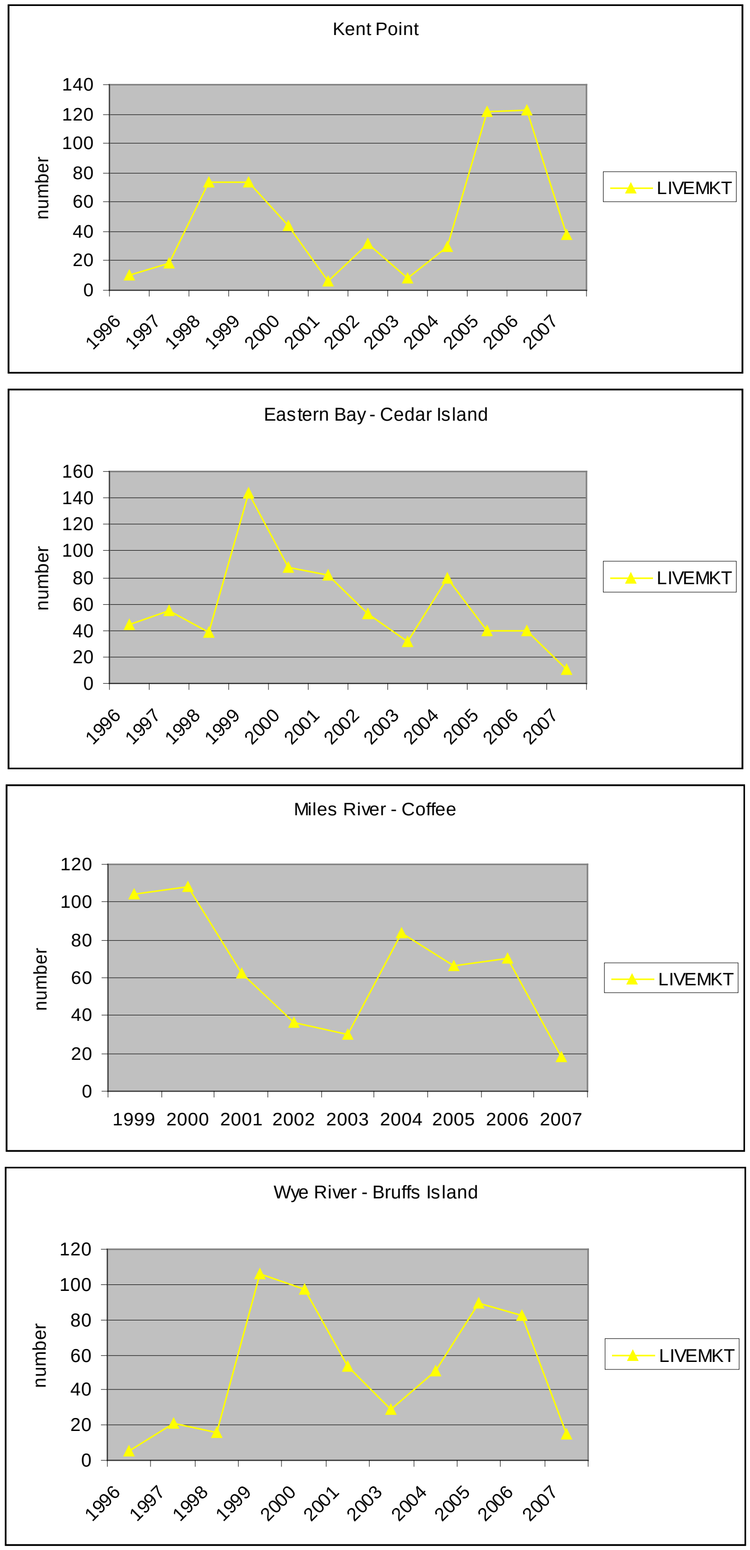

Figure 3a. Time series of market counts at Kent Point, Cedar Island, Coffee and Bruffs Island oyster bars s determined from the DNR fall survey and reported in Rothschild 2009.

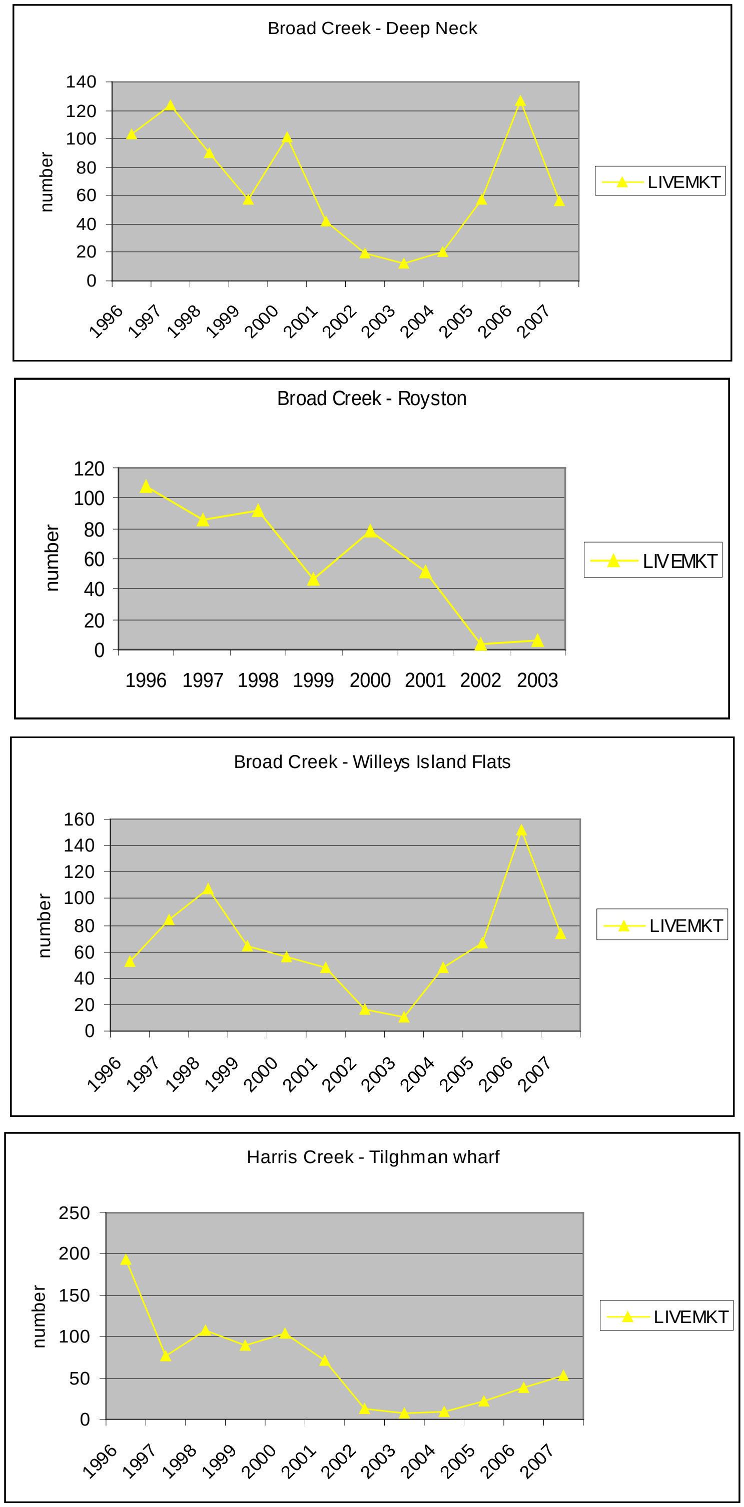

Figure 3b. Time series of market counts at Deep Neck, Royston, Willeys Island Flats and Tilghman wharf oyster bars s determined from the DNR fall survey and reported in Rothschild 2009.

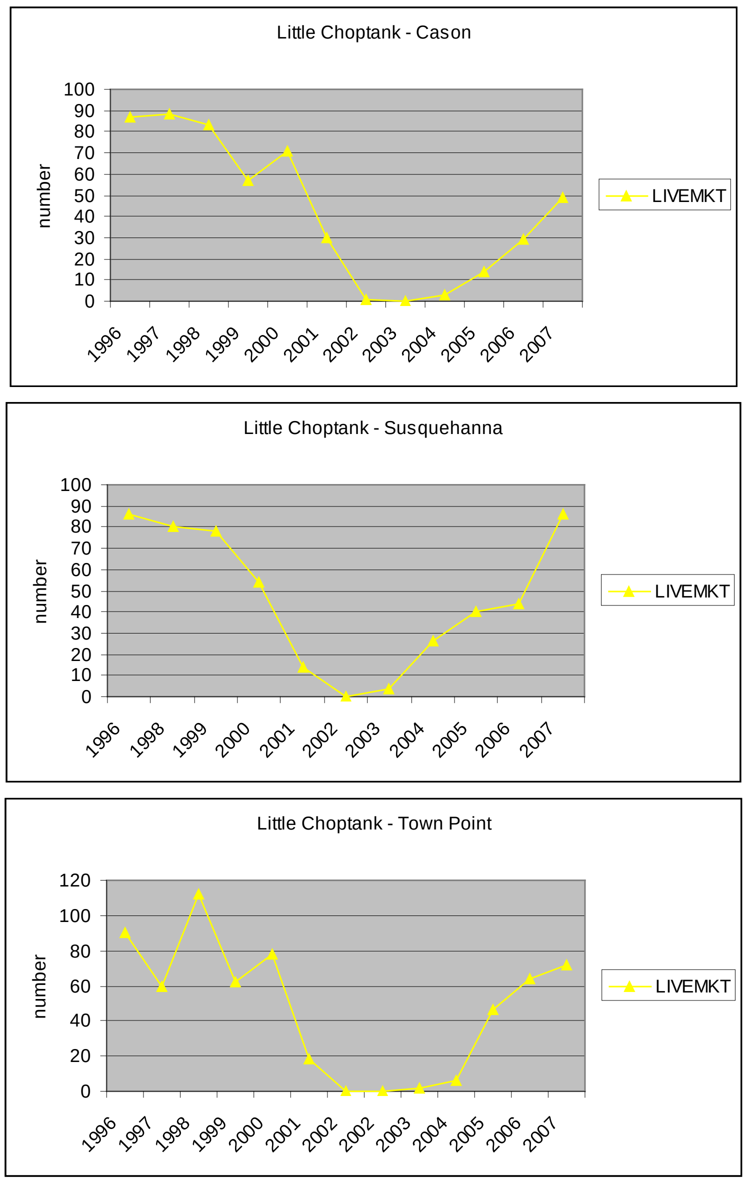

Figure 3c. Time series of market counts at Cason, Susquehanna and Town Point oyster bars as determined from the DNR fall survey and reported in Rothschild 2009.

Literature cited

Brown, B.L., A. Butt, D. Meritt and K. T. Paynter. 2005. Evaluation of resistance to Dermo in eastern oyster strains tested in Chesapeake Bay. Aquaculture Research 36, 1544 – 1554.

Brown, B. A. Butt, S. Shelton, D. Meritt and K. Paynter. 2005. Resistance of Dermo in eastern oysters, Crassostrea virginica(Gmelin), of North Carolina but not Chesapeake Bay Heritage. Aquaculture Research, 36 1391-1399.

Burke R., and R. Lipcius. 2009 Alternative Ecosystem-Based Restoration Approaches with Native Oyster Metapopulations in Chesapeake Bay: Lynnhaven River System Alternative Substrate Experiment. Final Report. Virginia Institute of Marine Science, The College of William and Mary.

Carlsson, J, R. Carnegie, J. Cordes, M. Hare, A. Leggett, and K. Reece. 2008. Evaluating Recruitment Contribution of a Selectively Bred Aquaculture Line of the Oyster, Crassostrea virginica used in Restoration Efforts. Journal of Shellfish Research 27(5):1117-1124.

Chesapeake Bay Program. 2007. Oyster Management Plan Meeting Relating to Oyster Disease Issues Potomac River Fisheries Commission, Colonial Beach, VA.

Chesapeake Research Consortium. 1999. Chesapeake Bay oyster restoration: consensus of a meeting of scientific experts. Virginia Institute of Marine Science. Wachapreague, VA.

Eastern Oyster Biological Review Team. 2007. Status review of the eastern oyster (*Crassostrea virginica*). Report to the National Marine Fisheries Service, Northeast Regional Office. February 16, 2007. 105 pp

Encomico et al. 2005. Performance of “natural dermo-resistant” oyster stocks – survival, disease, growth, condition and energy reserves. Journal of Shellfisheries Research. Jan. 2005.

Greenhawk, K. 2005. Development of a potential habitat layer for Chesapeake Bay oyster bottom. Maryland Department of Natural Resources. Oxford Cooperative Laboratory.

Gregalis K., S. Powers and K. Heck. 2008. Restoration of Oyster Reefs along a Bio-physical Gradient in Mobile Bay, Alabama. Journal of Shellfish Research 27(5):1163-1169. 2008.

Hargis, W. and D. Haven. 1999. Chesapeake Oyster Reefs, Their Importance, Destruction and Guidelines for Restoring Them. [In] Oyster Reef Habitat Restoration: A synopsis and Synthesis of Approaches Edited by M. W. Luckenbach, R. Mann and J. A. Wesson • 1999 • Virginia Institute of Marine Science Press , Gloucester Point, VA**.**

Judy, C. 2000. Oyster restoration in Maryland. Abstract. [In] Chesapeake Bay Program. 2000 Oyster restoration workshop proceedings and agreement statements. CBP/TRS 238-

Judy, C. 2000. Status of shell supply for reef restoration and environmental impacts of dredging. Abstract [In] Chesapeake Bay Program. 2000 Oyster restoration workshop proceedings and agreement statements. CBP/TRS 238-00.

Lenihan, H. S. and C. H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecol. Appl 8:128–140.

Luckenbach, M. 2000. Oyster reef habitat. Abstract [In] Chesapeake Bay Program. 2000 Oyster restoration workshop proceedings and agreement statements. CBP/TRS 238-00.

Mann, R. and E. Powell. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. Journal of Shellfish Research, Vol. 26, No. 4, 905–917.

Maryland Department of Natural Resources, Fisheries Service. 2005. Preliminary economic evaluation of Maryland's oyster reserve harvest program. Tawes State Office Bldg., 580 Taylor Avenue Annapolis Maryland.

National Oceanic and Atmospheric Administration (NOAA). 2007. NOAA Report to the Chairman, Committee on Appropriations, U.S. Senate. June 2007.

Paynter, K. 2008. 2007 sanctuary assessments. A report to the U.S. Army Corps of Engineers Baltimore District.

Peterson C., J. Grabowski and S. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation. Marine Ecology Progress Series Vol. 264: 249–264

Rodney, W.S. and K. T. Paynter. 2006. Comparisons of marcofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland. Journal of Experimental Marine Biology and Ecology 335 (2006) 39–51.

Rothschild, B., 2009. Indicative Analysis of the Fall Oyster Survey in Maryland waters of Chesapeake Bay. Draft report to the Maryland Department of Natural Resources.

Schulte, D., R. Burke and R. Lipcius, 2009. Unprecedented Restoration of a Native Oyster Metapopulation in the Great Wicomico River, Chesapeake Bay, VIMS Special Report in Applied Marine Science and Ocean Engineering, No. 409

Smith, G. 1997. Maryland's Historic Oyster Bottom. A Geographical Representation of the Traditional Named Oyster Bars. Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory, Oxford, MD.

Smith, G., D. Bruce, E.Roach, A. Hansen, R. Newell and A. McManus. 2005. Assessment of recent habitat conditions of eastern oyster *Crassostrea virginica* bars in mesohaline Chesapeake Bay. North American Journal of Fisheries Management 25:1569-1590

Southworth, M., R. Mann, J. M. Harding & J. A. Wesson.. 2008. Multiyear recruitment patterns of oysters (*Crassostrea virginica*) on constructed reefs in the Chesapeake Bay. J. Shellfish Research.

Tarnowski, M. 2005. An evaluation of the Maryland oyster sanctuaries monitored by the MDNR shellfish program's fall oyster survey. Maryland Department of Natural Resources. Fisheries Service.

Tarnowski, M. [Ed.] 2008. Maryland Oyster Population - Status Report 2007 Fall Survey. Maryland Department of Natural Resources Shellfish Program and Cooperative Oxford Laboratory MDNR Publication.

Tarnowski, M. [Ed.] 2009. Maryland Oyster Population - Status Report 2008 Fall Survey. Maryland Department of Natural Resources Shellfish Program and Cooperative Oxford Laboratory MDNR Publication.

U.S. Army Corps of Engineers. U.S. Army Corps of Engineers. 2008. Draft Programmatic environmental impact statement for oyster restoration in Chesapeake Bay including the use of a native and/or nonnative Oyster. U.S. Army Corps of Engineers, 803 Front Street, Norfolk, VA 23510.