Native Oyster (*Crassostrea virginica*) Restoration in Maryland and Virginia

An Evaluation of Lessons Learned 1990-2007

Metadata Analysis of Restoration and Monitoring Activity Database

Preliminary Report

Oyster Restoration Evaluation Team

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Maryland Sea Grant Publication UM-SG-TS-2009-02
CRC Publ. No. 09-168

Oyster Restoration Evaluation Team Members

Dr. Denise Breitburg, Smithsonian Environmental Research Center, Edgewater, MD
Dr. Mary Christman, University of Florida, Department of Statistics, Gainesville, FL
Dr. Victor Kennedy, University of Maryland Center for Environmental Science, Horn Point Laboratory, Cambridge, MD
Dr. Mark Luckenbach, Virginia Institute of Marine Science, Eastern Shore Laboratory, Wachapreague, VA
Dr. Roger Mann, Virginia Institute of Marine Science, Gloucester Point, VA
Dr. Kennedy Paynter, Marine Estuarine and Environmental Sciences Program, University of Maryland, College Park, MD

Data Compilation and Database Construction

Ms. Jodi Dew-Baxter, Versar, Inc., Columbia, MD

Data Analyses

Dr. Cherie Keller, University of Florida, Department of Statistics, Gainesville, FL

Facilitators

Dr. Jonathan Kramer, Maryland Sea Grant College Program, College Park, MD
Dr. Kevin Sellner, Chesapeake Research Consortium, Edgewater, MD

Reference: ORET (Oyster Restoration Evaluation Team). 2009. Metadata Analysis of Restoration and Monitoring Activity Database. J.G. Kramer and K.G. Sellner (eds.), Native Oyster (*Crassostrea virginica*) Restoration in Maryland and Virginia. An evaluation of lessons learned 1990-2007. Maryland Sea Grant Publication #UM-SG-TS-2009-02; CRC Publ. No. 09-168, College Park, MD. 40 pp.

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Executive Summary

The Oyster Restoration Evaluation Team has assembled, collated, critically examined and analyzed the available historical oyster restoration data sets from a diverse set of sources for Chesapeake Bay. The team collected 78,000 records of activities to monitor and enhance oyster populations locally or regionally between 1990-2007. MD and VA state agencies with mandated restoration responsibilities generated most of the data. While there are data limitations that impact our ability to answer certain questions, the metadata analyses reveal a number of trends over the 18-year period of the study. Of the 1035 sites for which we found data, 81% have restoration activities, 86% have monitoring activities, and 67% have both restoration and monitoring. During the study period, five direct restoration activities were conducted — bagless dredging, bar cleaning, hatchery or wild seed transplanting and substrate addition. Of these, substrate addition has been undertaken at more reefs than any other and predominantly in the tributaries. Seed transplanting has also been used extensively. While wild seed was most important during the early portion of the study period, hatchery seed transplanting began in the late 1990s and now dominates in both states. Multiple organizations (11) have participated in field visits for restoration and monitoring, often with several visits at a reef in a given year. Despite the large number of restoration activities cited above, the lack of replication across specific combinations of restoration activities within or among habitats, as well as the impact of harvest on restored reefs, severely hampers our ability to evaluate the effectiveness of restoration over the study period.

Although the data incorporated in the database represent a wide array of activities, goals and objectives, many of the data are qualitative and do not provide the opportunity to assess population level changes over time. Monitoring protocols of most restoration/stock assessment activities to date have been inadequate to assess the outcomes of those activities, and the wide range of types, habitats and combinations of restoration activities implemented to date would make analyses difficult even if additional monitoring had been conducted. Both restoration design and monitoring must be thoughtfully conceived, formally established with clear objectives, coordinated across reefs and carefully executed in order to assess the success or failure of restoration projects. This will continue to be true for assessing individual projects undertaken in the future, and for assessing the general efficacy of various restoration protocols implemented singly and in combination.

Future restoration and stock assessment efforts should collect quantitative data on both restored and unrestored reefs to facilitate definitive analyses of the results of restoration activities. Those quantitative data should include spatially explicit measures of oyster abundance (oyster/m^2), including separate quantification of differing cohorts (spat) where possible, as well as oyster sizes and appropriate histological/diagnostic analyses. It is critical that sound experimental design including replication, robust sample sizes and quantitative collection techniques be used to provide a rigorous and statistically powerful method of testing whether different restoration strategies are successful.

With this in mind, there are definitive steps that can be taken in order to move forward in a manner that can enhance and improve oyster restoration/stock assessment efforts Baywide. Recognizing that there will be numerous entities that engage in oyster restoration in the coming years and building upon the work done to date, the team recommends the following:

- All organizations performing restoration should be much more explicit with regard to the intent of their activities. Clearly articulated goals, whether to support the oyster fishery or for long-term restoration of ecological services or both, are essential. Different endpoints will likely require very different designs for given activities and possibly different methods of sample collection. In particular, for

restoration there needs to be a recognition that reefs must be maintained without fishing pressure, and that monitoring of growth and the progression of disease must be continued for sufficient duration to fully assess the efficacy of the restoration activity.

- There has often been limited or no coordination between those that perform restoration and those that engage in monitoring. Effective restoration will be greatly enhanced by more fully integrated data collection and monitoring of critical parameters. Rigorously planned restoration efforts that meet scientifically valid design, coupled to equally rigorous monitoring and assessment, are needed, and sustained funding must be anticipated to support those monitoring efforts.

- For all reefs (both those receiving a restoration activity and controls), data collection should include repeated measures of oyster sizes, abundances (which requires some form of random sampling with effort data), and disease status as well as other goal-specific data. All entities engaged must agree on common parameters that should be monitored and commit to rigorous quality control for all monitoring efforts. It is essential to employ the best use of geo-referencing technology to ensure that all measurements are spatially explicit so that sites can be accurately and easily identified in the future.

- A sound stock assessment program must be established that will detect local and system-wide changes that may be the result of restoration activities. This assessment program should be capable of tracking spatially explicit (i.e., reef-specific) changes in oyster abundance, mean oyster sizes, recruitment, disease levels and mortality.

- Data relative to restoration efforts and associated monitoring should be posted to a central collaborative database. Development of the database should build upon the work of this project and should explicitly identify the potential limitations of contributed data. The database should also be governed by clear guidelines for how and when data are to be provided and be based on clear agreements regarding data availability, sharing and use.

- The metadata analysis strongly suggests that restoration and monitoring efforts need to be organized and coordinated in a much more stringent manner to facilitate the collection of data essential for assessing the efficacy of these efforts. Eleven different agencies and organizations provided data in various formats to the team. The combined efforts are remarkable in many respects and the analyses conducted for this report make clear the many ways that these entities have worked to enhance oyster populations. Given the nature of the data, however, the team could draw few conclusions as to the efficacy of most restoration efforts.

The team's activities have highlighted the strengths and weaknesses of oyster restoration efforts over the past 18 years and the utility of the data collected to monitor them. While this examination has been informative, its greatest value is to define future oyster restoration activities — specifically, to construct guidelines that will help maximize return on the large investment of effort and funding that will be made in the coming years.

Perhaps the greatest lesson of the Oyster Restoration Evaluation Team effort is the recognition that the techniques, sampling protocols and stock assessment methods used to date are inadequate to assess real changes in oyster populations, locally or regionally, and that wholesale change is necessary to design and implement sound stock assessment and monitoring protocols and procedures in order to fully assess the health and growth of a recovering oyster population.

Acknowledgments

The Oyster Restoration Evaluation Team gratefully acknowledges the support and encouragement from Verna Harrison (Keith Campbell Foundation) and Peyton Robertson (NOAA's Chesapeake Bay Office). J. Dew-Baxter was instrumental in compiling and formatting the data in the Microsoft Access database. Data contributions from various regional organizations and individuals are also appreciated, including George Abbe, Academy of Natural Science Estuarine Research Laboratory and the Morgan State University Estuarine Research Center; Chesapeake Bay Foundation; Living Classrooms Foundation; Maryland Department of Natural Resources; Oyster Recovery Partnership; A.C. Carpenter, Potomac River Fisheries Commission (PRFC); Surf Riders Foundation (SRF); University of Maryland; University of Maryland Center for Environmental Science; U.S. Army Corps of Engineers; Virginia Institute of Marine Science; and Jim Wesson, Virginia Marine Resources Commission. Insights from Tom O'Connell, MDDNR were also informative and helpful. We thank Sandy Rodgers and Jack Greer for carefully editing and producing the final report. Funding for this study was provided by The Keith Campbell Foundation for the Environment (project titled "Evaluating Efforts, Outcomes and Next Steps for Native Oyster Restoration in the Chesapeake Bay"), the NOAA Chesapeake Bay Office (Grant #FNA06NMF4570276), the U.S. Fish and Wildlife Service (Grant#51410-6T585), Maryland Sea Grant College Program (Grant #NA50AR4171042, RP/FODR-206).

Introduction

Over many decades, a diverse group of stakeholders, supported by substantial investments of federal and state resources, have worked to restore the Chesapeake Bay's native oyster (*Crassostrea virginica*). In 2006, the Keith Campbell Foundation for the Environment, the NOAA Chesapeake Bay Office, and the U.S. Fish and Wildlife Service initiated a review and evaluation of past oyster restoration efforts to determine their extent and effectiveness. This report details a Bay-wide review conducted by a team of experts convened from the region.

The oyster restoration evaluation team constrained their study to an examination of restoration efforts since 1990. Their intent was to provide a synthesis of the lessons learned with regard to the specific scientific and management goals that have driven these restoration efforts and, in particular, the successes in reaching such goals (see Appendix 1).

The team's initial task was to develop a unified database of restoration efforts for the designated interval. The team requested data from the broad restoration community in Maryland and Virginia. Coincident with this wide call for information, they worked together with staff at Versar Inc. to develop architecture for the database that would be "accommodating" of different inputs from the restoration community, allow for analysis and be durable so that it might be seen as a model for future data archiving efforts. This task proved to be quite challenging, given the dispersed nature of the data and in some cases widely varying formats used by data providers.

This report summarizes the results of these efforts and describes the basic aspects of what the team believes is the first and most extensive database of its kind for oyster restoration in the region. The report also provides an initial metadata analysis structured by a series of questions that were used initially to frame the study (see Appendix 1).

Database Development and Architecture

The evaluation team received data from twelve sources in Maryland and Virginia (see Acknowledgements for a listing of the individuals and organizations who generously contributed to the effort). The database contains some 78,000 individual entries covering the diverse set of actions that comprise "oyster restoration" in Maryland and Virginia waters, as well as monitoring of reefs where no restoration activities occurred (see below). Entries are both geographically and temporally referenced, and the database is accessible for both statistical (i.e., SAS, Excel) and GIS (i.e., ArcGIS) analyses. The database was constructed using the software program, Microsoft Access. See Appendix 2 for a view of its architecture and how the user interface operates.

Restoration Activities

The team's initial analyses of how state, federal, and non-governmental organizations deployed resources to advance oyster restoration since 1990 revealed that there were six major types of restoration (i.e., "activities") employed for a sufficient duration of time and on a sufficient scale to be considered significant for inclusion in the database. These include:

- ***Substrate Addition.*** Oyster shell and occasionally other substrate is moved in large quantities by barge to new locations thought to be suitable for natural spat settlement or as a base for hatchery-reared animals.

- ***Wild Seed Transplanting.*** Large-scale shell plantings are made in areas thought to receive consistent natural spat set but where disease pressure may be prohibitive for extended survival. Wild seed on planted shell is harvested the first spring following planting and re-located to areas with low natural recruitment but also low disease pressure for grow out.

- ***Hatchery Seed Planting.*** Oyster hatcheries of various scales produce larvae from defined broodstock in a controlled manner. Small oysters or spat set on shell are employed in restoration programs. The oysters or spat are moved to various restoration reefs Baywide.

- ***Bar Cleaning.*** This management tool is used in an attempt to maximize survivorship of transplanted oysters by removing infected animals from restoration reefs. In practice, commercial waterman were contracted to use power (escalator) dredges to remove all live oysters, returning any empty shell back to the bar. The process excavates the bottom to a depth of approximately one foot, and through agitation and turnover, sediment-laden shell is cleaned prior to movement or returned to the original area.

- ***Bagless Dredging.*** Another bottom cleaning method, bagless dredging employs a harvesting dredge modified by removing or opening the catch bag. The gear is dragged across bars, stirring up shell and sediment. Shell re-settles while sediment is dispersed into the water column and advected from the reef. Bagless dredging is thought to be less disruptive than bar cleaning with power dredges.

- ***Monitoring.*** Various types of monitoring are relevant to evaluation of restoration success. Monitoring at sites not receiving restoration activities provide important reference points (or controls) for comparison with sites targeted for restoration. Data collected at restoration and reference reefs include measurements of oyster abundances, growth rate, and disease prevalence and intensity, as well as ecological observations, etc. In addition, there were numerous measurements of water quality parameters collected at or near oyster reefs that the team deemed important for inclusion in the database.

Restoration Events

The team considered the time and geographically referenced location (i.e., reef) for occurrence of an activity to define a discrete restoration or monitoring "event" for analysis. The metadata analyses that follow summarize information in the context of these operational definitions.

Metadata Analyses

The team structured the initial queries of the database to develop and understand the "inventory" of efforts associated with native oyster restoration efforts over the past 18 years. Such basic queries are very informative in terms of understanding the scale and pattern of native oyster restoration in the Bay, but consistent with the analysis of large historical databases of this type, there are important caveats that must be acknowledged at the outset.

While the team made exhaustive efforts to gather all relevant information from the study period, the dataset does not capture 100% of all restoration and monitoring activities during this time, either because the data were never recorded and archived or because data were not made available. Complete datasets were obtained from the Maryland Department of Natural Resources, University of Maryland, Oyster Recovery Partnership, Potomac River Fisheries Commission, US Army Corps of Engineers Baltimore District, and Academy of Natural Sciences/Morgan State University. Datasets from Virginia Institute of Marine Science, Virginia Marine Resources Commission, and the Chesapeake Bay Foundation were incomplete, summarized at scales (e.g. bar summaries rather than raw data) other than that needed for statistical analysis, or were not in electronic form. Reef status with respect to closures in Virginia is not currently known, but the team continues to work with data providers to assemble and include these important data.

Much of the monitoring data were collected for purposes not related directly to restoration but for other reasons. The team is exploring using these data for assessing restoration while noting that the data are not always temporally or spatially associated with restoration events. These constraints may limit analysis of the data and will be documented as needed in forthcoming report(s).

Harvest regulations vary among reefs included in the database. The team recognizes that varying levels of commercial harvest may have occurred at given restoration reefs. For example, in Maryland, some annual monitoring occurs at reefs that have been open to *harvest* throughout the period analyzed. Furthermore, frequent monitoring (more than once per year for multiple years) has occurred on some *harvest reserve reefs* (reefs closed for a period of time following restoration activities and subsequently opened to harvest), and some monitoring has been undertaken at *sanctuary reefs* (reefs closed to harvest after being designated as a sanctuary — often before receiving restoration activities). Specific data pertaining to the harvest status of given reefs in Maryland have been added to the database.

There is no direct correspondence between harvest regulations and actual harvest at reefs included in the database. Little data exist to quantify the extent of illegal harvest on restoration reefs and the accompanying impact on restoration success. In addition, bars open to harvest may or may not experience fisheries removals in any given year.

Given these constraints, the team focused on three questions in this metadata analysis:

- What restoration efforts have been made — Where, when, and by whom?
- How was restoration done?
- What monitoring efforts have been made — Where, when, by whom, and how does this monitoring intersect with the restoration efforts?

Each is addressed as a separate section below.

What Restoration Efforts Have Been Made — Where, When, and by Whom?

The compiled data revealed a Baywide geographic distribution of 1037 reefs in tidal waters (Fig. 1) targeted for either restoration activity or monitoring between 1990-2007.

Since 1990, restoration activities took place at 378 reefs in MD and 216 reefs in VA (Table 1). Monitoring occurred at 453 and 437 reefs in MD and VA, respectively, during the same interval (see pages 20-22). The sum of monitored and restored reefs (1484, Table 1) is greater than the number with either restoration or monitoring counted separately (1037; data not shown), indicating that some reefs were both monitored and restored. In sum, 86% of all reefs have been monitored, 81% have had restoration activities, and 67% have seen both restoration and monitoring activities (see Table 7 as well).

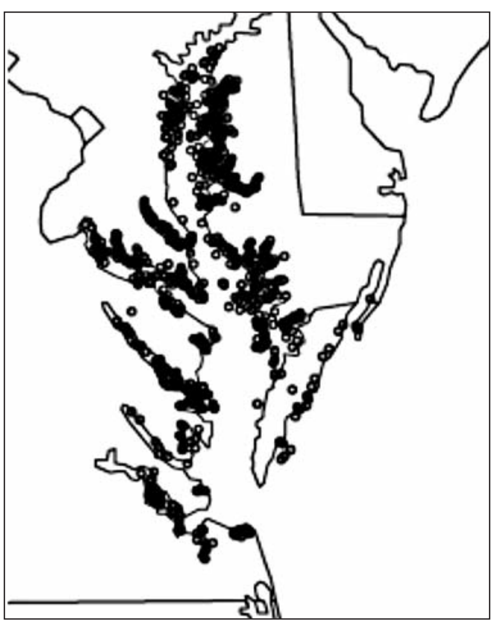


Figure 1. Spatial coverage of sites with monitoring and/or restoration 1990-2007.

Table 1. Maryland and Virginia reefs with restoration or monitoring activity for the period 1990-2007.

Activity*	State	# Reefs
Restoration	MD	378
Restoration	VA	216
Monitoring	MD	453
Monitoring	VA	437

*Restoration Activity (Substrate Addition, Wild Seed Transplant, Hatchery Seed Planting, Bar Cleaning, Bagless Dredging)
Monitoring (various types — see text)

The number of events undertaken in the two states (~12,000) for restoration and monitoring was much higher than the number of reefs restored and monitored. That is, a reef could be restored and then monitored several times, yielding more on-reef restoration and monitoring data points than a simple sum of the reefs that were manipulated. Table 2 provides a summary of the restoration and monitoring events across all reefs. Restoration approximated 18% of all events while monitoring (at restored and non-restored reefs) comprised 82% of the field time committed to oyster restoration and monitoring.

Multiple organizations have been involved in oyster restoration in tidal waters (Table 3). The vast majority of efforts, however, have been conducted by the two state agencies with mandated restoration responsibilities, Maryland's Department of Natural Resources (MDDNR) and Virginia's Marine Resources Commission (VMRC).

With respect to the number of reefs that have been restored or monitored in MD (Table 3), MDDNR has focused on substrate addition (174 reefs) and wild seed transplanting (154 reefs), with hatchery seed transplants conducted at only 6 reefs. The Oyster Recovery Partnership (ORP) and the Chesapeake Bay Foundation (CBF), working in MD's waters, have also been active in restoring oyster beds. ORP has focused on the use of hatchery seed transplants (68 reefs) and bar cleaning (38 reefs); CBF has nearly equal activity in hatchery seed transplants and substrate additions, with 73 and 65 reefs, respectively.

In Virginia, VMRC's primary restoration activity has focused on substrate addition (168 reefs). Wild seed transplant took place on 40 reefs, with bagless dredging and bar cleaning done at a limited number of locations as well (15 and 13 reefs, respectively). In VA, CBF has used hatchery seed transplants at 29 reefs, accounting for all but one other reef for this activity, which received seed through the efforts of the U.S. Army Corps of Engineers (USACE) (Table 3).

While some reefs were the focus of a single restoration and/or monitoring event, the very high number of restoration events reported in both states indicates that over the 18-year period restoration activities occurred multiple times at many of the reefs in the database (Table 4). For example, in MD, substrate addition took place on 35 monitored reefs at least two different times and one monitored reef received substrate addition 10 times over the 1990-2007 period.

Numerous organizations participated in restoration and monitoring through the study period (Table 4). In MD, MDDNR and CBF visited reefs frequently (i.e., 73 reefs received seed in CBF activities, over the course of 406 different events; Tables 3-4). MDDNR agency staff engaged in numerous restoration activities, conducting substrate additions and wild seed transplants 312 and 444 times, respectively, over the assessment period. CBF in MD focused on hatchery seed transplants and substrate additions, with 406 and 114 events, respectively. MDDNR was principally involved in monitoring at both restored reefs (3595 times) and non-restored reefs (1711 times). The University of Maryland (UMD) and the Morgan State University (MSU) laboratory on the Patuxent River (formerly the Academy of Natural Sciences Estuarine Research Center) assisted in MD's monitoring efforts as well, monitoring reefs 481 and 561 times, respectively (Table 4). Monitoring results for CBF reefs have not been provided for this analysis.

In Virginia, VMRC, Virginia Institute of Marine Science (VIMS) and VA CBF were most active (Table 4). VMRC conducted substrate additions 295 times over the 18 years, with lower frequencies for wild seed transplants (56), bagless dredging (17), and bar cleaning (13). VMRC monitored frequently as well, with nearly similar monitoring frequencies for restored (830) and non-restored (904) reefs. VIMS focused on monitoring, sam-

Table 2. Number of restoration and monitoring events in Maryland and Virginia, 1990-2007. An event could be a restoration activity or a sampling (monitoring) event.

Number of Events										
State	Bagless Dredging	Bar Cleaning	Hatchery Seed Transplant	Substrate Addition	Wild Seed Transplant	All Restoration Events	Monitoring without Restoration	Monitoring with Restoration	All Monitoring Events	Total Restoration & Monitoring Events
MD	0	46	595	469	457	1568	1883	4466	6349	7917
VA	17	13	133	304	59	526	2152	1351	3503	4029
Total	17	59	728	773	516	2094	4035	5817	9852	11946
% of Total Restoration Events	0.81	2.9	34.8	36.9	24.6	100				
% of Total Monitoring Events							41	59	100	
% of Total Restoration & Monitoring Events						17.53			82.47	

Table 3. Number of reefs restored or monitored by organization between1990-2007.

		Number of Reefs Restored or Monitored						
State	**Organization**	Bagless Dredging	Bar Cleaning	Hatchery Seed Transplant	Substrate Addition	Wild Seed Transplant	Monitoring without Restoration	Monitoring with Restoration
MD	CBF	0	0	73	65	2	0	0
	LCF	0	0	1	0	0	0	0
	MDDNR	0	0	6	174	154	158	257
	MSU	0	0	1	1	0	8	17
	ORP	0	38	68	6	0	0	0
	PRFC	0	0	1	15	5	0	0
	SRF	0	0	0	1	0	0	0
	UMD	0	0	0	0	0	15	72
	USACE	0	0	0	8	0	0	0
VA	CBF	0	0	29	0	3	0	0
	USACE	0	0	1	9	0	0	9
	VIMS	0	0	0	0	0	140	48
	VMRC	15	13	0	168	40	190	149

Organizations: Chesapeake Bay Foundation (CBF), Living Classrooms Foundation (LCF), Maryland Department of Natural Resources (MDDNR), Morgan State University Estuarine Research Center (MSU), Oyster Recovery Partnership (ORP), Potomac River Fisheries Commission (PRFC), Surf Riders Foundation (SRF), University of Maryland (UMD), U.S. Army Corps of Engineers (USACE), Virginia Institute of Marine Science (VIMS), Virginia Marine Resources Commission (VMRC).

Table 4. Number of restoration or monitoring events by organization in Maryland and Virginia, 1990-2007.

Number of Events								
State	**Organization**	Bagless Dredging	Bar Cleaning	Hatchery Seed Transplant	Substrate Addition	Wild Seed Transplant	Monitoring without Restoration	Monitoring with Restoration
MD	CBF	0	0	406	114	3	0	0
	LCF	0	0	1	0	0	0	0
	MDDNR	0	0	6	312	444	1711	3595
	MSU	0	0	3	1	0	114	447
	ORP	0	46	178	6	0	0	0
	PRFC	0	0	1	27	9	0	0
	SRF	0	0	0	1	0	0	0
	UMD	0	0	0	0	0	58	423
	USACE	0	0	0	8	0	0	0
VA	CBF	0	0	130	0	4	0	0
	USACE	0	0	3	9	0	0	9
	VIMS	0	0	0	0	0	1248	513
	VMRC	17	13	0	295	56	904	830

Organizations: Chesapeake Bay Foundation (CBF), Living Classrooms Foundation (LCF), Maryland Department of Natural Resources (MDDNR), Morgan State University Estuarine Research Center (MSU), Oyster Recovery Partnership (ORP), Potomac River Fisheries Commission (PRFC), Surf Riders Foundation (SRF), University of Maryland (UMD), U.S. Army Corps of Engineers (USACE), Virginia Institute of Marine Science (VIMS), Virginia Marine Resources Commission (VMRC).

pling non-restored reefs 1248 times and restored reefs 513 times. In VA, CBF distributed hatchery seed 130 times in VA with no monitoring reported.

The team attempted to estimate total acreage restored over the 18-year period. Unfortunately, acres for some activities are unknown (Table 5) and the limited data lead to an inaccurate estimation of total acres restored (Table 6). For example, hatchery seed was transplanted 595 times in MD, yet the data on area covered were available only for 35% of these events (Table 5). In VA, only 2% of hatchery seed transplant events have spatial information available (Table 5). Acres receiving wild seed are better represented, with 99% in MD and 68% in VA of the additions having associated areal data (Table 5).

In VA, reports of acreage restored using substrate addition are fairly complete: 82% of the restoration events (Table 5) can be related to known acreage. In contrast, MD acreage for the events employing substrate addition is known for only 19% (Table 5).

How Was Restoration Done?

Five direct restoration activities (bagless dredging, bar cleaning, hatchery or wild seed transplanting, and substrate addition) have been implemented by the two states in the past 18 years. Of these, substrate addition has been undertaken at more reefs than any other and primarily in the tributaries (Table 7). Baywide, 317 reefs in the tributaries have received substrate as part of native oyster restoration. Substrate has been added to 92 reefs in the

Table 5. Summary of state-specific restoration events with and without acreage recorded.

Number Events by State						
State		Bagless Dredging	Bar Cleaning	Hatchery Seed Transplant	Substrate Addition	Wild Seed Transplant
MD	Total Events	0	47	595	469	457
	Events With Area	0	46	207	91	451
	% With Area	0%	98%	35%	19%	99%
	Events Without Area	0	1	388	378	6
	% Without Area	0	2%	65%	81%	1%
VA	Total Events	17	13	133	304	59
	Events With Area	0	12	3	249	40
	% With Area	0%	92%	2%	82%	68%
	Events Without Area	17	1	130	55	19
	% Without Area	100%	8%	98%	18%	32%

Table 6. Acres restored over time by state for each restoration activity (derived from Table 5).

Number of Acres by Restoration Activity						
State	Bagless Dredging	Bar Cleaning	Hatchery Seed Transplant	Substrate Addition	Wild Seed Transplant	Total
MD	0	902	1,085	1,514	6,896	10,398
VA	0	157	3	1,749	214	2,124

This summary represents "effort" and not acres across the region. Each state may have planted the same site repeated times in the study period. Thus the numbers are not geographic but rather represent effort as measured by acres covered.

mainstem of both states (47 reefs) as well as the VA seaside and MD coastal bays (45 reefs). In total, substrate addition occurred at 49% of all restoration reefs.

Seed transplant has also been used extensively as a restoration method. In MD, 132 reefs received hatchery seed and 160 reefs received wild seed since 1990. In VA, 30 reefs received hatchery seed while 40 received wild seed. For the entire Bay, 43% of all reefs (362 of 845 reefs) have had transplants, with wild seed employed slightly more than hatchery-reared oyster seed (Table 7).

Other restoration techniques were employed with far less frequency at the reefs. In both states, bar cleaning was principally undertaken at tributary reefs. MD conducted bar cleaning at more reefs (38) than VA (13). Only one seaside bar in MD was cleaned (Table 7). Bagless dredging was modest and only occurred in VA at 15 reefs (11 in the tributaries and 4 in the mainstem).

Table 7. Geographic distribution of restoration activities in the Chesapeake Bay mainstem, in tributaries, and in the seaside bays.

Number of Reefs at which an Activity Occurred										
State	Area	Bagless Dredging	Bar Cleaning	Hatchery Seed Transplant	Substrate Addition	Wild Seed Transplant	Total Restoration Activities	Monitoring without Restoration	Monitoring with Restoration	Total Monitoring Activities
MD	None Given	0	0	2	7	0	9	2	0	2
	Mainstem	0	0	10	21	22	53	28	29	57
	Tributaries	0	37	107	200	136	480	137	245	382
	Seaside	0	1	13	12	2	28	3	9	12
	MD Total	0	38	132	240	160	570	170	283	453
VA	None Given	0	0	0	1	0	1	1	1	2
	Mainstem	4	0	5	26	6	41	37	33	70
	Tributaries	11	13	25	117	32	198	177	105	282
	Seaside	0	0	0	33	2	35	58	25	83
	VA Total	15	13	30	177	40	275	273	164	437
Total MD & VA		15	51	162	417	200	845	443	447	890
% Reefs		1.8	6.0	19.2	49.3	23.7	100			
% Reefs								49.8	50.2	100

The pattern of restoration has changed through time. In MD, hatchery seed transplants increased from 1997 on, reaching the highest level of bar seeding in 2006, when it exceeded reef placement for wild seed by about ten-fold (Fig. 2). The number of reefs receiving wild seed transplants was highest in 1992 and 1998, and declined thereafter as hatchery seed use began to dominate. Substrate addition was employed at more than 40 reefs in 1999, followed by lower and relatively constant usage at about 30 reefs through 2005. Thereafter, substrate addition declined markedly to around 5 reefs in 2007. Bar cleaning was initiated in 2003 in MD, with a modest increase to about 13 reefs in 2007.

The database contains information on restoration activities in VA (Fig. 3) for a shorter time period than in MD. In the database, wild seed transplant began in 1996 at a modest number of reefs in VA, with the highest number (23) receiving wild seed in 2000. As in MD, this technique has been surpassed by the use of hatchery seed with 15 reefs restored in this manner in 2001-2002. This declined to <10 after 2005. Substrate addition was initiated in 1999, with 38-47 reefs receiving substrate for 4 years. No substrate addition was reported in 2003; however, 40 reefs were supplemented with substrate the following year, declining to 24 reefs by 2006. Bagless dredging was only conducted in 1999 at 15 reefs. Bar cleaning was conducted at a limited number of reefs (5-8) in 2000-2001. A variety of additional activities (that include seed movement and reef construction) have also been conducted in VA over many years, chiefly in support of the oyster fishery. The team did not consider this set of efforts, however, as sufficient data were not available for analysis at this time (see page 26).

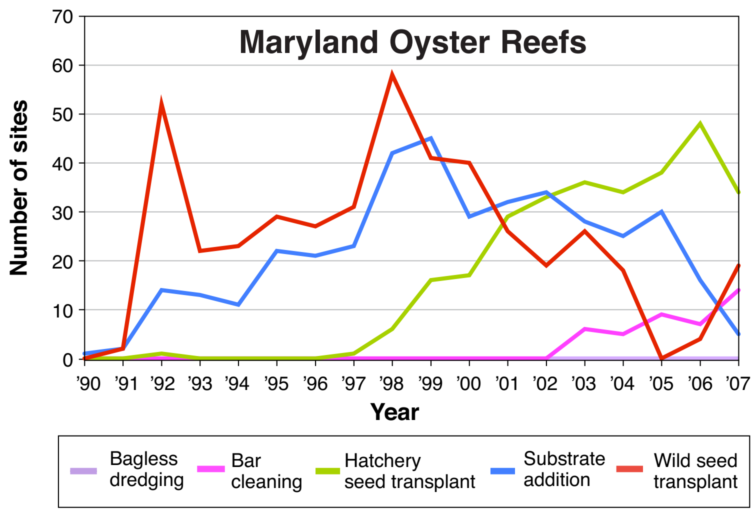


Figure 2. Number of sites that had a restoration activity in MD 1990-2007.

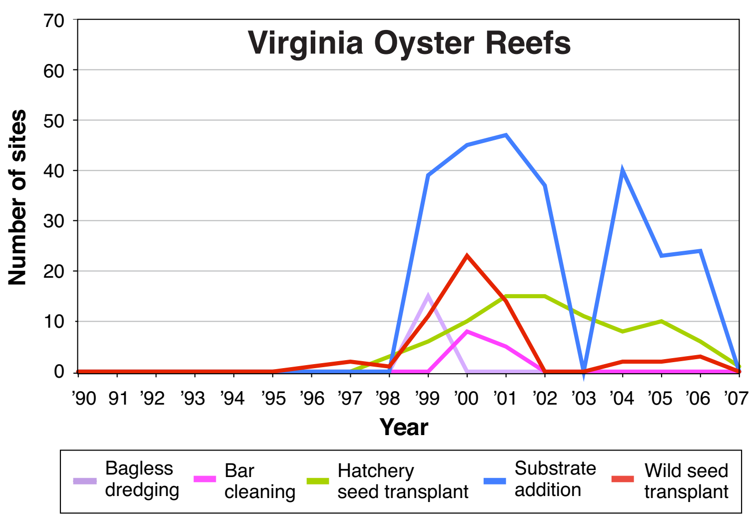


Figure 3. Number of sites that had a restoration activity in VA, 1990-2007.

An interesting outcome of the data compilation on restoration and subsequent monitoring is that few reefs have single restoration activities and subsequent monitoring that would permit assessment of the effectiveness of the restoration implemented. That is, most restored reefs have multiple restoration activities with aperiodic monitoring (Table 8), thereby preventing estimation of the effectiveness of an individual restoration method. Table 9 provides a summary of reefs with a single restoration activity and monitoring. As an example, in Maryland, 78 (25 + 53) reefs that received substrate addition over 18 years had monitoring after the substrate was added. 83 reefs (24+59) were

Table 8. Summary of reefs with different restoration activities by state, 1990-2007.

	Restoration Activities	Number of Reefs with Restoration Activities that WERE Monitored	Number of Reefs with Restoration Activities that WERE NOT Monitored	Number of Reefs without Restoration Activities that WERE Monitored
MD	No Restoration Activity	–	–	170
	One Restoration Activity Type	177	50	–
	Two Different Restoration Activity Types	74	44	–
	Three Different Restoration Activity Types	24	1	–
	Four Different Restoration Activity Types	8	–	–
VA	No Restoration Activity	–	–	273
	One Restoration Activity Type	118	43	–
	Two Different Restoration Activity Types	42	9	–
	Three Different Restoration Activity Types	4	–	–
	Four Different Restoration Activity Types	–	–	–

monitored following wild seed transplant in MD as well. Restoration at other reefs was less frequently monitored. In Virginia, frequent monitoring occurred only following substrate addition, 78 (58+20) times (Table 9). Monitoring following hatchery seed and wild seed transplants only occurred 9 and 8 times, respectively.

Monitoring a reef through time after a restoration activity might also provide the community an oppor- tunity to explore several aspects of oyster "success." For example, growth rates might be computed, age at disease infection, years to harvest size, etc. might be determined. Table 10 provides a summary of MD and VA monitoring through time following single restoration activities at a reef. MD restoration may have a large enough sample size to permit some of these estimates, at least for substrate addition and wild seed transplants.

What Monitoring Efforts Have Been Made — Where, When, and by Whom?

The extent of monitoring of oyster bars and restoration reefs has been similar in both states over the study interval. As noted above and in Table 1, monitoring occurred at 453 reefs in MD and 437 in VA. Tributaries were the focus of the majority of efforts in both states with 382 reefs in MD and 282 reefs in VA (Table 7, sum of last 2 columns). In MD, tributary reef monitoring was 84% of all monitoring areas, while in VA, tributaries accounted for 65% of all reefs monitored (tributaries, seaside bays, and mainstem reefs).

Fewer organizations conducted monitoring in the two states than those reporting restoration activities. MD DNR has assumed most monitoring responsibility in MD (examining 415), along with UMD (87 reefs) (Table 3). Only MSU has undertaken any other monitoring, sampling 25 reefs in the Patuxent River and off Calvert Cliffs. MDDNR was approximately fourfold more active than the other two organizations. Of those MD reefs with some restoration activity undertaken, 346 reefs have been monitored, accounting for 67% of monitoring efforts of all organizations in the state; 181 reefs that had no restoration activity were also monitored at some time. A substantial portion of monitoring of non-restored reefs (158) was also carried out by MDDNR.

Table 9. Number of reefs with one restoration activity and associated monitoring, 1990–2007.

Number of Reefs						
State	**Type of Activity**	**Activity With No Monitoring**	**Monitored Before Activity**	**Monitored After Activity**	**Monitored Before *and* After Activity**	**Total Monitoring**
MD	Bagless Dredging	0	0	0	0	0
	Bar Cleaning	3	1	0	1	2
	Hatchery Seed Transplant	11	2	3	6	11
	Substrate Addition	27	3	25	53	81
	Wild Seed Transplant	9	0	24	59	83
VA	Bagless Dredging	0	4	0	5	9
	Bar Cleaning	1	0	0	0	0
	Hatchery Seed Transplant	1	0	2	7	9
	Substrate Addition	38	12	58	20	90
	Wild Seed Transplant	3	2	2	6	10
Total		**93**	**24**	**114**	**157**	**295**

Table 10. Reefs with annual monitoring the year of the activity (*Year 0*) and subsequent years thereafter for the period 1990–2007.

Number of Reefs						
State	**Activity**	**Monitored Year 0**	**Monitored Year 0 and +1 Year After**	**Monitored Year 0,+1 and + 2 Years After**	**Monitored Year 0, + 1, + 2, and +3 Years After**	**Monitored Year 0, +1, + 2, +3, and +4 Years After**
MD	Bagless Dredging	0	0	0	0	0
	Bar Cleaning	1	0	0	0	0
	Hatchery Seed Transplant	1	2	2	0	4
	Substrate Addition	3	10	6	5	43
	Wild Seed Transplant	6	4	7	5	55
VA	Bagless Dredging	0	0	0	0	3
	Bar Cleaning	0	0	0	0	0
	Hatchery Seed Transplant	3	2	2	0	2
	Substrate Addition	8	9	7	10	11
	Wild Seed Transplant	1	0	0	1	5

On a reef-specific basis, in VA, VMRC (339 reefs) is the primary monitoring organization (Table 3), followed by VIMS (188 reefs) and far less frequently, the USACE (9 reefs). On those reefs with restoration activity, VMRC has monitored 149 reefs or 72% of all restored and monitored reefs in the state; VIMS has monitored 48 reefs or 23% of all restored and monitored reefs. Much more monitoring (330 reefs) has been undertaken at reefs without any associated restoration conducted (Table 3).

Table 8 summarizes reefs with multiple restoration activities as well as monitoring. Note that 170 reefs in MD and 273 in VA reefs have been monitored without any restoration practices identified for them. 177 and 118 reefs in MD and VA, respectively, have received only one restoration activity and some monitoring.

Overall, multiple organizations have participated in field visits for restoration and monitoring (Table 4), often with several field visits at a reef in a year. Monitoring of MD reefs/bars that had not been restored occurred 1883 times, versus 4465 monitoring events at restored reefs. This emphasis on monitoring of restored reefs was not seen in VA: non-restored reefs were monitored 2152 versus 1343 times for restored reefs/bars in VA waters.

The Impact of Harvest and Restoration Design on the Utility of Data

Analyzing the success of an individual restoration project (i.e., restoration at a particular reef) requires focused data collection, using techniques and sufficient quantitative sampling to compare outcomes to goals for that reef, and for comparison with unrestored reference reefs. More general analysis needed to improve the effectiveness of restoration and to meet larger-scale goals, however, requires that both the design of the array of restoration projects and the associated data collection be coordinated and planned with sufficient attention to replication and siting to draw meaningful conclusions. For example, replicating alternative techniques (e.g., bar sizes, substrates, seed densities) plus reference reefs within a single habitat (salinity zone, tributary vs. mainstem Bay) can guide future restoration efforts within that habitat type by providing information on the relative effectiveness of the tested techniques. Alternatively, replication across habitats can provide information on how the effectiveness of tested techniques varies with environmental conditions.

Despite the large number of restoration activities described above, the lack of replication of specific combinations of restoration activities within or among habitats will severely hamper our ability to evaluate the effectiveness of restoration to date. Tables 11-13 summarize activities at the 57 restoration reefs in Maryland that were closed to harvest for at least one year and for which data on live oysters was collected sometime during the 1990-2007 period included in the database. Replication of specific techniques was rare.

Ideally, reefs used as replicates should have received the same types and numbers of restoration activities. However, as shown in Table 11, the 57 reefs received a total of 35 different combinations of restoration activities. Only two restoration types had at least 4 replicates — reefs receiving one shell plant (Combination #31 in Table 11) and reefs receiving no restoration activities at all (Combination #35 in Table 11).

If we relax the conditions for inclusion of reefs in analyses and pool reefs receiving one or two repetitions of the same activities, four restoration types had at least four replicates: (1) shell addition + hatchery seed addition; (2) shell addition only; (3) hatchery seed addition only; and (4) reefs receiving no restoration activities (Table 12). Although these "treatments" would seem to form a basis for important analyses (e.g., Does addition of hatchery

Table 11. Combinations of restoration activities on Maryland reefs closed to harvest for at least one year (n = 57), 1990-2007*.

	Number of Events					
Combinations of Restoration Techniques	Bar cleaning	Bagless Dredging	Shell Addition	Hatchery Seed Addition	Wild Seed Addition	Number of Reefs (*possible replicates for analyses*)
1	1	0	0	4	0	1
2	1	0	3	0	0	1
3	1	0	0	1	5	1
4	1	0	0	2	2	1
5	1	0	0	2	8	1
6	1	0	0	5	1	1
7	1	0	1	1	0	1
8	1	0	2	3	0	1
9	1	0	3	2	0	1
10	1	0	4	5	0	1
11	1	0	1	1	8	2
12	1	0	2	5	1	1
13	2	0	1	1	9	1
14	2	0	2	3	6	1
15	0	0	1	1	0	3
16	0	0	1	2	0	3
17	0	0	1	4	0	1
18	0	0	1	8	0	1
19	0	0	2	1	0	1
20	0	0	2	2	0	1
21	0	0	2	4	0	1
22	0	0	1	0	1	1
23	0	0	5	0	1	1
24	0	0	1	1	1	1
25	0	0	2	5	1	1
26	0	0	3	1	3	1
27	0	0	4	4	2	1
28	0	0	0	0	2	1
29	0	0	0	0	3	1
30	0	0	0	0	7	1
31	0	0	1	0	0	6
32	0	0	2	0	0	1
33	0	0	0	1	0	3
34	0	0	0	2	0	1
35	0	0	0	0	0	11

*Planting and monitoring of multiple sites within restored Maryland natural oyster bars may provide significantly more replicates. Plot-specific data sets derived from multiple plantings made within individual oyster bars, but on separate plots and at differing times, may increase the number of replicates to as high as 40.

Table 12. Maryland reefs with repetitions of specific restoration activities, that were closed for some period of time, monitored at least once, and for which data on live oysters were collected, 1990–2007.

	Restoration Activity					
Number of Reefs *(possible replicates for analyses)*	Bar Cleaning	Bagless Dredging	Shell Addition	Hatchery Seed Addition	Wild Seed Addition	No Restoration Activity
1	•			•	•	
1	•		•	•		
8			•	•		
1			•		•	
1			•	•	•	
1					•	
0	•					
0		•				
7			•			
4				•		
1					•	
11						•

Table 13. Maryland reefs receiving shell and hatchery seed that were monitored and/or closed to harvest, 1990–2007.

Site ID	**Shell Addition**	**Hatchery Seed Addition**	**Years Between Shell & Seed Additions**	**Years When A Reef Was Monitored and/or Closed To Harvest***					
				-1	*Year of First Seed Addition*	+1	+2	+3	+4
MGERP0	1998	1999	1				•,c	c	
MGRUM0	1999	2006	7	c	c	•, c			
UPXEL0	2001	2001	0		•, c	c	c	c	c
UBWGL0	2002	2002 2003	0 1		c	c	•, c	c	c
UCHEW0	2005	2005 2006	0 1	•	•	•	•, c		
UPXTR0	2002	2002 2003	0 1	c	c	•,c	•,c	•,c	•,c
UCHBP0	1998 2003	2003	5 --	•, c	•, c	•, c	•, c	•, c	c
UPXKM0	1999 2003	2004 2007	5 4	c	•, c	•, c	•, c	•, c	

• = monitoring conducted, c=bar closed to fishing

*Monitoring based on years before or after first addition of hatchery seed

seed provide any benefit above and beyond addition of shell only?), variation among potential replicates renders some data unsuitable for such comparisons. For example, of the 8 reefs with one or two shell-plus-hatchery-seed additions: (1) the number of years between shell-and-hatchery-seed additions ranged from 0 to 7 years; (2) 2 reefs were not actually closed to fishing on the year after shell addition or in the subsequent year; and, (3) only 3 reefs were both monitored and closed for at least 2 years following seed addition (Table 13). Furthermore, reefs receiving similar restoration activities often varied in habitat, size, and specifics of the restoration techniques used.

A similar analysis of data from Virginia is pending. The opening dates and durations of opening of the Virginia public oyster grounds for harvesting are set annually by the VMRC at their September monthly meeting. Occasionally the dates and durations of opening have been modified by emergency action at subsequent meetings. These actions are recorded in the meeting minutes. Typically whole estuaries or sections of estuaries are defined as open or closed areas, with delineating landmarks such as buoys being identified for enforcement purposes. Less frequently are individual reefs identified in regulations guiding opening and closing of harvests. Assembly of such historical data for this project's period of interest requires examination of the minutes of the monthly VMRC meetings and subsequent translation of the boundary data to reef designations in the GIS databases.

Key Observations and Cautionary Comments

An important task of the oyster restoration evaluation team was to develop a unified database of restoration efforts from 1990 to 2007. The intent was to provide a synthesis of the lessons learned with regard to the specific scientific and management goals that have driven these restoration efforts and in particular, the successes in reaching such goals. The team requested data from the broad restoration community in Maryland and Virginia. Coincident with this wide call for information, they worked together with staff at Versar Inc. to develop architecture for the database that would be "accommodating" of different inputs from the restoration community, and allow for analysis. The lessons learned can be used to develop a model for future data archiving efforts. This task proved to be challenging given the dispersed nature of the data and in some cases, widely varying formats used by data providers. Here we provide some key observations, coupled with cautionary comments about data limitations. With these in mind, the team does feel that the database has great value and will provide a number of avenues for more detailed analyses. The team also feels that lessons learned from efforts that produced data of sufficient detail in one state should be broadly applicable Baywide and should inform future efforts as new restoration and monitoring protocols are implemented.

The majority of restoration activities conducted over the study period have been conducted by the two State agencies responsible for estuarine resource management (MDDNR: 6,068 of 7,914 events in Maryland; VMRC: 2,115 of 4,022 events in Virginia) but specific restoration goals were not tied to many entries in the database. In some cases, it is possible to infer the goals, but in others the goals are less certain, and evaluating success towards meeting inferred goals will be difficult.

Most restoration activities in Maryland were associated with "open" oyster bars (reefs), indicating that restoration efforts were targeted to support the fishery. For example, in Maryland, 388 reefs were open to the fishery between 1990 and 2007 and were also monitored at some point during the timeframe; of those, 235 had at least one restoration activity performed. Additional fishery-related restoration activities in Maryland were associated with oyster bars that were closed for one to several years before being re-opened. For example, there were 46 bars with at least one restoration activity and which were closed at some point during the time period of interest. Data for open/closed areas within Virginia were not available in an electronic or other format that was compatible with the database we compiled. Hence, the intent of restoration efforts for most reefs in Virginia cannot be drawn at this time.

In Maryland, most of the data on oysters came from qualitative sampling (untimed dredge samples: 6,463 events). Quantitative, spatially explicit sampling (timed dredge, patent tong or quadrat samples) comprised the remaining 1,013 events. The qualitative data may serve the purposes for which they were intended (e.g., evaluating recruitment success or informing fisheries management decisions), but unfortunately cannot be used to assess the success or failure of many restoration activities with respect to population dynamics and quantitative abundance estimates. In addition, harvest data are not available for specific reefs so we cannot tell if restoration efforts resulted in improved harvests. We do expect that the concomitant disease data will be useful for addressing potential changes in disease status on restored bars.

In Virginia, a greater proportion of monitoring data were collected by spatially explicit sampling (997 by quadrat or patent tong samples vs. 149 by untimed dredge) and thus provide more quantitative estimates of abundance. However, several issues will need to be resolved in order to make good use of the quantitative Virginia sampling. Different sampling protocols have yielded quite different density estimates, and, as noted above, restoration goals and information on whether reefs were closed to fishing during and subsequent to restoration efforts are missing. In addition, data on numbers of replicate samples taken for much of the VA monitoring data have not been provided. The absence of this information may preclude use of data in subsequent analyses.

The limitations cited above will hinder using these data to evaluate the success or failure of specific restoration activities on specific oyster bars or the efficacy of particular restoration techniques in general. Our further analysis of the data will reveal whether or not the data are adequate to do so.

Other recent collaborative restoration efforts in Virginia (USACE, NOAA Chesapeake Bay Office, VMRC and VIMS) and in Maryland (ORP partners) have been more explicit in their goals and more thoroughly monitored than were most of the state efforts. Designation of specific restoration reefs as sanctuaries (i.e., Palace Bar Reef in the Piankatank River, VA or Shoal Creek and States Bank in upper Choptank River, MD) imply ecological goals, but are not explicit in that they do not distinguish between particular ecosystem services that are being targeted (e.g., spawner sanctuary for repopulating the region vs. provision of habitat on the sanctuary reef itself). Monitoring activities associated with these reefs generally included quantitative estimates of recruitment and population abundance, oyster growth and survival, and disease prevalence and intensity. The data derived from these more quantitative activities may allow us to determine success or failure of individual projects. However, activities not recorded in the dataset (e.g., poaching on sanctuary reefs) could hinder our ability to interpret the results of statistical analyses of the available data. Further, the limited number of replicates in relation to sampling techniques, salinity zones, and habitats will limit our ability to draw general lessons from multi-project comparisons.

Additional problems with the data set include mismatches in the timing of restoration and monitoring activities relative to each other (e.g., whether monitoring occurred both before and after a restoration event); the number of different restoration activities done at individual reefs over the years; and, the timing and sequence of closures of some bars but not others. The order and timing of different restoration activities confounds any effort to discern the effects of individual activities. The repetition of the same activity at different times also makes it difficult to discern the effect of a single restoration activity. An important objective of our evaluation effort is to assess the successes and failures of specific restoration activities towards meeting their restoration goals. Here are some examples of limitations imposed by the data:

Among the most widespread restoration activity throughout the period has been the addition of substrate for enhancing oyster recruitment (418 reefs out of 598 reefs that had at least one restoration activity during the study period). This activity has been widely reported to result in short-term enhancement of oyster recruitment. The Baywide database we have assembled may permit us to evaluate this issue on a broader scale. However, our lack of data on other possible effects on recruitment such as sediment and fouling organisms on shells may limit our ability to ascribe causes to the patterns we uncover.

The addition of oysters to sanctuary reefs for the purpose of supplementing brood stocks and increasing spawning success has been conducted by both governmental agencies and non-governmental organizations with increasing frequency over the period in our study (150 reefs had hatchery seed transplanted at some point over the study period and 100 reefs had wild seed transplanted at some point). Some recent reports have supported the utility of supplementing brood stock. Unfortunately, most of these reefs had several restoration activities at different times with different monitoring events and different closure dates. As a result, the combined dataset may not provide the foundation for satisfactory analyses.

As mentioned above, the inferred goals of some of the activities in the database include the restoration of ecological functions provided by oyster reefs. Yet, few studies in the database have collected data directly related to those functions other than those (e.g. filtration rates) that can be directly calculated from size and abundance data. Recent studies on restored oyster reefs in low salinity areas in Maryland (Chester, Choptank, Severn and Patuxent rivers) and in mesohaline areas in Virginia (lower Rappahannock River) have related some additional aspects of ecological functions to oyster abundance data. Our ability to use the database to extend the inferences from these studies to other restoration reefs is uncertain at this point, but we expect that comparisons between reefs might enhance our ability to infer ecological success where they have not been specifically measured. Those inferences, of course, depend on the similarity of data collection methods and timing of the sampling between reefs.

One final caution is that the natural high variability in oyster population dynamics in the Chesapeake Bay (for example, the extremely large year-to-year variability in spat settlement) may require longer term studies than have been performed to date when assessing whether a restoration activity has modified the local population dynamics in a positive way or whether sustained restoration efforts would be required to increase the oyster population in the Bay.

In a positive note, in Maryland, a small subset of data within the database can be used to assess growth rates, time to market size, disease acquisition rates and other dynamic parameters in hatchery seed that require multiple or ongoing monitoring events. These data are typically from the sanctuary and managed reserve reefs monitored by UMD or MSU and have already been analyzed to some extent. In another area, the data are amenable to testing whether restoration has had an influence on disease rates since the data from several sources can be combined.

In general, the data incorporated in the database represent a wide array of activities, goals and objectives. Much of the data are qualitative and do not provide the opportunity to assess population level changes over time. Future restoration efforts should collect quantitative data on both restored and unrestored reefs to facilitate definitive analyses of the results of restoration activities. In addition, it is critical that good experimental design be used to provide a rigorous and statistically powerful method of testing whether different restoration strategies are successful. Data collection should include repeated measures of oyster sizes, abundances (which requires some form of random sampling with effort data), and disease status as well as other goal-specific data. The most important conclusion of the next phase of this exercise may be that monitoring protocols of most restoration activities to date have been inadequate, and that the wide range of types, habitats and combinations of restoration activities implemented to date make analyses difficult even if additional monitoring had been conducted. Both restoration design and monitoring must be thoughtfully conceived, formally established, coordinated across reefs and carefully executed in order to assess the success or failure of both individual restoration projects undertaken in the future and of the general efficacy of various restoration protocols implemented singly and in combination.

Recommendations for Future Restoration Efforts

The Oyster Restoration Evaluation Team has assembled, collated, critically examined and analyzed (within the acknowledged limitation of the source data) the available historical data sets from several sources for oyster restoration in Chesapeake Bay. The team's activities have highlighted the strengths and weaknesses of many restoration efforts and the utility of the data collected to monitor them. While this examination has been informative, its greatest value is to define future oyster restoration activities — specifically, to construct guidelines that will help maximize return on the investment of time, effort and funding for oyster restoration which will be made in the coming years.

Defining Restoration Goals

There is a need to separate ecological oyster reef restoration and fisheries maintenance goals. Those goals may be, and in fact probably are, incompatible. Well-defined goals will allow better definition of actions, delineation of methods to track progress, identification of realistic time frames, and the need to adapt both actions and data collection in response to progress (or lack thereof) towards the stated goals. All these elements are essential for employing a true adaptive management approach. Each ecological restoration or fishery support program must therefore employ a discrete set of activities specific to its goals. At a minimum, each must also include monitoring and, in appropriate cases, a mix of manipulation (sometimes experimental) and monitoring. In every case, however, the efforts must be focused on the quantification of progress towards a defined endpoint.

Defining and Separating the Goals of Ecological Restoration and Fishery Maintenance

Ecological Restoration is the re-establishment of oyster populations exclusively for the provision of ecological services. Ecological services include among other things: (1) benthic-pelagic coupling of energy/nutrient flow, (2) the physical creation of complex, three-dimensional habitat structure and (3) resultant enhanced species richness and biomass available to higher-level predators. Ecological restoration requires the realization that natural oyster populations exist not just on isolated bars or reefs but as spatially distributed populations (metapopulations) composed of multiple year classes interconnected via larval dispersal.

Fishery maintenance, in contrast, is the provision of a sustainable economic resource. It does not require ecological restoration although it may contribute to it. A wild fishery is primarily dependent on wild populations, wherein natural recruitment is critical. Recruitment is influenced by adult population sizes, which are influenced, in turn, by natural and fishing mortality. In addition, recruitment is affected by factors such as the abundance and suitability of habitat, climate influence on larval transport, growth and survival, and environmental and food-web regulation of adult fecundity. It is possible to sustain an economic resource at less than maximum sustainable yield and with hatchery supplementation to compensate for low natural recruitment. In all cases, careful management based on an understanding of recruitment and mortality rates is important. Management of exploited natural populations requires accurate estimations of both recruitment and mortality rates, including both natural and fisheries-related mortality. Investment and reliance on hatchery supplementation of natural recruitment and on practices such as substrate addition, bar cleaning and transplantation of juvenile oysters from recruitment to grow-out areas also requires careful calculation of economic costs and benefits.

The Gravity of the Challenge — Essential Measures Needed

The challenges to both ecological restoration and fishery maintenance are many. Evaluating the effectiveness of any single restoration or management activity is difficult, given that the stressors are many and overlapping and that the goals and objectives of those activities may differ. It is unlikely that any single action can address the entire spectrum of challenges that oysters face. We need integrated, full-scale approaches that address the challenges that impact oysters — efforts cannot be piecemeal. Our review of the historical data indicates that this approach has not been taken in the past. Future efforts should clearly and precisely (1) identify the full suite of stresses on oyster populations, (2) develop integrated approaches towards mitigating those stresses, (3) adapt management strategies to compensate for losses in production or biomass due to stressors, and (4) identify data requirements for tracking progress.

What are the minimal data required to evaluate progress on both a spatial and temporal basis towards either one of these long-term goals? A series of generic and commonly accepted measures exist that should, at a minimum, be employed as base-level quantitative measures in all monitoring efforts. These will be different for ecological and fishery goals.

Data Required to Assess Ecological Restoration

Achieving successful ecological restoration of oyster reefs will require that restoration be carried out in an experimental framework, at least for the near future, because the techniques, approaches and strategies to achieve healthy reef ecosystem endpoints are not well understood. Evaluating restoration success, with the ultimate goal of improving restoration effectiveness, therefore requires the establishment of specific goals, testable hypotheses formulated to evaluate means of achieving those goals, and specific techniques established to measure progress toward, or achievement of, those goals. Most important is to design restoration projects and to designate controls so that quantitative analyses of changes in identified endpoints are possible. For example, ecosystem restoration in terrestrial and aquatic systems has been tested using before-after-treatment-impact (BACI) designs to quantify changes in the ecosystem as a result of anthropogenic manipulations and to confidently ascribe ecosystem-level changes to those manipulations. This approach could also be used with oyster reef restoration. Other experimental designs are also possible. The design chosen should be appropriate for the scale of the anticipated response of the system to manipulations — for example, sophisticated experimental designs that explicitly include spatial components.

Ecological restoration goals will likely be multi-faceted and will vary among locations, but must have measureable endpoints such as oyster densities and spatial distribution. Predicting the sustainability of short-term benefits requires collection of data needed to predict changes in oyster densities. These data include size distribution, mortality rates, and recruitment. Therefore, at a minimum, monitoring of ecological restoration efforts should include annual estimates throughout the area intended for restoration and at control reference sites of oyster density, size distribution, mortality, and disease. Important environmental variables that can aid in interpretation of the data collected include the temperature, salinity, and dissolved oxygen profiles measured at the appropriate temporal and spatial scales.

To estimate ecologic or ecosystem-level success, other measures may be necessary, depending on the initial goals of the restoration project. As the predominant hard-substrate habitat in Chesapeake Bay, oyster reefs provide important habitat for resident benthic invertebrates, including other suspension-feeding organisms, and higher trophic level species, including fish and crabs. The enhancement of ecosystem services provided by reefs is a primary goal of ecological restoration. Improving our understanding of how reef characteristics (e.g., reef size, elevation, oyster density and oyster size) affect their use by resident and transient organisms will better enable us to design restoration efforts and evaluate their progress. For instance, does a single large reef or do several small reefs support more of the desired fauna? Does the placement of reefs along migration corridors enhance dispersal of other ecologically and economically important species? Do reefs comprised primarily of two or three year classes of oysters (i.e., few that would be market-sized) support abundant and diverse fauna? Additionally, great public interest lies in the potential effects of oysters on water quality. Those restoration projects that may be undertaken to test the effects of both the oysters and associated reef organisms on water quality will obviously need to measure relevant parameters including but not limited to chlorophyll levels, dissolved oxygen, nutrient concentrations and turbidity.

To date, most oyster restoration projects have been undertaken on a reef-by-reef basis with little consideration as to how those reefs were interspersed within the estuarine landscape and how their spatial arrangement affected their viability, their potential to contribute to and be sustained by recruitment, and the ecosystem services that they might provide. Greater use of hydrodynamically driven dispersal models to help define source and sink regions within larger basins may improve our ability to determine the most effective restoration strategies. These models should be used with a level of caution, however, appropriate to the assumptions that have been made in constructing them. Similarly, understanding how oyster reef habitats may provide corridors for the movement of some species throughout the Bay would enhance some of the ecosystem services to be gained from their restoration.

It is critical that the agencies and programs involved in oyster restoration agree to the quality of data being collected as restoration projects are undertaken. Different techniques may provide similar data but should be carefully reviewed to ensure that data are comparable. For instance, in Delaware Bay, dredges are used to collect oysters for surveys. The dredge tows have been carefully calibrated by diver surveys and are conducted under strict constraints of time and area swept (Powell, et al. 2002) providing spatially explicit oyster abundance data (i.e. oysters/m2). As currently used in Chesapeake Bay, similar gear yields only qualitative data. Standardization of Chesapeake Bay oyster sampling protocols should be mandated.

In summary, the success of ecological restoration can only be determined and improved by undertaking a well-planned series of restoration experiments. These should collect data that are comparable across all activities. Experiments should be designed to provide conclusions that can be used in an adaptive management context to improve the next set of experiments/restoration approaches.

Data Required to Assess Fishery Maintenance

Fishery restoration can be addressed using accepted standards for finfish, wherein basic parameters of recruitment, fishing mortality and natural mortality are estimated and used to guide basic principals of stock management. In support of this effort, a fishery independent stock assessment that minimally predicts absolute density and numbers, preferably on an age basis, is essential. Reference points must be identified and used as management tools. Inclusion of temporal and spatial variation in recruitment and disease mortality will be important.

Data Collection and Recording

The team's effort to analyze data from multiple sources revealed a number of critical areas that need to be improved to facilitate analysis of the efficacy of oyster restoration efforts. Specific requirements for data collection and recording are essential and the team recommends that the following guidelines be implemented:

- There is a need for better spatial information on the location and extent of restoration treatments and for monitoring events. At a minimum, latitude and longitude of restoration and monitoring activities should be recorded, although detailed geo-referencing is preferred. A true spatial database should be developed so that areas can be easily mapped and activities can be tracked in time and space.

- All activities should be located by bar, sub-bar, stations within sub-bars, and samples within station. This is necessary with or without the attachment of a fully functional spatial database. Replicate samples should be easily identifiable.

- Some of the difficulties with the analysis of the current database reflect the various data collection methods used over the years. For example, disease data are not collected on the same scale by each organization. Standardizing methods of data collection/disease diagnosis would render the database more useful, and the database itself should be helpful in determining possible standard methods.

- Environmental data need to be collected and recorded on biological meaningful scales, both temporally and spatially, for them to be useful in examining effects on oysters and/or restoration efforts. Data that are averaged across large time scales and large areas, for example, are of insufficient detail and therefore unlikely to provide any insights into how environmental variables affect oyster survival and recovery in the Bay.

- All metadata needed to interpret monitoring data, or to identify the location and methods used for restoration, should be easily accessible in electronic form, and should be sufficiently detailed to facilitate use and interpretation of monitoring results.

Enhancing Coordination of Efforts

Oyster restoration and monitoring has been a focused interest of at least 12 organizations during the 18-year period covered in the present study. In some cases, increasing ecosystem services (i.e., enhanced oyster densities and recruitment potential) was probably one priority, while in others, providing fishery benefit following 2-3 years of growth was presumably the goal. Given these goals and a variety of extant mechanisms (see Oyster Fishery Management Plans 1994, 2004), it appears that activities in both MD and VA were carried out with far less coordination between organizations than desired and with less than adequate communication regarding activities undertaken at specific locations. This is exemplified by the multiple activities at individual bars by different organizations. Such overlap is an important factor preventing a thorough evaluation of the efficacy of a restoration activity. Our inability to determine cause and effect relationships and restoration-specific responses is a direct outcome of this overlap (i.e., multiple activities per reef). Coordination is essential to ensure quantitative assessments of restoration practices and a determination of those most promising for oyster population growth and recruitment necessary to achieve ecosystem or fisheries benefits.

Principles to Enhance Coordination

Strong Baywide interest in a viable, sustained native oyster population that can support an industry, improve water quality, and increase production of reef-associated fish and other macrofauna is likely to drive the commitment of public and private funds for oyster restoration for some time. A standard set of methods for all restoration activities should be mandated as a prerequisite for funding from any party, with prescribed data collection methods, scheduling and location identification, coordination, and data-sharing requirements. The team is in consensus that this must be a priority for organizations examining sites that have already been manipulated, and for those planned for new restoration projects.

The team recommends adoption of a coordination protocol that can be jointly implemented by both Maryland and Virginia:

- A coordination committee composed of scientists and managers from MD and VA should be established that oversees and coordinates all oyster restoration efforts. The composition of the committee should reflect the breadth of expertise required to provide strong guidance and oversight. The committee should operate using transparent mutually agreed upon rules for decision-making.
- All restoration efforts should be permitted and linked to explicit goals.
- Activities should meet minimum standards with respect to design and integrated monitoring.
- Sufficient funding should be allocated to ensure that effective monitoring of activities can be accomplished.
- Sufficient data for critical parameters should be obtained at relevant sites and in an agreed-upon, standard manner to ensure data quality.
- Data should be collected and reported in a timely manner to a collaborative database administrated by the coordination committee or a technical subcommittee. Data contained within this database should be available to all stakeholders. However, publication rights should be protected for those actively engaged in data collection, or by other parties specified by funding agencies.

Using these principles as a starting point, the coordination committee or a technical subcommittee should establish a series of protocols. Agencies and groups should adhere to these protocols in order to undertake restoration with appropriate scientific rigor. Central to this approach is the need for careful review of proposals and work plans and a permitting process to which all organizations agree to adhere when actively restoring or monitoring oysters in the tidal Bay or its tributaries. One of the primary tasks of the coordination committee or a technical subcommittee should be to develop a highly credible and transparent review process for all restoration proposals.

Regional Communication Network

Success will depend on a much higher level of regional communication and collaboration than is currently being employed. As a condition of funding or permitting, any organization actively restoring or monitoring tidal areas for oyster restoration should be required to participate in a communication network for sharing of information on restoration activities and monitoring data. The communication network should exist as a physical forum among participants and perhaps as a semi-annual meeting of groups and agencies involved in restoration. Permitting should require communication and coordination of oyster restoration activities by all groups and agencies.

Powell, E., K. Ashton-Alcox, J. Dobarro, M. Cummings & S. Banta. 2002. The inherent efficiency of oyster dredges in survey mode. J Shellfish Res. 21(2):691-695.

Appendix 1

An Evaluation of Native Oyster Restoration in Chesapeake Bay *1990-Present*

While oyster restoration has been a priority in the Chesapeake Bay for nearly a century, the past decade and a half has brought a new focus on rebuilding oyster reefs. This effort is driven by a diverse group of stakeholders interested not only in economic benefits but also in the ecological health of the Bay. Restoration has been supported by substantial state and federal appropriations. Recently the Keith Campbell Foundation for the Environment, the NOAA Chesapeake Bay Office (NCBO) and the U.S. Fish and Wildlife Service have initiated a review of past oyster restoration efforts to be held in cooperation with the Chesapeake Bay scientific and management communities. Discussions with stakeholders from Congress, federal and state agencies, non-profit groups, and the leaders of the major research institutions involved in oyster research and management have indicated that such a review is needed and timely. Considering the fiscal investment in oyster restoration, the importance of fully understanding native oyster restoration within the context of the issue of non-native oyster introduction, and the need for increased funding to support restoration at the necessary scales, this evaluation is of vital importance.

This Bay-wide review conducted by a regional group of experts (Science Content and Analysis Committee) will summarize restoration efforts since 1990 and provide a synthesis of the lessons learned with regard to the specific scientific and management goals that have driven the restoration effort and any successes in reaching such goals. The review process involves community-wide input of relevant data and ideas for assessing restoration activities. The analysis and synthesis of this information will serve as a critical foundation for formulating more efficient and effective restoration practices for the future. The recommendations resulting from this effort will provide an important complement to the oyster research priorities developed and distributed in reports from the Maryland and Virginia Sea Grant Programs, the National Academy of Science, the U.S. EPA Chesapeake Bay Program Scientific and Technical Advisory Committee, and others. This effort will also dovetail with the Environmental Impact Statement currently under development to evaluate the proposed introduction of *Crassostrea ariakensis* to Chesapeake Bay as well as native oyster alternatives.

Goal

The goal of the project is for the scientific and management communities to critically evaluate native oyster restoration from 1990 to the present from three perspectives:

- What has been done, in what locations, over what duration, and under what conditions?
- How have efforts addressed the goals set for oyster restoration over this period?
- What lessons can be learned from the results of these efforts?

This evaluation will yield recommendations for the most promising restoration procedures and strategies to be undertaken in the Bay over short (1-2 years) to longer (~10 years) timeframes, recognizing that there will be economic and ecological incentives that will drive the overall efforts.

Overarching Questions

Oyster beds occur in a mosaic of habitats affected by variables such as salinity, substrate, sedimentation rates, dissolved oxygen, and presence of harmful algal blooms, with some sites being more suitable for spat settlement and others better for fast growth or greater survival. With this in mind, the Science Content and Analysis Committee is addressing the following overarching questions:

1. What is the "guiding image" (relative to location, physical configuration, current and sedimentation patterns in vicinity, biotic make-up of constituents, disease variables) of a healthy oyster bed at a given site? What are the desired restoration goals relative to this image?

in Chesapeake Bay, 1990-Present

2. What might be measured that would indicate progress toward that image (more oysters per unit area; greater diversity and abundances of fish and invertebrates on the bed; clearer water; greater harvest levels)?

3. How do restoration techniques, physical factors and disease interact to affect the success of restoration efforts as measured by survival, recruitment and growth of oysters and the persistence of physical habitat?

4. What ecological conditions are required to allow an oyster bed to be a more resilient, sustainable system, and are such conditions region-specific?

Specific Questions for Particular Restoration Efforts

Oyster Restoration Inventory: What efforts have been made? Where, when, by whom and how (placement of shell, seed, adults; bed configuration, etc.)?

Rationale for Restoration Efforts: For what reason were these restoration efforts done (ecological, fishery or both)? What proportion of efforts have focused on shell planting, seed placement, broodstock enhancement, or disease tolerance?

Monitoring Restoration Efforts: Which of these efforts incorporated some sort of follow-up study (e.g. monitoring, either cursory or detailed) of the outcome? What information was collected (when, how often, how long, by whom, how and how extensively)?

Data Availability: Are these monitoring or ancillary data analyzed or available to be analyzed? If analyzed, what do they tell us about the outcome of the restoration effort (spat set, revived fishery)? If not analyzed but available, what can be learned?

Ecosystem Factors: Are ancillary data on water quality, harmful algal blooms, disease, or other relevant variables available for sites on which monitoring was not performed by the restoration effort?

Restoration Success or Failure I: Why have some restoration efforts succeeded and some failed? What is the measure of success? What performance measures have been used to evaluate restoration sites? What standards or performance measures are being used in other oyster restoration programs domestically and internationally that could be applied here?

Restoration Success or Failure II: To what extent has the scale of restoration been a factor in limiting success? At what scale will restoration make a difference? What production level (spat/year) will be required to implement restoration at such scales?

An Evaluation of Native Oyster Restoration in Chesapeake Bay

Socioeconomic Factors: What can the restoration efforts and the monitoring efforts tell us about the factors (historical, socioeconomic, conservation goals) that have impelled each effort? Have any of these factors enhanced or inhibited a particular effort?

Long Term Trends: Can we learn anything about the length of time required for restoration to be successful in different parts of the Bay? Do sanctuaries work? Under what conditions should sanctuaries be established? What is our definition of the measure of success over different time scales?

Oyster Disease Links: Is there evidence of natural disease tolerance evolving in any areas of Chesapeake Bay? How successful have selectively bred, disease tolerant strains been for restoration?

Economics of Restoration: How much have these efforts cost, individually or in concert? For those efforts where an economic as opposed to an ecological return was expected (commercial aquaculture or harvest) what has been the economic impact of native oyster restoration programs?

The Science Content and Analysis Committee is comprised of active members of the Chesapeake Bay research community with expertise in a wide range of relevant disciplines and direct experience in the native oyster restoration effort. The committee will complete its work by Summer of 2007 and anticipates publication of a final report at that time.

Funding for this effort has been provided by The Keith Campbell Foundation for the Environment, the NOAA Chesapeake Bay Office, and the U.S. Fish and Wildlife Service. The process is facilitated by the Maryland Sea Grant College Program with logistical support from the Chesapeake Research Consortium.

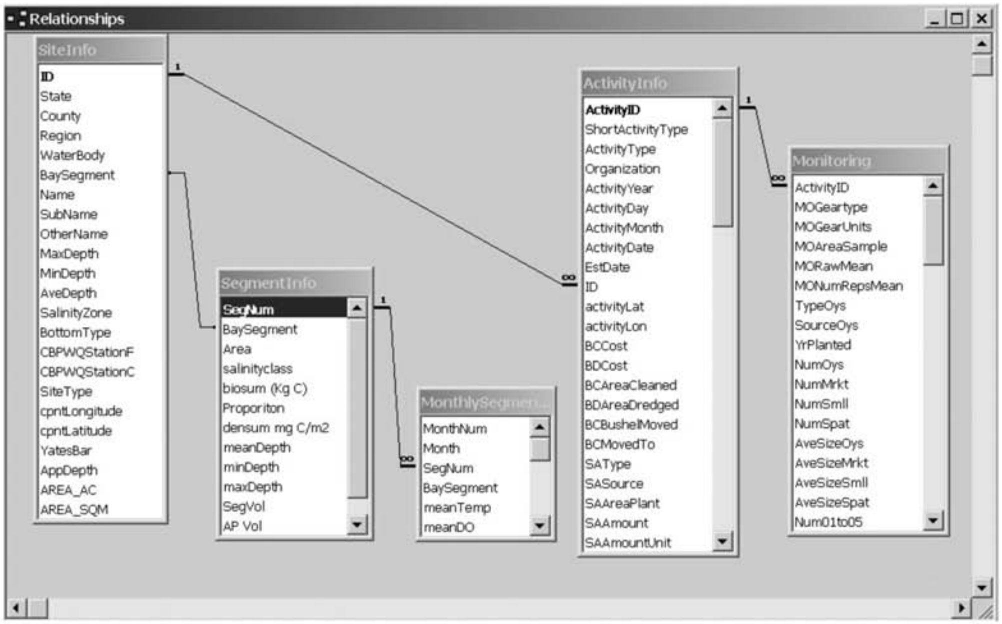
For additional information please contact:
Dr. Jonathan G. Kramer, Director
Maryland Sea Grant College Program
301-405-7500 or kramer@mdsg.umd.edu

The Campbell Foundation | NOAA Chesapeake Bay Office | U.S Fish & Wildlife Service | Maryland Sea Grant College | Chesapeake Research Consortium

Appendix 2

Database Description

The database is in Microsoft Access. The data is in five tables joined in the following way:



The variables in each table as defined as:

Table: SegmentInfo		
Parameter	**Type**	**Description**
SegNum	**Number**	**Segment ID Number matching with the Segment number in SegmentInfo Table**
BaySegment	Text	CBPSEG - Bay Segment 2003 Name
Area	Text	WaterBody
salinityclass	Text	Salinity Classification (oligohaline, mesohaline, polyhaline)
biosum (Kg C)	Number	Kg of Phytoplankton Carbon
Proporiton	Number	
densum mg C/m2	Number	
meanDepth	Number	Mean depth (m)
minDepth	Number	Minimum Depth (m)
maxDepth	Number	Maximum Depth (m)
segVol	Number	Volume of Segemt (m3)
AP Vol	Number	Above Pycnolcline Volume of water
BP Vol	Number	Below Pycnolcline Volume of water

Table: MonthlySegmentInfo		
Parameter	Type	Description
MonthNum	Number	Numeric Month Number
Month	Text	Month or Annual
SegNum	**Number**	**Segment ID Number matching with the Segment number in SegmentInfo Table**
BaySegment	Text	CBPSEG - Bay Segment 2003 Name
meanTemp	Number	Mean Water Temperature (C)
meanDO	Number	Mean Dissolved Oxygen (g/m3)
meanSalinity	Number	Mean Salinity (ppt)
meanTSS	Number	Mean TSS (mg/L)
OysBiomass	Number	Oyster Biomass (Kg C)
PhytoplanktonBiomass	Number	Phytoplankton Biomass (mg C)
AdjFiltration	Number	Adjusted Filtration Rate (m3/ Kg C/day)
TotalFiltration	Number	Total Filtration (m3/day)
DenPicoplankton	Number	Density (mg C/m3) of picoplankton
DenPicoplankton_002_004	Number	Density (mg C/m3) of Size 2-4 micm
DenPicoplankton_004_010	Number	Density (mg C/m3) of Size 4-10 micm
DenPicoplankton_010_050	Number	Density (mg C/m3) of Size 10-50 micm
DenPicoplankton_050_100	Number	Density (mg C/m3) of Size 50-100 micm
DenPicoplankton_100	Number	Density (mg C/m3) of Size >100 micm
Total denAbovePycnocline	Number	Total density above pycnocline (mg C/m3)
BiomassAbovePycnocline	Number	Total biomass above pyc (Kg C)

Table: ActivityInfo		
Parameter	Type	Description
ActivityID	**Text**	**Unqiue Activity ID to link to the Montioring Data**
ShortActivityType	Text	Abbriviation for the activity type (BC, BD, SA, WS, HS, HM, MO)
ActivityType	Text	Bar Cleaning, Baglass Dredging, Substrate Addition, Wild Seed Transplant, Hatchery Seed Transplant, Harvest Management, Montioring
Organization	Text	Organization who performed the activity (VMRC, MDDNR, etc...)
ActivityYear	Number	Year of which the activity occured
ActivityDay	Number	Day of which the activity occured
ActivityMonth	Number	Month of which the activity occured
ActivityDate	Date/Time	Date of which the activity occured
EstDate	checkbox	If the date is an estimated or assumed Date
ID	Text	ID for eachbar/reef/aquaculture site
activityLat	Number	Centerpoint Latitude (Decimal Degrees) of the activity
activityLon	Number	Longitude (Decimal Degrees) of the activity
BCCost	Number	Bar Cleaning: Cost of Bar Cleaning
BCAreaCleaned	Number	Bar Cleaning: Area Cleaned (acres)
BCBushelMoved	Number	Bar Cleaning: Number of bushels moved off bar
BCMovedTo	Text	Bar Cleaning: Where oysters taken off the bar was moved to
BDCost	Number	Bagless Dredging: Cost of Bagless Dregding
BDAreaDredged	Number	Bagless Dredging: Area Dredged (acres)
SAType	Text	Substrate Addition: Type of Substrate Added (Shell, Concrete, Clam Shell, etc..)
SASource	Text	Substrate Addition: Source (Fossil/Dredged or House/Fresh)
SAAreaPlant	Number	Substrate Addition: Area substrate was planted (acres)
SAAmount	Number	Substrate Addition: The amount of substrate added to the area
SAAmountUnit	Text	Substrate Addition: The units of the amount of substrate added to the area (tons, bushels, etc...)
SANumBushShell	Number	Substrate Addition: If Shell, Number of Bushels of Shell
SACostBushShell	Number	Substrate Addition: Cost of a Bushel of Shell
SABushArea	Number	Substrate Addition: Number of Bushels planted per area
SADTR	Text	Substrate Addition - Desired Topographic Relief
SAFoundSub	Text	Substrate Addition - Foundation Substrate
SACapSub	Text	Substrate Addition - Capping Substrate
SAIBC	Text	Substrate Addition - Initial Bottomtype Charateristics
WSTType	Text	Wild Seed Transplant: For Harvest or For Broodstock
WSTTypeOys	Text	Wild Seed Transplant: Type of Wild Seed Oysters
WSTSource1	Text	Wild Seed Transplant: Source of the Seed Location (Site ID)
WSTSource2	Text	Wild Seed Transplant: Source of the Seed Location (Site ID)
WSTOysterSize	Number	Wild Seed Transplant: Size of Oysters Planted
WSTSpatSize	Number	Wild Seed Transplant: Size of Spat Planted
WSTSmallSize	Number	Wild Seed Transplant: Size of Smalls Planted
WSTMarketSize	Number	Wild Seed Transplant: Size of Markets Planted
WSTpctSmall	Number	Wild Seed Transplant: Percent of Smalls planted
WSTAreaPlant	Number	Wild Seed Transplant: Area planted (acres)
WSTNumBush	Number	Wild Seed Transplant: Number of bushels of spat on shell planted
WSTSeedBush	Number	Wild Seed Transplant: Number of spat per bushel
WSTBushArea	Number	Wild Seed Transplant: Number of bushels planted per area
WSTCost	Number	Wild Seed Transplant: Cost per bushel of seed
WSTDzP	Number	Wild Seed Transplant: Dermo status of seed planted (prevelance)
WSTDzWP	Number	Wild Seed Transplant: Dermo status of seed planted (weighted prevelance)
WSTMSXDz	Number	Wild Seed Transplant: MSX prevelance of seed planted
HSTObjHarvest	checkbox	Hatchery Seed Transplant: Reason for transplant = Harvest
HSTObjBroodstock	checkbox	Hatchery Seed Transplant: Reason for transplant = Broodstock
HSTObjEcosystem	checkbox	Hatchery Seed Transplant: Reason for transplant = Ecosystem
HSTObjResearch	checkbox	Hatchery Seed Transplant: Reason for transplant = Research
HSTObjUnknown	checkbox	Hatchery Seed Transplant: Reason for transplant = Unknown
HSTSSource1	Text	Hatchery Seed Transplant: Source of broodstock (Wild or Selected)
HSTSSource2	Text	Hatchery Seed Transplant: Source of broodstock (DEBY, Crosbred, etc...)
HSTType	Text	Hatchery Seed Transplant: Type of Seed (i.e. spat on shell, hatchery seed, 1 year old oysters, etc...)
BatchNumHS	Text	Hatchery Seed Transplant: Batch # from hatchery
HSTHatch	Text	Hatchery Seed Transplant: Hatchery where seed came from (i.e. VIMS, Hornpoint, etc...)
HSTCultch	Text	Hatchery Seed Transplant: If the seed is cultched (yes/no)
HSTOSize	Number	Hatchery Seed Transplant: Size of oyster seed planted
HSTAreaPlant	Number	Hatchery Seed Transplant: Size of area where seed was planted (acres)
HSTBushTotal	Number	Hatchery Seed Tranplant: Number of bushels planted total
HSTBushArea	Number	Hatchery Seed Tranplant: Number of bushels planted per area
HSTSpatShell	Number	Hatchery Seed Transplant: If seed plant was on shell, Mean number of spat per shell

Table: ActivityInfo, continued		
Parameter	Type	Description
ActivityID	**Text**	**Unqiue Activity ID to link to the Montioring Data**
ShortActivityType	Text	Abbriviation for the activity type (BC, BD, SA, WS, HS, HM, MO)
ActivityType	Text	Bar Cleaning, Baglass Dredging, Substrate Addition, Wild Seed Transplant, Hatchery Seed Transplant, Harvest Management, Montioring
Organization	Text	Organization who performed the activity (VMRC, MDDNR, etc...)
HSTSpatPlant	Number	Hatchery Seed Transplant: Total number of spat planted
HSTNumPlant	Number	Hatchery Seed Transplant: Total number of oysters planted
HSTSpatShellMin	Number	Hatchery Seed Transplant: If seed plant was on shell, Min number of spat per shell
HSTSpatShellMax	Number	Hatchery Seed Transplant: If seed plant was on shell, Max number of spat per shell
HSTCost	Number	Hatchery Seed Transplant: Cost to plant seed
HSTDzP	Number	Hatchery Seed Transplant: Disease status of seed planted (prevelance)
HSTDzWP	Number	Hatchery Seed Transplant: Disease status of seed planted (weighted prevelance)
HSTMSXDz	Number	Hatchery Seed Transplant: MSX prevelance of seed planted
EstimatedAreaPlanted	Number	Estimated Area (m2) planted of substrate or seed
DzMethod	Text	Diagnostic Method used for testing disease
TypeofArea	Text	Unit of Area - i.e acrea, m2, etc...
HMAreaClosed	Text	Harvest Management: Total Area Closed to Harvest
HMReasonClosed	Text	Harvest Management: Reason why area was closed
HMReasonOpen	Text	Harvest Management: Reason why area was opened
HMGearType	Text	Harvest Management: Bar Opened/Closed to a specific geartype
MOPrePost	Text	Monitoring: Pre or Post Restoration Event
MOSurTemp	Number	Monitoring: Surface Temperature (C)
MOSurSalinity	Number	Monitoring: Surface Salinity (ppt)
MOSurDO	Number	Monitoring: Surface DO
MOBotDepth	Number	Monitoring: Bottom Depth (ft)
MOBotTemp	Number	Monitoring: Bottom Temperature (C)
MOBotSalinity	Number	Monitoring: Bottom Salinity (ppt)
MOBotDO	Number	Monitoring: Bottom DO
Comments	Memo	

Table: Monitoring		
Parameter	**Type**	**Description**
ActivityID	Text	Unqiue Activity ID to link to the Montioring Data
MOGeartype	Text	Monitoring: Type of Gear Used (i.e. Dredge, Patent Tong, Diver,...)
MOGearUnits	Text	Monitoring: Unit of the Gear Type Used (i.e. m2, VA Bushel, MD Bushel,...)
MOAreaSample	Number	Monitoring: Area or number of bushels that is sampled
MORawMean	Text	Monitoring: Is the data in raw format or averaged?
MONumRepsMean	Text	Monitoring: If the data is averaged, what is the number of samples/reps that determined the mean
TypeOys	Text	If the oysters are live, recent box, old box, all box
SourceOys	Text	If the oysters are planted, or native/feral, or transplanted
YrPlanted	Number	If the oysters are planted then what year were they planted
NumOys	Number	Total Number of Oysters
NumMrkt	Number	Number of Market-sized oysters (greater than 76mm)
NumSmll	Number	Number of Small-sized oysters (greater than 40mm and less than 76mm)
NumSpat	Number	Number of Spat-sized oysters (less than 40mm)
AveSizeOys	Number	Average Size of Oysters mm
AveSizeMrkt	Number	Average Size of Market-sized oysters mm (greater than 76mm)
AveSizeSmll	Number	Average Size of Small-sized oysters mm (greatern than 40mm and less than 76 mm)
AveSizeSpat	Number	Average Size of Spat-sized oysters mm (less than 40mm)
Num01to05	Number	Number of oysters from 0 to 5 mm
to		
Num246to250	Number	Number of oysters from 246 to 250 mm
MSXPrev	Number	MSX Prevelance Value
DermoPrev	Number	Dermo Prevelance Value
DermoInt	Number	Dermo Intensity
DermoScale	Text	The Scale for the Dermo Test
NumDZSamples	Number	The number of oysters tested for dermo and/or msx
DermoInt0	Number	Number of Oysters Tested for Dermo in the Category 0 = Negative or None
DermoInt1	Number	Number of Oysters Tested for Dermo in the Category 1 = Very Light
DermoInt2	Number	Number of Oysters Tested for Dermo in the Category 2 = Rare or Light
DermoInt3	Number	Number of Oysters Tested for Dermo in the Category 3 = Between Light and Moderate
DermoInt4	Number	Number of Oysters Tested for Dermo in the Category 4 = Moderate
DermoInt5	Number	Number of Oysters Tested for Dermo in the Category 5 = Between Moderate and Heavy
DermoInt6	Number	Number of Oysters Tested for Dermo in the Category 6 = Heavy
DermoInt7	Number	Number of Oysters Tested for Dermo in the Category 7 = Very Heavy