Chesapeake Bay Oyster Recovery: Native Oyster Restoration Master Plan

Maryland and Virginia

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Prepared by
U.S. Army Corps of Engineers
Baltimore and Norfolk Districts

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U.S. Army Corps of Engineers

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September 2012

Final

Forward

The State of Maryland and the Commonwealth of Virginia are the local sponsors for this study. As such, the native oyster restoration master plan (master plan) was prepared in close partnership with the Maryland Department of Natural Resources (MDNR) and the Virginia Marine Resources Commission (VMRC). The National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service (USFWS), and the U.S. Environmental Protection Agency (EPA), The Nature Conservancy (TNC), the Potomac River Fisheries Commission (PRFC), and the Chesapeake Bay Foundation (CBF) are collaborating agencies for the project.

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EXECUTIVE SUMMARY

The eastern oyster, *Crassostrea virginica*, helped shape the Chesapeake Bay and the people that have settled on its shores. The demise of the oyster in the 20th century culminated from a combination of overharvesting, loss of habitat, disease, and poor water quality. The problems faced by the oyster in the Chesapeake Bay are not uncommon along the Eastern Seaboard of the United States (Jackson et al. 2001; Beck et al. 2011). However, oyster restoration in the Chesapeake Bay has proven challenging. Past restoration efforts have been scattered throughout the Bay and have been too small in scale to make a system-wide impact (ORET 2009). Broodstocks and reef habitat are below levels that can support Bay-wide restoration, and critical aspects of oyster biology, such as larval transport, are only beginning to be understood. However, even in their current state, oysters remain an important resource to the ecosystem, the economy, and the culture of the Chesapeake Bay region that warrant further restoration efforts. Comprehensive oyster restoration is paramount to a restored Chesapeake Bay. This native oyster restoration master plan (master plan) presents the U.S. Army Corps of Engineers' (USACE) plan for large-scale, concentrated oyster restoration throughout the Chesapeake Bay and its tributaries.

This master plan represents the culmination of a collaborative, science-based planning effort focused on native oyster restoration in the Chesapeake Bay. This effort, which builds on USACE's *Final Programmatic Environmental Impact Statement for Oyster Restoration Including Use of Native and/or Non-Native Oyster* in 2009 (www.nao.usace.army.mil/Portals/31/docs/civilworks/oysters/FinalPEISOysterRestoration.pdf), is unprecedented in that it lays out the first comprehensive Bay-wide strategy for large-scale oyster restoration. Development of the document and the approaches laid out herein incorporates peer reviewed publications, and scientific and technical work accomplished by Bay experts, state partners, Federal collaborating agencies, non-government agencies, numerous stakeholders, and others with interest or expertise in native oyster restoration. Critical and controversial topics were isolated by the project team and analyzed through a series of Technical White Papers that were vetted among USACE, the project sponsors, and collaborating agencies. Agency technical review of this document was accomplished by USACE with complementary reviews by other Federal and state partners to ensure technical quality and to address the full spectrum of technical and institutional concerns. Public review was carried out in spring 2012.

USACE, Baltimore and Norfolk Districts, have the authority under Section 704(b) of the Water Resources Development Act of 1986 (as amended by Section 505 of WRDA 1996, Section 342 of WRDA 2000, Section 113 Fiscal Year 2002 Energy and Water Development Appropriations Act, Section 126 of the Fiscal Year 2006 Energy and Water Development Appropriations Act, and Section 5021 of WRDA 2007) to construct oyster reef habitat in the Chesapeake Bay and have been designated as co-leads with the National Oceanic and Atmospheric Administration (NOAA) to achieve oyster restoration goals established by the *Chesapeake Bay Protection and Restoration Executive Order* (E.O.) (May 12, 2009).

USACE restoration efforts have been ongoing in Maryland since 1995 and in Virginia since 2000. In recognition that a more coordinated Bay-wide approach is needed to guide USACE's future Chesapeake Bay oyster restoration efforts and the investment of federal funding, USACE's Baltimore and Norfolk Districts partnered with multiple agencies to create a joint Bay-wide master plan for oyster restoration efforts. Federal involvement is warranted due to the magnitude at which oyster populations have been lost in the Bay; the significant role oysters play in the ecological function of the Bay, as well as the socio-economics, culture, and history of the region; and the challenges confronting successful restoration.

The purpose of this master plan is to provide a long-term strategy for USACE's role in restoring large-scale native oyster populations in the Chesapeake Bay to achieve ecological success. Concentrating restoration in selected tributaries will be an improvement over previous, scattered efforts by providing the best circumstances for influencing stock/recruit relationships and for promoting the development of disease resistance; which, in turn, will make restoration more likely to succeed. The master plan will serve as a foundation, along with plans developed by other federal agencies, to work towards achieving the oyster restoration outcome established by the *Chesapeake Bay Protection and Restoration Executive Order* (E.O. 13508) to restore native oyster habitat and populations in 20 tributaries by 2025.

The master plan is a programmatic document that: (1) examines and evaluates the problems and opportunities related to oyster restoration; (2) formulates plans to restore sustainable oyster populations throughout the Chesapeake Bay; and (3) recommends plans for implementing large-scale Bay-wide restoration. The document does not identify specifically implementable projects.

The long-term goal or vision of the master plan is as follows:

> *Throughout the Chesapeake Bay, restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to an oyster fishery.*

USACE recognizes that self-sustainability is a lofty goal. It will require focused and dedicated funding and strong political and public support over an extended period, likely decades. It will require the use of sanctuaries and the observance of sanctuary regulations. In addition to the long-term goal, the master plan defines near-term ecological restoration and fisheries management objectives. The ecological restoration objectives cover habitat for oysters and the reef community as well as ecosystem services.

The master plan lays out a large-scale approach to oyster restoration on a tributary basis and proposes that 20 percent to 40 percent of historic habitat [equivalent to 8 percent to 16 percent of Yates Bars/Baylor Grounds (defined in Section 1)] be restored and protected as oyster sanctuary. In recognition that one number will not fit perfectly for every tributary, the master plan is recommending a range that should be revised to a more precise number by the follow-on specific tributary investigations. The concentrated restoration efforts are necessary to have an impact on depleted oyster populations within a tributary. To accomplish tributary-level restoration, the master plan includes salinity-based strategies to address disease and jumpstart reproduction.

USACE and its partners evaluated 63 tributaries and sub-regions for their potential to support large-scale oyster restoration using salinity, dissolved oxygen, water depth, and hydrodynamic criteria. Salinity largely controls disease, predation, and many other aspects of the oyster life cycle and by its consideration, the master plan indirectly addresses these other factors. The evaluation was largely performed using geographic information system (GIS) analyses. The master plan identifies that 24 (Tier 1) tributaries or distinct sub-segments (DSS) of larger tributaries in the Chesapeake Bay are currently suitable for large-scale oyster restoration (Table ES-1). These tributaries are distributed throughout the Bay with 14 sites in Maryland and 10 sites in Virginia, as shown in Figure ES-1. Tier 1 tributaries are the highest priority tributaries that demonstrate the historical, physical, and biological attributes necessary to provide the highest potential to develop self-sustaining populations of oysters. The remainder of the tributaries and mainstem Bay segments are classified as Tier 2 tributaries, or those tributaries that have identified physical or biological constraints that either restrict the scale of the project required or affect its predicted long-term sustainability. The master plan also discusses additional criteria that should be investigated during the development of specific tributary plans such as mapping of current bottom substrate, sedimentation rates, and larval transport and provides a framework for developing specific tributary plans.

The restoration targets provided in Table ES-1 are estimates of the number of functioning acres of oyster habitat needed within a tributary to affect a system-wide change and ultimately provide for a self-sustaining population. The targets are not meant to be interpreted strictly as the number of new acres to construct. Any existing functioning habitat identified by bottom surveys would count towards achieving the restoration goal, but would not be counted toward new restoration benefits. Similarly, there may be acreage identified that only requires some rehabilitation or enhancement. Work done on that acreage would also count toward achieving the restoration target. Accounting for the presence and condition of existing habitat is recommended as an initial step of tributary plans. Once that information is obtained, restoration actions will be tailored to the habitat conditions and projected restoration costs revised.

Table ES-1. Tier 1 Tributaries and Restoration Targets

Tier 1 Tributaries/Areas	*Restoration Target (Acres)*
Maryland	
Severn River	190 – 290
South River	90 – 200
Lower Chester River	500–1,100
Lower Eastern Bay	700 – 1,400
Upper Eastern Bay	800 – 1,600
Lower Choptank River	1,400 – 2,800
Upper Choptank River	400 – 800
Harris Creek	300 – 600
Little Choptank	400 – 700
Broad Creek	200 – 400
St. Mary's River	200 – 400
Lower Tangier Sound	800 – 1,700
Upper Tangier Sound	900 – 1,800
Manokin River	400 – 800
Virginia	
Great Wicomico River	100 – 400
Lower Rappahannock River	1,300 – 2,600
Piankatank River	700 – 1,300
Mobjack Bay	800 – 1,700
Lower York River	1,100 – 2,100
Pocomoke/Tangier Sound	3,000 – 5,900
Lower James River	900 – 1,800
Upper James River	2,000 – 3,900
Elizabeth River	200 – 500
Lynnhaven River	40 – 150

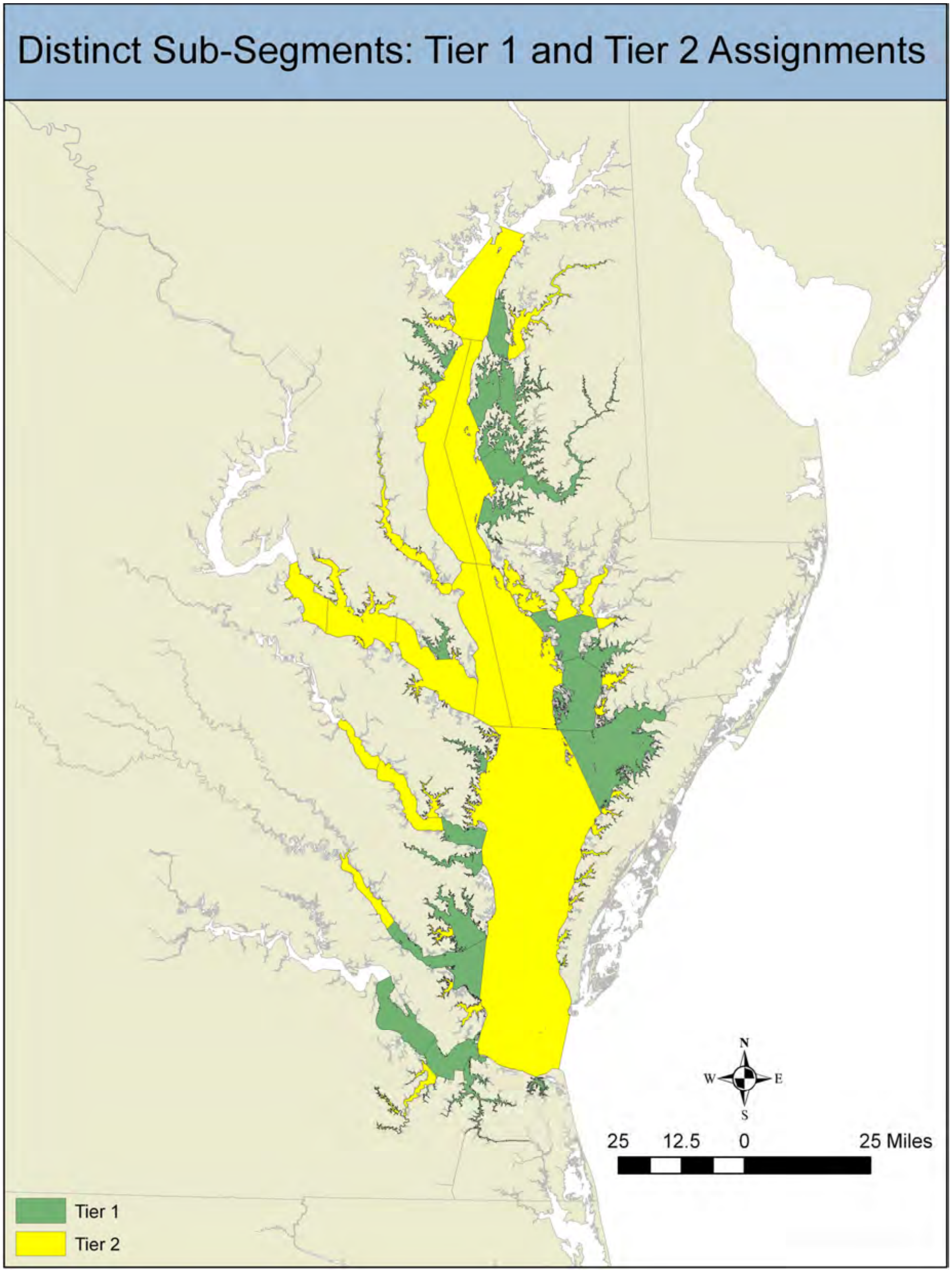

Figure ES-1. Tier Assignments by Tributary and Sub-Segment

The master plan includes planning level restoration costs that incorporate construction of high relief (12 inches) hard reef habitat (using shell and/or alternate substrates), seeding with spat (baby oysters), and adaptive management actions. Estimates are provided in Section 5.7.2 for the full construction of the low and high restoration targets for each individual tributary or DSS as well as three implementation scenarios. A summary of these costs for three implementation scenarios is provided in Table ES-2. The salinity-based restoration scenario (2) assumes that low salinity tributaries require more habitat acreage to be restored because reproduction is lower compared to high salinity tributaries, and therefore calculated costs using the high acreage target for low salinity tributaries and the low acreage target for high salinity tributaries. The scenarios are fully described in Section 5.7.2.5. Figure ES-2 depicts the cost estimate ranges for the three scenarios.

Table ES-2. Projected Restoration Costs

	Number of Tier 1 Tributaries	Oyster Reef Restoration Target (acres)	Total Estimated Low Range Cost	Total Estimated High Range Cost
Maryland Tier 1	14	7,300-14,600	$0.87 billion	$2.85 billion
Virginia Tier 1	10	10,100-20,400	$0.97 billion	$3.63 billion
Scenario 1- All Tier 1 Tributaries	24	17,400–35,000	$ 1.85 billion	$ 6.50 billion
Scenario 2- Salinity-based restoration	24	18,200	$ 1.99 billion	$ 3.42 billion
Scenario 3- E.O. Implementation	20	14,400–28,400	$ 1.56 billion	$ 5.38 billion

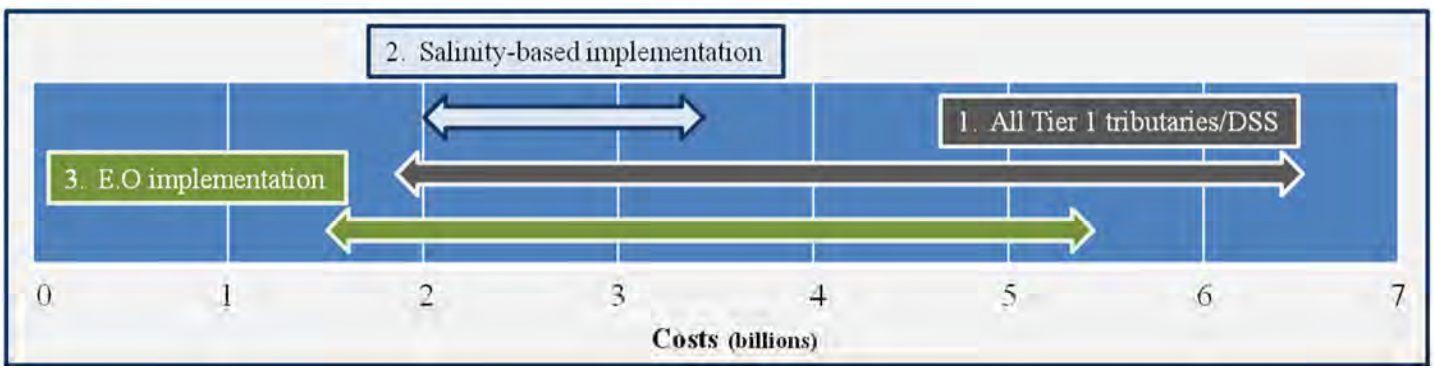

Figure ES-2. Cost Range Comparison for Implementation Scenarios

All cost estimates are conservatively high in that the assumption was made to develop the cost estimates using the assumption that each targeted acre would require construction of new hard habitat; however, it is anticipated that restoration will not require new habitat construction for every targeted acre once populations surveys are completed. Although Table ES-2 concisely shows the costs for restoring a group of tributaries or DSS for each scenario, one should not assume that all tributaries need to be restored before benefits are achieved. Further, ecosystem benefits described below are expected to be achieved, at least on a local level while healthy oysters and reef habitat persist on the restored reefs, regardless of whether self-sustainable populations are realized. USACE is not recommending an investment of this magnitude at any one time. Restoration should progress tributary by tributary. Benefits are achieved with each reef and each tributary that is restored. The master plan provides a further breakdown of costs by tributary and separate costs for substrate placement and seeding.

The ecosystem services provided by oysters are numerous (Grabowski and Peterson 2007), but largely difficult to quantify at this stage of restoration. These services include:

(1) production of oysters,
(2) water filtration, removal of nitrogen and phosphorus, and concentration of biodeposits (water quality benefits),
(3) provision of habitat for epibenthic fishes (and other vertebrates and invertebrates),
(4) sequestration of carbon,
(5) augmentation of fishery resources,
(6) stabilization of benthic or intertidal habitat (e.g. marsh), and
(7) increase in landscape diversity.

Given the vast resources required to complete restoration in all Tier 1 tributaries and the fact that large-scale restoration techniques are in the early stages of development, USACE recommends choosing a tributary or two in each state for initial large-scale restoration efforts following completion of the master plan. This would facilitate the concentration of resources to enact a system-wide change on oyster populations in the tributary and achieve restoration goals, as well as provide for monitoring and refinement of restoration techniques. Monitoring will be guided by the report of the multi-agency Oyster Metrics Workgroup convened by the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program (OMW 2011).

Implementation of large-scale oyster restoration should begin with the selection of Tier 1 tributary(ies) for restoration by restoration partners. Specific tributary plans should be developed for the chosen tributary(ies) and should include a refinement of the restoration target, originally developed in the master plan. (NOAA has initiated development of a draft Tributary Plan Framework that is attached to the master plan in Appendix D.) Restoration partners should work together to acquire and evaluate mapping of current bottom substrates to initiate plan development and scale refinement. The master plan describes many other implementation factors that need to be considered during tributary plan development. Appropriate National Environmental Policy Act (NEPA) documentation would accompany each tributary plan. Once a tributary plan is complete, construction would proceed in a selected tributary by restoring a portion of the target (e.g., 25, 50, or 100 acres) per year given available resources until goals and objectives are met.

The master plan presents a proposal for a sanctuary approach to fulfill USACE's ecosystem restoration mission and the E.O. goals. However, sanctuary designation is at the discretion of Maryland and Virginia. In developing the master plan, USACE views oysters as "an ecosystem engineer that should be managed as a provider of a multitude of goods and services" (Grabowski and Peterson 2007). The recommendation for large-scale restoration in sanctuaries has been developed to concentrate resources, provide for a critical mass of oysters and habitat, and promote the development of disease resistance; this strategy is expected to be a significant improvement over past restoration efforts. Establishment of long-term, permanent sanctuaries is consistent with recommendations of the Chesapeake Research Council (CRC 1999), the Virginia Blue Ribbon Oyster Panel (Virginia Blue Ribbon Oyster Panel 2007), and the Maryland Oyster Advisory Commission 2008 Report (OAC 2009). Sanctuaries are necessary to enable the long-term growth of oysters, develop the associated benefits that increase with size, and develop disease resistance. Carnegie and Burreson (2011) also have proposed that sanctuaries may be a mechanism by which to slow shell loss rates.

Although limited, current information suggests that greater economic and ecological benefits are achieved through the use of sanctuaries (Grabowski and Peterson 2007; Santopietro 2008; USACE 2003, 2005). USACE is undertaking additional investigations into the costs and benefits of sanctuaries and harvest reserves. Future tributary plan development which will include applicable NEPA analyses and documentation will incorporate the findings of these investigations. Inclusion of management approaches other than sanctuaries will be considered in specific tributary plans, if justified. On the basis of current science and policy, USACE does support establishment of harvest reserves by the State's within proximity of sanctuaries to provide near-term support to the seafood industry and establish a diverse network of oyster resources.

There are a number of issues that may jeopardize the success of any large-scale oyster restoration program. Illegal harvests pose a major risk. Illegal harvests are suspected to have impacted nearly all past Maryland restoration projects as well as the Great Wicomico restoration efforts. Recent estimates are that 33 percent of oysters placed in Maryland sanctuaries between 2008 and 2010 have been removed by illegal harvests; a potentially greater percentage have been illegally harvested since the beginning of restoration efforts in 1994 (Davis 2011). Significant investments are lost and project benefits compromised when reef habitat is impacted by illegal harvests. The expansion of designated sanctuaries in Maryland and enforcement efforts by both Maryland and Virginia should help with reducing illegal harvests.

A second critical factor is the availability of hard substrate for reef construction. Oyster reef is the principal hard habitat in the Bay and significant amounts of reef habitat will need to be restored to meet restoration goals. However, a sufficient supply of oyster shell is currently not available for oyster restoration. Alternate substrates will need to be a part of large-scale habitat restoration. Alternate substrates such as concrete and stone are significantly more expensive and may not be publicly acceptable on such a large-scale; however, these materials greatly eliminate the risk of poaching because the materials can damage traditional harvest equipment. A third issue impacting the success of large-scale oyster restoration is water quality. A restored oyster population has the potential to return filtering functionality to shallow water areas where restored reefs are located. However, poor land management and further degradation of water quality will jeopardize any gains. Excess nutrients, sediment, and toxics that enter the Bay reduce suitable habitat, diminish the health of oysters, and potentially lead to conditions that impact the shell budget and an oyster's ability to form shell. Within the Chesapeake Bay, nutrients from runoff and sewage produce more carbon dioxide than atmospheric CO_2 (Nash 2012). Increasing carbon dioxide could result in an increase in acidity which, in turn, could lead to reduced shell formation and increased shell dissolution. Further, water quality benefits provided by oyster restoration will rely on sustainable land management and development. Efforts being undertaken to support the Chesapeake Bay Restoration and Protection Executive Order and the nutrient reduction goals established in the Chesapeake Bay Total Maximum Daily Loads (TMDL) will help address water quality issues. The Executive Order goals targeting water quality, habitat, and fish and wildlife and the efforts of the various Goal Implementation Teams are directly related to achieving the goals presented in the master plan. Opportunities to match oyster restoration efforts, spatially and temporally, with land management projects should be implemented to the greatest extent.

Although USACE and its partners have developed this master plan to guide USACE's long-term oyster restoration activities, large-scale oyster restoration in the Chesapeake Bay will only succeed with the cooperation of all agencies and organizations involved. VMRC and USACE-Norfolk are working together towards some common ground activities including oyster benefits modeling, a fossil shell survey, monitoring, and rehabilitation of existing sanctuary reefs; and these efforts should continue in the future. Resources and skills must be leveraged to achieve the most from restoration dollars. The greatest achievements will be made by joining the capabilities of each agency in a collaborative manner to pursue restoration activities.

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USACE Native Oyster Restoration Master Plan

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ACRONYMS

ac	**Acre**
ADH	**Adaptive Hydraulics model**
AFDW	**Ash-free dry weight**
ASMFC	**Atlantic States Marine Fisheries Commission**
atm	**Standard measurement of pressure; 1 atm – 101,325 Pa (paschal)**
B IBI	**Benthic Index of Biotic Integrity**
bu/hrs	**bushels Per Hour**
C/yr	**Carbon per year**
C/ac	**Carbon per acre**
C/ac/yr	**Carbon per acre per year**
CASM	**Comprehensive Aquatics System Model**
CBF	**Chesapeake Bay Foundation**
CBP	**Chesapeake Bay Program**
CBT	**Chesapeake Bay Trust**
CENAB	**U.S. Army Corps of Engineers, Baltimore District**
CENAE	**U.S. Army Corps of Engineers, New England District**
CENAO	**U.S. Army Corps of Engineers, Norfolk District**
CI	**Confidence interval**
cm/s	**Centimeter(s) Per second**
Crossbred	**Domesticated, disease-resistant oyster strain originating from crossing a native Chesapeake Bay oyster with an oyster strain from Louisiana**
cy	**Cubic yard**
d	**Days**
DEBY	**Domesticated, disease-resistant oyster strain originating in Delaware Bay**
DO	**Dissolved oxygen**
DSS	**Distinct sub-segment**
DW	**Dry weight**
EIS	**Environmental impact statement**
EO	**Executive Order**
EPA	**U.S. Environmental Protection Agency**
ERDC	**Engineer Research and Development Center**
ESA	**Endangered Species Act**
ft	**Foot or feet**
ft/sec	**Feet per second**
ft/yr	**Feet per year**
FY	**Fiscal year**
GIT	**Goal Implementation Team**
GIS	**Geographic information system**
HAB	**Harmful algal bloom**
HRR	**High relief reef**
hrs/yr	**Hours per year**

IDW	**Inverse-distance weighting**
in	**Inches**
ISTC	**Inter-State Shellfish Transport Committee**
lbs	**Pounds**
LTM	**Larval transport model**
m	**Meter(s)**
m^2	**Square meter**
m^3	**Cubic meter**
MBBS	**Maryland Bay Bottom Survey**
mcy	**Million cubic yard(s)**
mcy/yr	**Million cubic yards per year**
MD	**Maryland**
MDE	**Maryland Department of the Environment**
MDNR	**Maryland Department of Natural Resources**
mg/L	**Milligrams per liter**
MGS	**Maryland Geological Survey**
mi	**Mile**
MLLW	**Mean lower low water**
MPA	**Marine protected area**
MSX	**Multinucleated Sphere X; an oyster disease caused by the parasite,** *Haplosporidium nelsoni*
NEPA	**National Environmental Policy Act**
NMFS	**National Marine Fisheries Service**
NOAA	**National Oceanic and Atmospheric Administration**
NOB	**Natural oyster bar**
NOI	**Notice of intent**
NRC	**National Research Council**
OAC	**Oyster Advisory Commission**
ODM	**Oyster demographic model**
OHL	**Oyster harvesting license**
OMP	**Oyster Management Plan**
OMW	**Oyster Metrics Workgroup**
OPs	**Organophosphate pesticides**
ORET	**Oyster Restoration Evaluation Team**
ORP	**Oyster Recovery Partnership**
PAHs	**Polycyclic aromatic hydrocarbons**
PCBs	**Polychlorinated biphenyls**
PEIS	**Programmatic environmental impact statement**
PL	**Public law**
ppt	**Parts per thousand, a measure of salinity**
PRG	**Peer Review Group**
PRFC	**Potomac River Fisheries Commission**
SAV	**Submerged aquatic vegetation**
SE	**Standard error**
SLR	**Sea level rise**
Spat/ac	**Spat per acre**

Spat/bu	**Spat per bushel**
TCF	**The Conservation Fund**
TFL	**Tidal fish license**
TMDL	**Total Maximum Daily Load**
TNC	**The Nature Conservancy**
TSS	**Total suspended solids**
UMCES	**University of Maryland Center for Environmental Science**
USACE	**U.S. Army Corps of Engineers**
USDA	**U.S. Department of Agriculture**
USFWS	**U.S. Fish and Wildlife Service**
USGS	**U.S. Geological Survey**
VA	**Virginia**
VIMS	**Virginia Institute of Marine Science**
VMRC	**Virginia Marine Resources Commission**
WRDA	**Water Resources Development Act**
yr	**Year**

GLOSSARY OF OYSTER RESTORATION TERMS

Adaptive management – a paradigm that views management actions as flexible, emphasizing careful monitoring of economic and environmental outcomes of management actions; a "learning while doing" process

Adductor Muscle – a prominent organ situated in the posterior region of the oyster body, consisting of an anterior translucent part and a smaller, white crescent-shaped region; it functions to close the oyster shells (relaxation of the adductor muscle allows the shells to gape open).

Alternative substrate – a hard substance used in lieu of natural oyster shell to provide a hard place for oyster spat to settle

Annelids – segmented worms in the phylum Annelida, including earthworms and leeches; they are found in most wet environments, and include terrestrial, freshwater, and marine species

Anoxia – a condition in which the concentration of oxygen available to animals is insufficient to support the full function of body tissues (adj.: anoxic); >0.2 mg/L in Chesapeake Bay

Anthropogenic – relating to or resulting from the influence humans have on the natural world

Bar cleaning – the act of cleaning the sediment from oyster bar material (usually shell) using dredges

Bar rehabilitation – the removal of sediment and diseased oysters from an oyster bar

Bathymetry – the measurement of depths of large bodies of water such as oceans, seas, and bays

Benthos – organisms that live on or in the bottom of a body of water

Biodeposit – excreted undigested materials, including feces and pseudo-feces, after active filter feeding by suspension-feeding bivalves; such material that falls to the sediment surface

Biomass – the dry weight of living matter, including stored food, or a measurement used to quantify the population of a particular species in terms of a given area or volume of the habitat

Bivalves – marine mollusks, including clams, oysters, and scallops, with a 2-valved, hinged shell; usually filter feeders that lack a distinct head

Broodstock – a small population of any mature animal maintained as a source of population replacement or for the establishment of new populations in suitable habitats

Collaborating Agency – Interested agencies, including federal, state, local, and NGOs, with an interest and/or expertise in Chesapeake Bay oyster restoration that, at the request of USACE, participated closely in development of this master plan, by providing technical guidance, participating in meetings, and providing a review of master plan documents. There are no legal, binding responsibilities of the collaborating agencies to participate.

Commensal Organisms – organisms that rely on a host for a benefit but does not harm or benefit the host (i.e., an oyster bar provides protection for crabs and a hard substrate for barnacle settlement)

Cooperating Agency – Within the NEPA process, the lead Federal agency can request any other Federal agency which has jurisdiction by law to be a cooperating agency. In addition, any other Federal agency which has special expertise with respect to any environmental issue, which should be addressed in the statement may be a cooperating agency upon request of the lead agency. An agency may request the lead agency to designate it a cooperating agency. Responsibilities of the lead and cooperating agencies are specified in 40 C.F.R. § 1501.6.

***Crassostrea virginica* –** Eastern or American oyster indigenous to the Chesapeake Bay

Crustaceans – a class of anthropod animals in the subphylum Mandibulata with jointed feet and mandibles, two pairs of antennae, and segmented bodies encased in chitin

Cultch – this often means any substrate for oysters, not just oyster shells, such as surf clam shells forming an oyster bed and furnishing points of attachment for the spat of oysters.

Dermo – an oyster disease caused by a parasitic, single-celled organism called *Perkinsus marinus*

Disease resistant strains – several oyster strains known as DEBY and Crossbred have been developed that show some resistance to MSX and dermo; there is no known oyster immune to MSX and dermo

Dissolution – the process of dissolving a solid into solution

Dredged shell – shell dredged from historic oyster bars that no longer function as such, only one active area is used in this way and is nearly depleted

Ecological restoration – a branch of natural resource management wherein active intervention is undertaken because natural processes are unable to remedy the impairment in a timely manner

Ecology – the scientific study of the distribution and abundance of life and the interactions between organisms and their environment

Ecosystem – a functional system that includes the organisms of a natural community, together with their environment

Epibenthic – relating to the area on top of the sea floor

Epifauna – organisms that live on the surface of the bottom of an ocean, lake, or stream, or on other bottom-dwelling organisms (adj: epifaunal)

Fecundity – an oysters' capacity of producing offspring

Fishery restoration – the combination of measures undertaken to achieve a sustainable economic fishery resource

Fishing Mortality – deaths in a fish stock caused by fishing

Flocculant – An aggregate that causes suspended particles to clump or aggregate

Freshet – a huge influx of freshwater during storm events that can kill very young oysters; typically affects low salinity oyster populations

Genetic Rehabilitation – strategy to promote the development of disease resistance in wild oyster stock by concentrating oysters with some level of disease resistance into hydrodynamically retentive systems so that reproduction will be retained with the system

Harvest reserves – oyster restoration areas protected from harvest for several years to allow oysters to mature then open to harvest

Hinge – the area formed by the joined valves at the anterior of the oyster

Hydrodynamic – the study of the motion of a fluid and of the interactions of the fluid with its boundaries, especially in the incompressible, viscid case

Hypoxia – oxygen deficiency; any state wherein a physiologically inadequate amount of oxygen is available to or used by tissue, without respect to cause or degree (adj.: hypoxic); > 2.0 mg/L in Chesapeake Bay

Intensity (of disease) – a measure of the concentration of disease-causing parasites within an oyster; high disease intensity generally results in mortality

Intertidal zone – the area that is exposed to the air at low tide and submerged at high tide; also known as the foreshore

Invertebrate – an animal without a backbone or internal skeleton

Keystone species – a species that has a disproportionate effect on its environment relative to its abundance; such species affect many other organisms in an ecosystem and help to determine the kinds and numbers of other species in a community

Mantle – Two fleshy folds of tissue that cover the internal organs of the oyster and are always in contact with the shells but not attached to them. Its principal role is the formation of the shells and the secretion of the ligament as well as playing a part in other biological functions (i.e., sensory reception, egg dispersal, respiration, reserve stores, and excretion).

Maryland Historic Named Oyster Bars – the traditional boundaries and names of the historic oyster bottom based on Yates survey where generations of watermen have harvested oysters; replaced in 1983 by legally defined “Natural Oyster Bars” (see definition below)

Mean lower low water – a tidal datum; the average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch

Megalops – the postlarval stage of crabs that has a large or flexed abdomen and the full complement of appendages

Mesohaline – moderately brackish, estuarine water with salinity ranging from 5 to 18 ppt

Metapopulation – a “population of populations” in which distinct subpopulations (local populations) occupy spatially separated patches of habitat; The habitat patches exist within a matrix of unsuitable space, but organism movement among patches does occur, and interaction among subpopulations maintains the metapopulation

Mollusks – one of the divisions of phyla of the animal kingdom containing snail, slugs, octopuses, squids, clams, mussels, and oysters; characterized by a shell-secreting organ, the mantle, and a radula (a food-rasping organ located in the forward area of the mouth)

Natural Oyster Bars – The present locations and classifications of legally defined Oyster bars which were formally adopted in 1983 and defined by statute in the Annotated Code of Maryland. Extensive changes to the original charted bar boundaries were made, and coded numbers replaced names of individual oyster bars. These new legally defined "Natural Oyster Bar" boundaries were developed in an attempt to simplify the complex oyster bar boundaries of the historic oyster bar locations.

Oligohaline – nearly fresh to mildly brackish, estuarine water with salinity ranging from 0.5 to 5 ppt

Oxic – containing oxygen; with oxygen; oxygenated

Oyster bar – the structure and habitat created by oysters as they grow; interchangeable with oyster bed; often referred to as ‘bar’

Oyster bed – see oyster bar; interchangeable with oyster bar

Oyster reef – oyster bar or bed with substantial three dimensional elevation off the bottom as was typical of historic southern-style oyster habitat; ‘reef’ (rather than bar) is used when referring to all habitat structure such as the ‘reef matrix’ or ‘reef community’; ‘reef’ is also used to refer to oyster habitat when referencing a scientific paper that used reef as opposed to bar or bed

Pelagic – the part of a body of water that is located in the upper layer of open water column, overlaying the demersal and benthic zones i.e., the part of the ocean that is not near the coast or continental shelf; also known as the open-ocean zone

Phytoplankton – microscopic algae suspended in the part of the water column of lakes, rivers, and seas that is penetrated by light

Plankton – small organisms, usually minute plants and animals, that float or drift in water, especially at or near the surface

Polychaete – a class of chiefly marine annelid worms (e.g. clam worms) usually with paired segmental appendages, separate sexes, and free-swimming larvae

Polyhaline – estuarine water with salinity ranging from 18 to 30 ppt

Prevalence (of disease) – A measure of the frequency of occurrence of infection (i.e., the percent of examined oysters that contain at least one disease causing parasite)

Propagate – to reproduce sexually or by other forms of multiplication or increase

Protozoans – a diverse phylum of microorganisms; the structure varies from a simple, single-celled animal to colonial forms

Pseudofeces – material rejected by suspension feeders or deposit feeders as potential food before it enters the gut

Recruitment – the process of adding new individuals to a population or subpopulation by reproduction, growth, immigration, or stocking; for the purposes of the master plan, recruitment refers to adding new individuals by reproduction

Rehabilitation (of habitat) – any of a range of approaches for attempting to increase the amount of suitable habitat for oyster settlement and growth by counteracting siltation; "standard" habitat rehabilitation involves placing relatively thin layers of clean shell on existing hard bottom; other methods include constructing three-dimensional bars of oyster shell or using alternative materials to provide settlement substrate

Repletion – the noun form of the adjective 'replete' meaning filled or well supplied; specifically, efforts or programs to increase the supply of oyster-shell substrate to encourage settlement of larval oysters

Resilience – the capacity of an ecosystem to withstand disturbances without shifting to an alternate state

Resistance (to disease) – an oyster either is not susceptible to disease or is subject to only limited infection

Restoration (of population) – any of a range of approaches for attempting to increase the population of oysters in Chesapeake Bay to a level at which it provides desired ecosystem services and supports a commercial fishery (e.g., habitat rehabilitation, planting seed oysters)

Salinity – a measure of the concentration of salt in water

Sanctuary – oyster bar or bars protected from harvest

Scarp – a terrace feature, generally a sloping side wall or edge that descends into, and defines the boundary of an existing river channel or sediment filled paleochannel (Smith et al. 2003)

Seed bar – an oyster bar created for the purpose of growing, collecting, and redistributing spat

Self-Sustaining Population – For oysters, recruitment exceeds mortality and shell is accreting faster than it is degrading

Sessile – permanently attached to a substrate

Seston – particulate matter, such as plankton, organic detritus, and silt suspended in seawater

Shell reclamation – the collection and reuse of shell from oyster bars that are no longer functioning

Shell-string – twelve oyster shells of similar size drilled through the center and strung on heavy gauge wire

Shell-string survey – placement of shell-strings in an estuary for the settlement of spat; a survey involves regular replacement of shell-strings and the counting of the number of spat that settle on the smooth underside of the middle ten shells; the resulting data provide an index of oyster population reproduction, an estimate of the development and survival of larvae to the settlement stage in a particular estuary, and an estimate of potential oyster recruitment into a particular estuary (VIMS 2011)

Siltation – the building up of fine-grained sediment on the bottom of a water body

Socioeconomics – the study of the relationship between economic activity and social life

Spat – a young oyster

Spatset (or spatfall) – the number of sessile oyster spat found attached to an oyster bar or other substrate, a measured amount of oysters such as a bushel; reproduction measure of oyster production in that year

Specific Pathogen Free (SPF) hatchery bred spat – spat produced at a hatchery and known to be free of MSX or dermo; also referred to as 'disease free hatchery bred spat'

Stakeholder – a party who affects, or can be affected by an action

Stock – semi-discrete subpopulations of a particular species of fish with some definable attributes which are of interest to fishery managers

Strain – an animal or plant from a particular group whose characteristics are different in some way from others of the same group

Subtidal – pertaining to that part of the bay bottom immediately below the intertidal zone and thus permanently covered with seawater

Suspension feeder – an animal that feeds on small particles suspended in the water; particles may be minute living plants or animals, or products of excretion or decay from other organisms

Sustainable – the state of a resource, whereby function is able to maintained either naturally or which periodic manipulations

Terrace – typically flat, terrestrial land mass in the Chesapeake Bay that became submerged during the Holocene period as sea level rose; can now be either buried with sediment or exposed

Topography – the general configuration of a surface, including its relief; may be a land or water-bottom surface

Total suspended solids – a measure of solids in the water

Turbidity – a measure of the cloudiness of water

Valves – the two shells of the oyster

Veliger – a larval planktotrophic mollusk in the stage where the shell, foot, and other structures make their appearance; they are planktonic (drifting) and most (but not all) are planktotrophic (they eat phytoplankton, except those groups that live on yolk sacs)

Zooplankton – small to medium sized (usually microscopic) animals that are free-swimming and thus are suspended in the water of oceans, rivers, and lakes; jellyfish are one of the largest zooplankton in Chesapeake Bay

1.0 INTRODUCTION

The eastern oyster (*Crassostrea virginica*) was once abundant throughout the Chesapeake Bay and its tributaries, and was a critical component of the ecological character of the Bay. Oysters once contributed significantly to maintaining water quality and aquatic habitat in the Chesapeake Bay ecosystem. Oysters also supported an economically important fishery and were of great cultural value to many residents of the Bay area. Approximately 450,000 acres of oyster habitat were mapped by Baylor (1894) and Yates (1906-1911) around the turn of the 20th Century. It has been widely accepted that current oyster populations are approximately 1 percent of historic abundance (Newell 1988 as cited by USACE 2009), and that remaining bars are in poor condition. Wilberg et al. (2011) have refined that estimate and project that oyster abundance has declined by 99.7 percent since the early 1880s and 92 percent since 1980, and that habitat has been reduced by 70 percent between 1980 and 2009.

Oyster restoration efforts have been ongoing in the Chesapeake Bay for decades. However, past efforts have mostly been very small in scale and scattered throughout many tributaries. This native oyster restoration master plan (master plan) presents the U.S. Army Corps of Engineers' (USACE) plan for large-scale, concentrated oyster restoration throughout the Chesapeake Bay and its tributaries.

The USACE oyster restoration program was established by Section 704(b) of the Water Resources Development Act of 1986 with subsequent amendments in 1996, 2000, and 2007. WRDA provides USACE the authority to construct oyster reef habitat. USACE (Baltimore and Norfolk Districts) began to assess the potential for oyster restoration in the Chesapeake Bay in 1995 and 2000, respectively. Both districts had completed oyster restoration projects independently before determining that a more coordinated approach was needed for the entire Chesapeake Bay. The master plan is in response to that need.

In 2009, the Norfolk District, in cooperation with the Maryland Department of Natural Resources (MDNR) and the Virginia Marine Resource Commission (VMRC), as well as the Potomac River Fisheries Commission (PRFC), the Environmental Protection Agency (EPA), the National Oceanographic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service (USFWS), and the Atlantic States Marine Fisheries Commission (ASMFC), prepared the 2009 *Programmatic Environmental Impact Statement EIS (PEIS) for Oyster Restoration in Chesapeake Bay Including the Use of Native and/or Non-native Oyster* (USACE 2009). This document recommends pursuing only native oyster restoration in the Chesapeake Bay and serves as an umbrella document to this master plan.

The population of the native eastern oyster has declined to a small fraction of its historical abundance, and restoration efforts undertaken to date have failed to reverse the decline. Recognizing this failure and the significant ecological, economic, and cultural role that oysters play in the Chesapeake Bay, this master plan will provide a detailed programmatic approach to large-scale restoration of this valuable resource.

The master plan is a planning document, covering an expected 20 years of restoration efforts in waters throughout the Chesapeake Bay and its tributaries. The purpose of the master plan is to provide a long-term strategy for USACE's role in restoring native oyster populations in Chesapeake Bay. The master plan will serve as a foundation, along with plans developed by other federal agencies, to work towards achieving the oyster restoration outcome established by the Chesapeake Bay Protection and Restoration Executive Order (E.O. 13508) (further discussed in Section 2.2.1) to restore native oyster habitat and populations in 20 tributaries by 2025.

The master plan describes a restoration strategy that is consistent with USACE authorization, policy guidance, and regulations as well as other Chesapeake Bay Restoration Plans. The master plan is only one piece of a comprehensive effort to restore oysters in the Chesapeake Bay. It benefits from a tremendous amount of hard work, planning, and research on the part of many individuals and organizations and the documents they produced, including the 2004 *Chesapeake Bay Program Oyster Management Plan* (OMP) (CBP 2004a), and 2009 PEIS. For comprehensive restoration to take place, many federal, state and local partners will need to be involved. These federal, state, and local agencies and groups may develop complementary master plans within their own unique mission, funding, and authorizations. The master plan is not intended to describe all of these efforts, but is intended to be consistent with other agency's plans and to allow USACE to work in conjunction with the partners in the Chesapeake Bay region.

1.1 STUDY AREA

The study area for the master plan includes all portions of the Chesapeake Bay that historically supported oysters. The Chesapeake Bay is the nation's largest estuary, encompassing approximately 2,500 square miles of water (Figure 1-1). The watershed discharging into the Bay is approximately 64,000 square miles and includes parts of six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) and the District of Columbia.

1.2 STUDY PURPOSE AND NEED

The purpose of the master plan is to provide a long-term plan for USACE's role in restoring native oyster populations in Chesapeake Bay. The master plan will: (1) examine and evaluate the problems and opportunities related to oyster restoration; (2) formulate plans to restore sustainable oyster populations throughout the Chesapeake Bay; and (3) recommend plans for implementing large-scale Bay-wide restoration.

1.2.1 BACKGROUND

This study builds upon the findings of the 2009 PEIS. The PEIS identified a need for the commitment of sustained resources (over $35 to 60 million per year for a 10-year period) to implement its recommendations for native oyster restoration. The decision making process, ranked the assessment category of Environment and Ecological as the highest priority, and the category of Social Effects as the lowest priority. The preferred alternative consists of the following recommendations:

Figure 1-1. Chesapeake Bay Watershed

- ***Alternative 2 (Enhanced Native Oyster Restoration)*** - Expand, improve, and accelerate Maryland's oyster restoration and repletion programs, and Virginia's oyster restoration program in collaboration with federal and private partners. Most spat would be planted on sanctuaries. Although the kinds of future restoration activity may differ from those evaluated, the level of activity will be substantially greater than past levels.

- ***Alternative 3 (Harvest Moratorium)*** – Implement a temporary harvest moratorium on native oysters and an oyster industry compensation (buy-out) program in Maryland and Virginia or a program under which displaced oystermen are offered on-water work in a restoration program. In lieu of a total moratorium, the lead agencies envision implementing more restrictive oyster harvesting management regimes (e.g., annual harvest quotas; closed and open harvesting areas) that would be biologically and economically sustainable, that would include accountability measures, and that would minimize the effects of harvest on the potential development of disease resistance.

- ***Alternative 4 (Expansion of Native Oyster Aquaculture)*** - Establish and/or expand State-assisted, managed or regulated aquaculture operations in Maryland and Virginia using the native oyster species. Both states may expand technical aquaculture support programs, particularly in the training of watermen who may be interested in transitioning from wild harvest to aquaculture. State expenditures to support aquaculture expansion may increase in the future and, thus, may be greater than those considered in the PEIS.

- Pursue the establishment of realistic metrics, accountability measures, and a performance-based adaptive management protocol for all efforts to revitalize the native oyster for purposes of achieving commercial and ecological goals.

Historically, oysters were found in extensive, beds many acres in size, throughout their range in the Chesapeake Bay. Approximately 450,000 acres of oyster habitat were mapped in Virginia by Baylor in 1894 (Baylor 1895) and in Maryland by Yates from 1906-1911 (Yates 1913). Oyster populations in the Chesapeake Bay have declined dramatically, largely due to parasitic diseases, historic overharvesting, degraded water quality, and the loss of habitat. Today, oyster population is estimated to be just 1 percent of its historical abundance.

Oysters provide significant ecological value and ecosystem services. The eastern oyster is a keystone species in the Chesapeake Bay ecosystem, providing critical habitat and performing essential water quality functions. The bars and reefs created by oysters are the principal hard structural habitat naturally found in the Chesapeake Bay. They provide refuge and foraging habitat for estuarine fish and invertebrates, supporting species abundance and diversity in the Bay, including commercially important species such as juvenile striped bass and blue crabs.

Historically, the oyster served as the Bay's primary filter-feeding organism. Newell (1988) projected that prior to Bay-wide degradation, the oyster population filtered the entire Bay water volume within days; and that it takes over a year at present population levels. The loss of the oyster's filtering capacity coupled with historic and ongoing human-induced pollution from the watershed has had a profound negative effect on the entire Chesapeake Bay ecosystem.

Restoring functioning oyster bars will provide physical habitat for native fish and aquatic wildlife as well as water quality improvements that will promote a more healthy estuarine system. Oysters filter the Bay's water, playing an important role in sediment and nutrient removal and transformation, helping to maintain clean water that contributes to habitat quality. The commercial oyster fishery contributes social and economic value to the Bay area and would also benefit from a restored network of sustainable oyster bars. It is anticipated that indirect benefits of large-scale restoration such as increased recruitment in areas open to harvest and the potential development of disease resistance within the oyster population would greatly benefit the oyster industry.

1.3 ONGOING AND PRIOR STUDIES AND RESTORATION

1.3.1 USACE RESTORATION

USACE has been involved in the Chesapeake Bay since colonial days with civil works and military missions. Recently, both the Baltimore and Norfolk Districts have been actively involved in ecosystem restoration efforts within the Chesapeake Bay watershed including oyster restoration. Appendix A contains the full text of the study authority, Section 704(b) of the Water Resources Development Act of 1986, as amended, under which this work is being accomplished.

In 1996, USACE-Baltimore completed a report entitled *Chesapeake Bay Oyster Recovery Project, Maryland 1996* (USACE 1996). This 1996 report documents the plan formulation conducted by the Baltimore District and its local sponsor, MDNR.

Implementation of the recommendations made by this plan began in 1997 and is ongoing. The recommendations included the following activities:

- ***Hatchery upgrades*** – The State of Maryland completed upgrades to the Piney Point and Horn Point hatcheries to increase spat production needed for restoration efforts.
- ***New bar construction*** – Placement of cultch, or oyster shell, to create a suitable bottom substrate on which spat will settle and fix themselves to form a bar.
- ***Seed bar construction*** – Even with upgrades, hatcheries were not expected to meet the demand of spat necessary for the work recommended under the 1996 plan; bars that would produce spat and could be harvested for use on nearby new substrate bars were recommended.

Planting fossil shell for restoration in the Lynnhaven River, VA. Shell is blown from barges using high-powered water cannons. Photograph provided by USACE-Norfolk.

- ***Rehabilitation of existing bars*** – Raising, reclaiming, and cleaning oyster bars involves removing sediment that has covered an existing bar, making the substrate suitable for oyster spat.

- ***Use of disease-free spat and disease-resistant strains of the eastern oyster*** – Some strains of the eastern oyster developed at universities or found in other parts of the Atlantic seaboard may be more resistant to disease than the disease-free oysters currently developed. Recently, disease resistance is being documented in high salinity wild stocks (Malmquist 2009; Carnegie and Burreson 2011).

Using combinations of these recommendations, a 5-year construction plan was implemented in the Maryland waters from 1996 through 2000. The tributaries and sites chosen to implement these measures were largely based on experience and the designation of oyster recovery areas (ORA), as defined in the *Maryland Oyster Roundtable Action Plan* (MDNR 1993). The selected sites were located in the Choptank, Patuxent, Chester, Magothy, Severn and Nanticoke Rivers.

In May 2002, the Baltimore District prepared an additional decision document to include project construction beyond 2000 and to increase the total project cost. This construction, known as Phase II, continues today. To date the Baltimore District has constructed approximately 450 acres of oyster bars throughout the Maryland portion of the Chesapeake Bay.

Of these 450 acres, 181 acres were constructed as harvest (official and unofficial) reserves through 2005. Harvest reserves were set aside to permit the oysters to grow to 4 inches in size. Typically, oysters are harvested at 3 inches. Permitting the oysters to reach 4 inches before being harvested provided increased ecosystem benefits. Harvest reserves were also an approach to disease management by permitting the harvest of oyster populations that were beginning to develop disease. Harvest reserves were monitored and opened for a managed harvest only when a set percent of the oysters were 4 inches in size or if disease hit a certain level. USACE no longer views harvest reserves as being in the federal interest since the benefits of the federal investment are ultimately harvested. Additionally, the approach to manage disease has evolved. The value of leaving diseased populations in the water is accepted as a way to promote disease resistance.

The Norfolk District has been active in oyster restoration since 2000. The local sponsor is the Virginia Marine Resources Commission acting on behalf of the Commonwealth of Virginia. Several reports on these projects are cited in Section 10 (References). The first project was completed under Section 510 of the WRDA 1986, as amended, and the remaining projects were constructed under Section 704(b), as amended. To date, about 400 acres of oyster bars have been constructed in the Virginia waters of the Bay. Norfolk led restoration activities have been focused in the Rappahannock River, Tangier/Pocomoke Sound, Great Wicomico River, and Lynnhaven River. Past USACE efforts are summarized in Table 1-1.

1.3.2 SUMMARY OF PAST BAY-WIDE OYSTER RESTORATION

The most comprehensive analysis of past restoration efforts was coordinated by Maryland Sea Grant and is summarized in *Native Oyster (Crassostrea virginica) Restoration in Maryland and Virginia: An Evaluation of Lessons Learned 1990-2007* (ORET 2009). The evaluation team gathered data from 11 agencies. Restoration activities were reported for 378 and 216 bars in Maryland and Virginia, respectively; whereas monitoring was performed at 453 and 437 bars in Maryland and Virginia, respectively. A total of 1,035 sites had restoration, monitoring, or both activities. Restoration actions differed widely at each site and included bagless dredging, bar

Table 1-1. USACE Oyster Restoration Projects

Location	Year	Acres	Cost**	Cost/acre	Status
MARYLAND					
Choptank, Patuxent, Kedges Straight (Tangier Sound)	1997	38	$402,000	$10,700	Illegally harvested or killed by Dermo; one bar mud covered; spatset minimal on seed bars; one site performed well through last monitoring in 2008.
Chester, Kedges Straight	1998	30	$302,000	$10,100	Illegally harvested; spatset minimal on seed bars; patchy high densities of large oysters on sanctuary.
Magothy, Severn, Patuxent, Eastern Bay	1999	30	$673,000	$22,800	Sediment and MSX impacted Patuxent bars; moderate densities on some Magothy sites, other covered by mud.
Choptank	2000	3	$144,000	$57,600	Patchy high densities of large oysters at base of mounds.
Chester	2001	5	$25,000	$5,000	Harvested in 2004.
Choptank, Patuxent	2002	55	$746,000	$13,600	Patchy high densities of large oyster on sanctuaries; reserves harvested in 2004/2005; one bar mud covered.
Chester, Choptank	2003	84	$794,000	$9,400	Patchy high densities of large oyster on sanctuaries; reserves harvested; one bar potentially mud covered.
Chester, Choptank	2004	63	$678,000	$10,800	Patchy high densities of large oyster on sanctuary; reserve harvested.
Chester	2005	72	$696,000	$9,700	Patchy high densities of large oyster on sanctuary; reserves harvested.
Chester	2006	59	$585,000	$9,900	One site dense oysters. Others unknown.
Severn	2009	13	$1,681,000	$126,000	Seeded in August 2010, monitored 2011
Choptank River-Cook Point	2011	8.5	$1,387,000	$163,000	Seeded in August 2011, monitoring is being planned
Harris Creek	2012	22	$1,477,000	$67,000	Seeded in August 2012, monitoring is being planned

VIRGINIA					
Rappahannock*	2000/ 2001	3 (sanctuaries), 90 (harvest grounds)	$1,200,000	$100,000 (sanctuaries); $10,000 (harvest grounds)	Habitat resulted in small increases in local oyster populations on sanctuaries.
Tangier/Pocomoke Sound	2002	8 (sanctuaries), 150 (harvest grounds)	$3,600,000	$264,000 (sanctuaries); $10,000 (harvest grounds)	Habitat resulted in small increases in local oyster populations on sanctuaries.
Great Wicomico	2004	68	$3,000,000	$44,100	Population has increased 50-fold over 1994 estimates
Lynnhaven	2007 /2008	40	$5,000,000	$125,000	Monitoring on-going

*Project constructed under Section 510 of WRDA 1986; all other projects constructed under Section 704(b) of WRDA 1986
**Costs are federal including planning, design, and construction (projects are cost-shared 75 percent federal/25 percent Non-federal).

cleaning, hatchery seed transplant, substrate addition, wild seed transplant, with and without monitoring. These activities were employed singularly and in various combinations on 10,398 acres in Maryland and 2,214 acres in Virginia. Wild seed transplant was the largest effort in Maryland, being carried out on 6,896 acres, mostly prior to 2000. In Virginia, substrate addition constituted the greatest application on 1,749 acres.

To put past restoration efforts into perspective, the extent of historic habitat needs to be considered. Although oyster resources were already showing signs of diminished harvests, the Yates survey of 1906-1911 is the most comprehensive account of historic oyster resources in Maryland (Yates 1913). The Yates survey identified 779 named bars on 214,772 acres. The past restoration efforts of 10,398 acres in Maryland accounts for restoring 4.8 percent of the habitat identified by Yates. It can be assumed that the wild seed transplant efforts targeted fishery improvements rather than ecological restoration. Therefore, if those acres are removed from the picture, that reduces the effort focused on ecosystem restoration to just 1.6 percent of historic acreage. In 1894, the Baylor survey mapped 232,016 acres of oyster habitat in Virginia. The 2,214 acres of restoration performed in Virginia amounts to addressing approximately 1.0 percent of historic acreage. The USACE team has compared the Baylor grounds to the more detailed Moore survey (Moore 1909), and estimated that only 47 percent of the Baylor grounds contained oyster habitat. Even with that in consideration, restoration efforts in Virginia have only addressed 2 percent of historic acreage. Figure 1-2 depicts the oyster bars identified by the Yates and Baylor surveys. Contextually, it also needs to be considered, that these past restoration efforts were scattered across the Maryland and Virginia tributaries and not concentrated in any way. Further, there is no adjustment of the total restored acres for multiple actions on individual acres, likely resulting

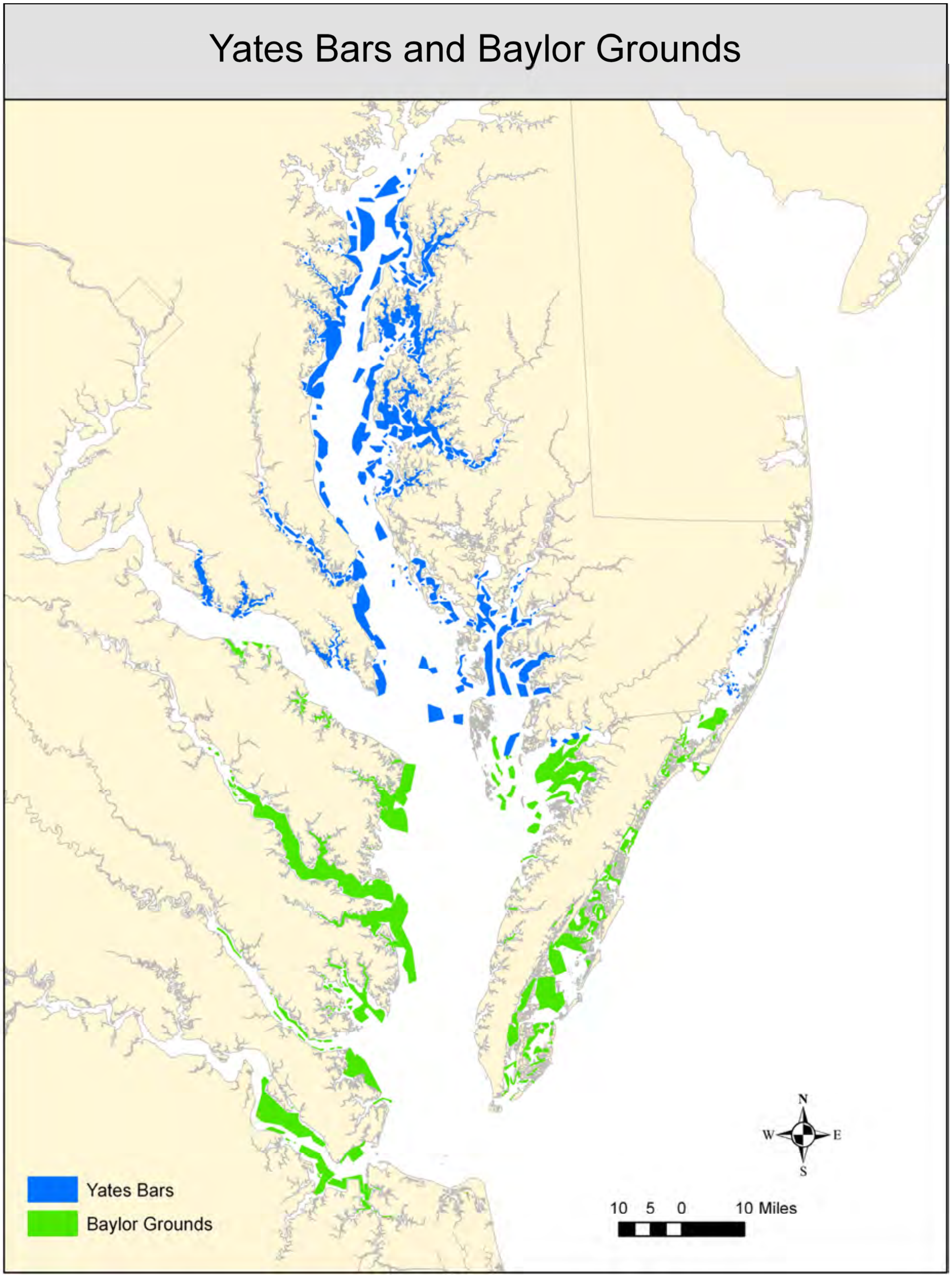


Figure 1-2. Yates Bars and Baylor Grounds in the Chesapeake Bay

in an overestimation of acres restored. That is, if two actions were performed on the same acre at the same time, ORET (2009) recorded this as 2 acres of restoration. Given this, it can be assumed that an even smaller percentage of historic acreage has received restoration treatments in Maryland.

The small gains achieved by past restoration practices (efforts through 2007) are understandable once the scale at which they were carried out is understood. At best, only 2 percent of the historic acreage has been the focus of restoration efforts since 1990. It also needs to be recognized that past restoration was largely completed as discrete projects rather than as part of a holistic approach. These areas were small and scattered, often focused on fishery enhancements rather than comprehensive ecosystem goals, and neither addressed a critical biomass or critical area for spatial complexity necessary for system-wide restoration.

1.3.3 Oyster Restoration by Partners

The following sections discuss oyster related activities by USACE's restoration sponsors and partners. Numerous agencies and groups are involved with oyster restoration because of the magnitude and significance of the problem. Efforts span many aspects of restoration based on differences in missions, expertise, and capabilities.

1.3.3.1 Maryland Department of Natural Resources

Since the 1960s, MDNR managed an oyster program to repopulate natural oyster bars in harvest areas where natural reproduction or habitat were inadequate. This repletion program was focused on increasing the oyster harvest by placing fresh or dredged shell and transplanting seed oysters. This program has been discontinued because shell is not available and spatsets have been too low to warrant transplanting.

Maryland has recently expanded its oyster sanctuary network to include 24 percent of oyster habitat remaining in state waters, including several of the state's most productive oyster bars. By removing fishing pressure from these areas, the state hopes to increase oyster population size, foster the development of disease resistance, and encourage the development of three-dimensional bar structure. The state is rehabilitating those oyster bars that have been covered by sediment. Through collaboration with the Oyster Recovery Partnership (ORP), the state works with local watermen to dredge up and aggregate buried shell; any live oysters collected are placed on top of the clean shells. The state is also reclaiming old shell plantings that have been covered with sediment, and redeploying these shells in areas likely to receive a spatset. Through MDNR's Marylanders Grow Oysters program, private citizens participate in restoration efforts. Citizens raise oysters in cages hung from their docks, and deposit the oysters in sanctuaries when they reach an age of approximately nine months. Maryland also works with federal agencies including NOAA, USACE, and the USFWS to restore oyster habitat in the Chesapeake Bay.

1.3.3.2 Virginia Marine Resources Commission

The Virginia Marine Resources Commission (VRMC) manages oyster resources in Virginia through restoration efforts, enforcement of fishing regulations, determination of areas open to harvest/sanctuaries, surveying grounds for public and private leasing, and permitting and licensing of aquaculture permits. Since the early 1990s, the Virginia Institute of Marine Science (VIMS) Molluscan Ecology program has partnered with VMRC to monitor the status of oyster populations at restoration sites in Virginia. VIMS has been active in oyster monitoring in Virginia waters since the 1940s.

1.3.3.3 National Oceanic and Atmospheric Administration

NOAA plays an extensive role in Chesapeake Bay native oyster restoration. Historically, NOAA has provided congressionally-directed funding to MDNR and VMRC for in-water oyster restoration work. Additionally, NOAA funds oyster research and community-based oyster restoration projects. NOAA provides habitat mapping and assessment using multi-beam sonar equipment to inform oyster restoration site selection and for project monitoring. Currently NOAA is developing the Oyster Data Tool. This is a geospatially-referenced data base that will house data on oyster harvest, restoration activity, spatset, disease, abundance, boundaries (ex: leases, sanctuaries, public bars, seed areas, historic bars, etc), bottom quality, and water quality, among other parameters. It will be available to resources managers and the public. NOAA is also working to promote oyster aquaculture in the Chesapeake. Examples include presenting the draft Oyster Data Tool to the MD Aquaculture Coordinating Council and similar groups in VA, and by helping USDA NRCS staff in MD to develop reporting and monitoring criteria for the Environmental Quality Incentives Program (EQIP) funding that will pay growers to put shell and spat-on-shell on their aquaculture leases to improve bottom habitat. Similar to other federal agencies involved in oyster restoration, NOAA's current oyster restoration work is driven by the restoration goals in E.O. 13508. In keeping with this, NOAA also chairs the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team (GIT) to coordinate oyster restoration and fisheries management issues Bay-wide based on the best available science.

1.3.3.4 U.S. Fish and Wildlife Service

USFWS views oyster bar restoration in the Chesapeake Bay as an essential part of their core mission to conserve, protect, and enhance the region's fish, wildlife, plants, and their habitats for the continuing benefit of the American people. In addition to the benefits to water quality, USFWS recognizes the significant role oyster bars have as habitat for feeding and refuge by many valued fish species. Additionally, the diverse faunal bar assemblage provides valuable winter foraging to waterfowl such as the black scoter.

To support E.O. 13508, USFWS has developed a draft strategy to guide the agency's oyster restoration activities. USFWS recognizes that there are many key players involved in a comprehensive Bay-wide strategy, and is looking to focus its efforts on sites and oyster bar habitat restoration projects that will maximize benefits to habitat for anadromous fish, migratory birds, and endangered species as well as those that will have direct benefits to the National Wildlife Refuge System. USFWS's draft strategy is available on its website: *http://www.fws.gov/chesapeakebay/OysterInitiative.html.*

1.3.3.5 U.S. Environmental Protection Agency

Although not directly active in construction of oyster restoration projects, the EPA is a key partner in oyster restoration given their mission to regulate clean water, administer the Chesapeake Bay Program, and coordinate *The Strategy for Protection and Restoration of the Chesapeake Bay* developed under E.O. 13508 to restore the Chesapeake Bay. Further, EPA played a significant role in completion of the PEIS.

1.3.3.6 The Potomac River Fisheries Commission

The Potomac River Fisheries Commission (PRFC) was created by the adoption of the *Maryland and Virginia Potomac River Compact of 1958* (Compact) by the states of Maryland and Virginia. PRFC is charged with the establishment and maintenance of a program to conserve and improve the abundant fishery resources of the tidewater portion of the Potomac River. PRFC regulates the fisheries of the main stem of the tidal Potomac River, including oysters, from the Maryland/Washington D.C. boundary line (near the Woodrow Wilson Bridge), to the mouth of the river at Point Lookout, MD and Smith Point, VA. PRFC is pursuing oyster restoration efforts in targeted areas of the Potomac mainstem and permits oyster gardening.

Healthy (top) oyster bar habitat compared to poor oyster bars (bottom). Photographs courtesy of Paynter Labs.

1.3.3.7 Chesapeake Bay Foundation

The Chesapeake Bay Foundation’s (CBF) oyster restoration program provides citizens with the tools and information needed to help restore native oysters to the Chesapeake. CBF is focused on leveraging public and private investment for oyster restoration, improving public awareness and knowledge of the value of oysters to the Bay, providing the public hands-on involvement in restoration, developing partnerships, and promoting education and scientific research. CBF acknowledges that oyster restoration is a long-term process that will require the participation and commitment of federal and state agencies and citizens alike for many years.

CBF has established the Oyster Restoration Center (ORC) to serve as the central location for all of CBF’s oyster restoration activities in Maryland. The ORC houses a facility to set hatchery bred spat onto shell. The spat-on-shell are then planted on sanctuaries. CBF's restoration vessel, *Patricia Campbell*, transports and places hatchery-produced seed oysters onto sanctuary bars throughout Maryland waters, as well as oyster shell and other materials for bar construction. CBF also coordinates an oyster gardening program in Maryland. This program enables local citizens to grow oysters at their dock for planting onto sanctuaries. In Virginia, CBF runs a shell recycling program, creates living shorelines using oyster shells, runs a citizen based oyster gardening program, works with the non-profit, Lynnhaven River Now, on a student based oyster gardening program, operates a small commercial scale oyster farm to support aquaculture, produces up to 10 million spat-on-shell for broodstock enhancement on sanctuary reefs, and produces up to 200 low profile reef balls set with oyster larvae for planting on Virginia sanctuary reefs.

1.3.3.8 Oyster Recovery Partnership

The Oyster Recovery Partnership (ORP) is a non-profit organization that promotes, supports and restores oysters for ecologic and economic purposes. ORP is engaged in various aspects of oyster restoration from large on-the-ground and in-the-water recovery efforts to research and education. ORP oversees and manages the planting of hatchery seed throughout Maryland waters each summer. ORP facilitates the hiring of watermen to perform various restoration efforts including the removal of ghost crab pots and the dredging of buried oyster shell. ORP's Shell Recycling Alliance collects oyster shell from regional restaurants to be reused by the Horn Point Hatchery for recovery efforts. ORP also provides seed for aquaculture, partners with local universities to perform research, and is active in public outreach and education.

1.3.3.9 The Nature Conservancy

The Nature Conservancy (TNC) is a leading conservation organization working around the world to protect ecologically important lands and waters for nature and people. TNC supports oyster restoration in Chesapeake Bay. At a national scale, TNC has dozens of oyster restoration projects organized into a "shellfish network" that shares best practices and lessons learned, and has also recently launched a year-long project to develop a set of estuary-specific and ecoregional-scale restoration goals for oyster bar habitat in the United States.

In the Chesapeake, TNC partners with public and private groups, including MDNR, VMRC, VIMS, CBF, ORP, and Virginia Commonwealth University to restore oyster reefs. They also work to raise public awareness of the importance of oysters for the Bay and funding for restoration through events such as "The Sprint for Spat Earth Day 5K" race. Oyster bar restoration is a main focal area of TNC because of the vital role oyster bar habitats play in the Bay's ecology and economy, the level of restoration needed, and the roles TNC can fill. Work to date has included rebuilding sanctuary bars, planting seed, coordination, providing scientific and policy analysis, serving on Maryland's Oyster Advisory Commission and Virginia's Blue Ribbon Oyster Panel, and advocating for increased federal and state funding for oyster restoration.

1.4 OVERVIEW OF THE MASTER PLAN APPROACH

Oyster restoration is affected by variable physical and biological factors in different regions of the Bay. The master plan team evaluated the restoration potential of tributaries and sub-regions of the Bay and grouped potential locations based upon their likelihood for long-term success. The master plan is intended to be a living document that can be modified based on new information and lessons learned through project implementation, monitoring, and adaptive management.

Native oyster restoration work implemented under this master plan is intended to be implemented in phases. By examining the oyster restoration potential of tributaries and sub-regions of the Bay, the master plan sets forth guidelines for future oyster restoration activities. The master plan team assumed that these restoration efforts would proceed in a logical sequence and pattern that is based on previous successes and lessons learned. In this way, future restoration efforts will complement and augment earlier efforts. The master plan assumed that completed restoration projects will build population strongholds that contribute to the success of succeeding restoration efforts and the overall restoration of oyster populations throughout the Bay.

1.4.1 MASTER PLAN APPROACH

The master plan incorporated information developed through the comprehensive PEIS and used its information and findings to support a more detailed evaluation of the tributaries in the Bay for <u>native</u> oyster restoration. Because of the scale of the effort, the master plan team relied on analyses performed using a geographic information system (GIS).

Information presented in the master plan is based primarily on existing data, and input from resource agencies and other restoration partners. This level of analysis is commensurate with the decisions being made and is at an appropriate level of detail to allow a comparison of the relative differences in the range of costs and potential impacts of the restoration concepts. Subsequent NEPA (National Environmental Policy Act) documents prepared for projects in individual tributaries will address site-specific details, followed by detailed design.

Many factors including, but not limited to: salinity, disease, water quality, hydrodynamics, recruitment, growth, survival, project scale and interconnectedness, historic bar locations, and substrate, must be considered when locating oyster restoration projects. It is appropriate to consider some of these factors at a Bay-wide scale while others must be investigated at a finer, tributary scale. The master plan evaluated the suitability of areas throughout the Bay to support oyster restoration by examining those factors or criteria that are available on a Bay-wide scale. The master plan also identified the factors that need to be investigated at a finer scale during development of follow-on tributary plans. (See Section 5.5 for a focused discussion of site screening criteria.) The master plan does not identify specific restoration sites, but instead groups areas of the bay into two tiers according to their potential for successful restoration.

The purpose of tier classification is to focus follow-on feasibility study efforts within the Chesapeake Bay in areas with the highest likelihood of overall success. Tier 1 tributaries would consist of the sites throughout the Bay that make up the critical first step toward achieving large-scale native oyster restoration. Tier 1 tributaries are those that are determined to have the most suitability and greatest potential to support large-scale oyster restoration efforts. Tier 2 tributaries were identified to have a current physical limitation that is concluded to limit restoration potential under current conditions. Tier 1 sites are not constrained significantly by other factors such as sedimentation, poor water quality, and/or bottom conditions, or a high incidence of predation. Success in oyster restoration in Tier 1 tributaries throughout the Bay will make up the critical first step toward achieving wide-scale native oyster restoration. In some cases, successful restoration in Tier 2 areas may depend on the success of the Tier 1 sites or other restoration projects. Tier 2 sites may also depend on other environmental changes (such as stormwater management or other water quality restoration measures) to improve restoration potential.

Photograph provided by USACE-Norfolk.

Monitoring restoration sites (above). Clean oyster shell in setting cages at Horn Point Hatchery, MD (below).

Photograph provided by MDNR.

1.4.2 Follow-On Design/Supplemental Documents

Individual tributary-specific plans will follow the master plan, with alternatives formulated separately for each Tier 1 tributary. These tributary plans may be developed as either detailed site-specific feasibility studies or, in the case of smaller efforts, design analyses with appropriate NEPA documentation. It is recognized that the age and accuracy of the information used to evaluate existing conditions and assign tributaries to tiers at the Bay-wide scale of the master plan is quite variable from one tributary to the next and in some situations very limited. The investigations and data analysis undertaken as part of the tributary plan efforts may justify changing the tier classification of a tributary.

Tributary plans would be implemented under the Section 704(b) authority until expenditures reach the funding limit. Once this limit is reached, an increase in the Congressional authorization would be needed. It is also envisioned that other partners at the Federal and state level, and even non-profit organizations, may contribute to the implementation and design of the tributary plans. Field investigations, use of alternative substrates, hydrodynamic evaluations, and other site-specific studies as necessary will be conducted to facilitate tributary-specific plan formulation.

Following the master plan, as Tier 1 tributaries are selected for restoration, an individual tributary plan will be developed to identify site-specific restoration actions to achieve restoration goals in the selected tributary. Tributary plans may take the form of detailed site-specific feasibility studies or, in the case of smaller efforts, design analyses with appropriate NEPA documentation.

2.0 PROBLEM IDENTIFICATION AND SIGNIFICANCE

2.1 PROBLEM IDENTIFICATION

The master plan has been undertaken to address the problem of a degraded oyster population in the Chesapeake Bay. The degraded oyster population has been driven by four main causes:

- Loss of habitat (substrate)
- Oyster diseases: MSX and Dermo
- Water quality degradation
- Commercial harvesting

The remainder of this section discusses these four main causes and their effects on restoration efforts.

Beck et al. (2011) summarized the typical sequence of events that have led to oyster decline globally, which is also characteristic of what has occurred in the Chesapeake Bay. Initially, harvesting operations degraded and reduced oyster habitat by removing shell substrate, flattening and fragmenting oyster bars. In most cases, harvesting continued until commercial fishing could no longer occur. The flattening of bars places oysters lower in the water column where water currents, food availability, and oxygen are reduced. Flattened bars with inadequate shell production are more susceptible to being buried by sediment and impacts from poor water quality. Siltation of oyster bars reduces the amount of suitable habitat for larval setting and impairs the health of adult oysters (Heral et al. 1983 as cited by Rothschild et al. 1994). These processes lead to further habitat loss. Finally, diseases reduced oyster populations even further in the second half of the 20th Century. Chesapeake Bay oyster resources were classified as "poor" (Beck et al. 2011). In this application, "poor" is defined as 90 to 99 percent habitat loss with partial or complete fishery collapse. While some bars remain, their long-term viability is questionable. At 99 percent habitat loss, oyster resources are determined to be "functionally extinct" in a region (Beck et al. 2011).

2.1.1 Loss of Habitat (Substrate)

Naturally occurring historical oyster bars and reefs, unaltered by human activities, no longer exist in the Chesapeake Bay. The remaining oyster habitat in the Chesapeake Bay has been reduced to remnants or footprints of the historic bars and reefs. These 'remnants' can be substantial, as is the case in the James River, compared to remaining habitat elsewhere in the Bay. The initial loss of oyster bars and reefs due to human activities resulted from intensive harvests during the late 1800s and early 1900s. The impacts of harvest during this time were:

1) Unsustainable harvest levels greatly reduced oyster populations by removing tremendous numbers of individuals; approximately 75 percent of the oyster population was removed from the Chesapeake Bay between 1860 and 1920.

2) Removal of the bar shell matrix and failure to return this material to the bottom substantially reduced available substrate for oyster recruitment and settlement, preventing the population from replacing the oysters lost to harvest and mortality.

3) Harvest gear, especially dredges and patent tongs, physically destroyed the fabric of the bar habitat and changed the pattern of oyster distribution from dense aggregations to diffusely-scattered individuals. Recent restoration projects including those by USACE in the Great Wicomico River, Lynnhaven Bay, Severn River, and Choptank River, and State wide efforts by VMRC, along with naturally occurring reefs in the upper James River are expected to comprise the only three-dimensional oyster habitat existing in the Chesapeake Bay today.

Shell is naturally lost due to burial, the impacts of predation, and physical and chemical processes. The impacts of harvesting along with degraded water quality and natural shell loss have magnified the problem of habitat loss.

The current high rate of loss of oyster habitat combined with the disappearance of sources of shell for enhancing habitat are generally recognized as major obstacles to all oyster restoration efforts. A sampling of 16 oyster bars considered to be representative of oyster habitat in Maryland's portion of the Bay revealed a 70 percent loss of suitable oyster habitat on those bars between about 1980 and 2000, suggesting a 3.5 percent loss of oyster habitat each year (Smith et al. 2005). Sedimentation and the deterioration of existing shell both contribute to this loss. Although the impact of dredging was not considered, Mann (2007) determined that 20 percent or more of the shell stock in the James River is lost each year as a result of natural processes.

The high rate of habitat loss is a critical issue for the future of oyster populations because larval oysters require hard substrate on which to settle. A healthy, growing oyster population creates its own habitat through production of new shell. At their current low level of abundance in the Bay, oysters are not creating adequate amounts of new shell to support a significant increase in the population. Further, as it settles, sediment covers oyster bars and other hard-bottom substrates that oysters need to settle on if shell production is inadequate. Consequently, sedimentation has dramatically reduced the amount of hard-bottom habitat in Chesapeake Bay (Smith et al. 2005), which severely limits future increases in oyster abundance.

There is a significant shortage of new shell for oyster restoration programs. The two sources of shell available for habitat restoration in the past were shucking houses and buried fossil shell deposits dredged from the bottom of the Bay. Shell from shucking houses has been drastically reduced. Dredging buried fossil shell deposits continues in Virginia, but is currently not permitted in Maryland. As a result, alternate substrates including concrete and stone are now being incorporated into restoration efforts.

Continuing habitat degradation throughout the Bay decreases whatever potential may exist for reproductive success of the existing remnant oyster stock (Mann and Powell 2007). The limited ability to increase and maintain new areas of clean substrate for larval settlement, therefore, is a major constraint on restoration programs in both states. Loss of habitat is also tied to declines in overall coastal diversity, which has further economic impacts (Lotze et al. 2006 and Airoldi et al.

2008 as cited by Beck et al. 2011). Restoration projects will need to address this problem. Successful projects will be those that are able to maintain a stable or positively accreting shell budget.

2.1.2 OYSTER DISEASES

The Bay's oyster population is now estimated to be less than 1 percent of its size during the 1800s, with estimates as low as 0.3 percent (Newell 1988 as cited by USACE 2009; Wilberg et al. 2011). The more recent declines in the population have been attributed primarily to the introduction of two diseases. The diseases Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*) are harmless to humans but usually are fatal to Eastern oysters. The diseases are caused by protozoan parasites that were first found in the Bay in 1949 (Dermo) and 1959 (MSX). In the absence of MSX and Dermo, the average lifespan of the eastern oyster is 6 to 8 years, and the maximum is probably 25 years (NRC 2004). These two diseases have been especially detrimental to the oyster fishery because they kill many oysters before they reach market size. Eastern oysters are marketed in the United States when they reach 3 inches or more, typically after 3 to 4 years in the Chesapeake Bay (NRC 2004). Oysters infected with Dermo, however, generally live only 2 or 3 years, and oysters infected with MSX generally die within 1 year. The eastern oyster initially appeared to have no resistance, given the large increase in disease-related mortality that was observed. Recent investigations have identified that high salinity oyster populations that are regularly challenged by disease are developing resistance to MSX and Dermo (Carnegie and Burreson 2011).

Dermo is caused by a parasitic, single-celled organism called *Perkinsus marinus*, which is found along the Atlantic and gulf coasts of the United States and is distributed throughout the water column. MSX is believed to have been introduced into the Bay through an illegal planting of the nonnative Pacific oyster, *C. gigas*. MSX is caused by a single-celled, infectious parasite called *Haplosporidium nelsoni*, which is now found along the entire Atlantic coast of the United States.



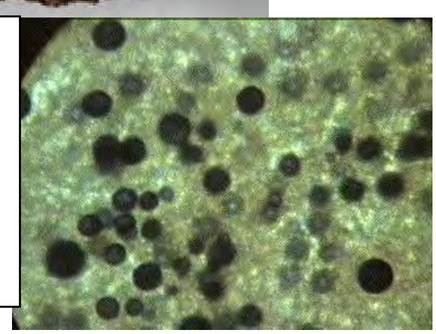


Figure 2-1. Dermo Disease in Oysters.
A healthy oyster (top left- courtesy of Paynter labs) compared to a dermo infected oyster (top right). Magnified dermo cells in oyster tissue (bottom right). (Dermo pictures from Living Classrooms Foundation- http://www.livingclassrooms.org/lbo/dermo/dermoframe).html).

The likelihood that disease will kill an oyster is influenced by many factors and the relationship between environmental stressors and how disease affects oysters is not well understood. Salinity, and thus annual precipitation, as well as water temperature are major factors in determining whether oysters become infected with Dermo or MSX and the level of intensity of disease. Both diseases are more virulent at higher salinities. Dermo is active during the warmer months (at temperatures above 20°C) but can survive much colder temperatures. Cool water temperatures during winter and early spring suppress Dermo infections. A recent trend toward warmer winters has allowed Dermo to flourish in the Bay. Dermo develops the heaviest infections at salinities greater than 10 ppt and is relatively inactive at salinities less than 8 parts per thousand (ppt), but can survive at much lower salinities (3 ppt). Infection rates decrease during wet rainfall years, when a larger-than-average volume of freshwater runoff reduces salinity in the Bay. The prevalence of MSX is controlled by water temperature and salinity, similarly to Dermo. Initial MSX infection generally occurs at water temperatures greater than 20°C and salinities greater than 10 ppt. Virginia's oyster fishery was affected disproportionately by MSX and Dermo because both diseases are more active in the salty water of the southern portion of the Bay (NRC 2004).

Disease can also affect other biological characteristics of an oyster. For example, diseased oysters generally exhibit slower growth rates than healthy oysters. The high mortality rates of these diseases not only remove oysters potentially available for harvest, they also reduce the number of large, highly reproductive oysters that are left to propagate. Overall, oyster populations in the Bay are now strongly controlled by disease pressure (Ford and Tripp 1996), in addition to being negatively affected by harvest, degraded oyster habitat, poor water quality, and complex interactions among these factors.

2.1.3 WATER QUALITY DEGRADATION

Declining water quality has also contributed to reducing the oyster population. A substantial increase in anthropogenic nutrient input following World War II from artificial fertilizers and other sources vastly increased the portion of Bay water vulnerable to hypoxic and anoxic conditions, limiting or eliminating oysters below the pycnocline (Kemp et al. 2005; Boynton et al. 1995). The pycnocline typically occurs below about 18 feet in the middle and lower Bay, whereas historically preferred oyster habitat extended to about 30 feet depth. Bay seiches cause hypoxic/anoxic bottom waters to slosh into waters shallower than the pycnocline, affecting oysters even above the pycnocline.

Nutrients, mainly phosphorus and nitrogen, in dissolved form and attached to sediment contribute to determining the amount of algae and other small primary producers (collectively called phytoplankton) that grow in the water column. Excess nitrogen typically drives eutrophication because the Bay is primarily nitrogen limited. Phytoplankton provides food for oysters and small invertebrate animals called zooplankton, which in turn provide food for fish and other animals in the Bay. Small increases in nutrient loads can increase primary production with repercussions throughout the food web, all the way up to fish and other animals. Large nutrient increases can cause phytoplankton blooms that reduce the penetration of light through the water and adversely affect water quality in the Bay. Shading by phytoplankton and suspended sediment reduces the amount of light available to support the growth of submerged aquatic vegetation (SAV), which provides habitat for many species and helps to trap sediment.

Concomitant increased suspended sediments and loss of plant debris in the water column further degrades quality of the Bay as habitat for oyster.

Anthropogenic nutrients and sediment that enter the Bay have altered the system from one dominated by benthic production and SAV to one heavily influenced by pelagic (water column) processes (mainly phytoplankton production). Although food for oysters is plentiful under these conditions, failure of a reef to accrete shell because of overharvesting, disease, and other factors allows otherwise favorable substrate to become covered with sediment from either natural or anthropogenic sources, rendering it unsuitable for oyster habitat.

2.1.4 COMMERCIAL HARVESTING

Persistent overharvesting, with its concomitant impacts on broodstock size and composition, recruitment, oyster habitat, and oyster genetics, has been recognized as the prime factor in reducing oyster numbers to their currently extremely low population and biomass levels throughout the Chesapeake Bay (Hargis and Haven 1999, Haven et al. 1978, Rothschild et al. 1994).

During pre-colonial times, oysters were highly abundant, having developed over several thousand years as sea level rose at the end of the most recent ice age. During the early colonial period, settlers adapted harvest techniques used by Native Americans and oystermen eventually used up to 18-foot-long, hand-held tongs to harvest oysters from bars throughout the Chesapeake Bay. Oysters in shallower, easier to reach waters were depleted first and a full accounting of the initial extent of intertidal bars in the Chesapeake Bay does not exist. Deeper areas were then accessed as the oyster fishery expanded, with a number of bars in Tangier and Pocomoke Sound being the last discovered (Winslow 1882). Oysters were an important food source for the colonists; in fact, during the Revolutionary War, oysters were a staple food for soldiers (CBF 2000) and prior to that, Jamestown settlers (Harding 2010). While harvests of oysters likely had an effect on oyster populations within the Chesapeake Bay, little hard data are available from this early period of European colonization. Overall, harvest pressure on oysters was relatively low until the mid-19th century.

The Chesapeake oyster fishery became the largest in the world during the 1880s (NRC 2004). During the 1800s, watermen began to fish more efficiently by using sailboats (the iconic "skipjack") to dredge oyster bars instead of the traditional hand-tong method. The use of increasingly destructive harvesting methods increased after 1865, when the use of large mechanized dredges was legalized (Stevenson 1894). Dredging for oysters began to degrade the physical integrity of centuries-old bars and reefs (DeAlteris 1988) by breaking off shell and oysters that were too small to harvest, thereby reducing the population and the habitat available for future production and harvest.

In the late 1800s total oyster harvests in the Chesapeake Bay approached, and sometimes exceeded, 20 million bushels per year. Even before this peak, the poor condition of the oyster bars was noticed. Legislative attempts, including seasonal restrictions and gear limitations, were made to reduce the damage by the mid 1800s (Paxton 1858, Kennedy and Breisch 1983). Attempts were also made to assess oyster stocks. For example, the U.S. Coast Guard extensively surveyed Maryland waters in the late 1870s, providing the first real indication that the oyster fishery was in trouble. It was noted in the survey that oyster beds in Tangier Sound and Pocomoke Sound, some of the most productive areas in the Chesapeake Bay, were severely depleted from the level in the previous 30 years (Winslow 1882).

During a survey of Tangier Sound performed in 1878, only 1 oyster to 3 square yards of beds was found, on average (Winslow 1882). The surveyor, Francis Winslow, who had also served as an officer in the Maryland oyster police, prepared detailed reports. These reports documented that lax enforcement of culling laws that prevented harvest of oysters less than 3 inches in length, as well as the failure to reseed the oyster beds with oyster shell, would soon doom the oyster harvest industry to failure.

Oysters were being taken out of the Chesapeake Bay at a rate far greater than they could be replenished by natural reproduction (Wennersten 1981). Despite these early warnings, harvest activity continued virtually unrestricted, due to mismanagement, lack of enforcement, and the lack of the political will to address the problem in an effective fashion. Again, warnings about potential problems with the high (and unsustainable) harvest levels were made, this time by the foremost oyster biologist of his day, William K. Brooks. In 1891, he published a book entitled *The Oyster* that took a strong stand against the public fishery and argued for oyster aquaculture as a means of establishing a sustainable oyster fishery (Brooks 1891). Brooks stated, "It is a well-known fact that our public beds have been brought to the verge of ruin by the men who fish them…all who are familiar with the subject have long been aware that our present system can have only one result—extermination." His advice was largely ignored. In fact, at this time, the oyster fishery was so valuable that watermen dubbed them "Chesapeake Gold" (CBF 2000). These were the peak years for the Chesapeake Bay oyster fishery.

As seen in Figure 2-2, commercial landings of oysters in Chesapeake Bay declined steadily during the late 19th and early 20th centuries. Harvest yields declined by half in the 50 years between the late 1880s and about 1930. A policy could not be agreed upon that would conserve the rapidly-diminishing oyster populations of the Chesapeake Bay (Wennersten 1981). It was only after harvest levels fell significantly over successive years without any sign of recovery that Maryland and Virginia attempted to address the problem. Aquaculture, the planting of seed oysters in private grounds, began to be encouraged. In 1894, Virginia set aside 110,000 acres of barren ground for leasing and 143,000 acres to remain as public oyster grounds, following advice provided to them at the time (Baylor 1895). Virginia also passed legislation to encourage oyster aquaculture on the private, leased grounds. Maryland followed in 1906 with the passage of the Haman Oyster Act, which allowed private planters to lease 30 acres in the tributaries, 100 acres in Tangier Sound, and 500 acres in the Chesapeake Bay's open waters.

Unfortunately, the oyster planters, as people in the oyster aquaculture business were called, found their leased grounds under constant threat of poaching by oystermen. The resulting conflicts that pitted oystermen against oyster planters, the law, and each other, often escalated into pitched battles, sunken ships, and lost lives, were the "Oyster Wars" of the late 1800s and early 1900s. The last casualties were in the late 1950s in the Potomac River, which had always been disputed by Virginia and Maryland watermen regarding who can harvest where, how, and when. It took action by President Kennedy in 1962 signing the "Potomac Fisheries Bill" to induce the two states to form the Potomac River Fisheries Commission to oversee the Potomac

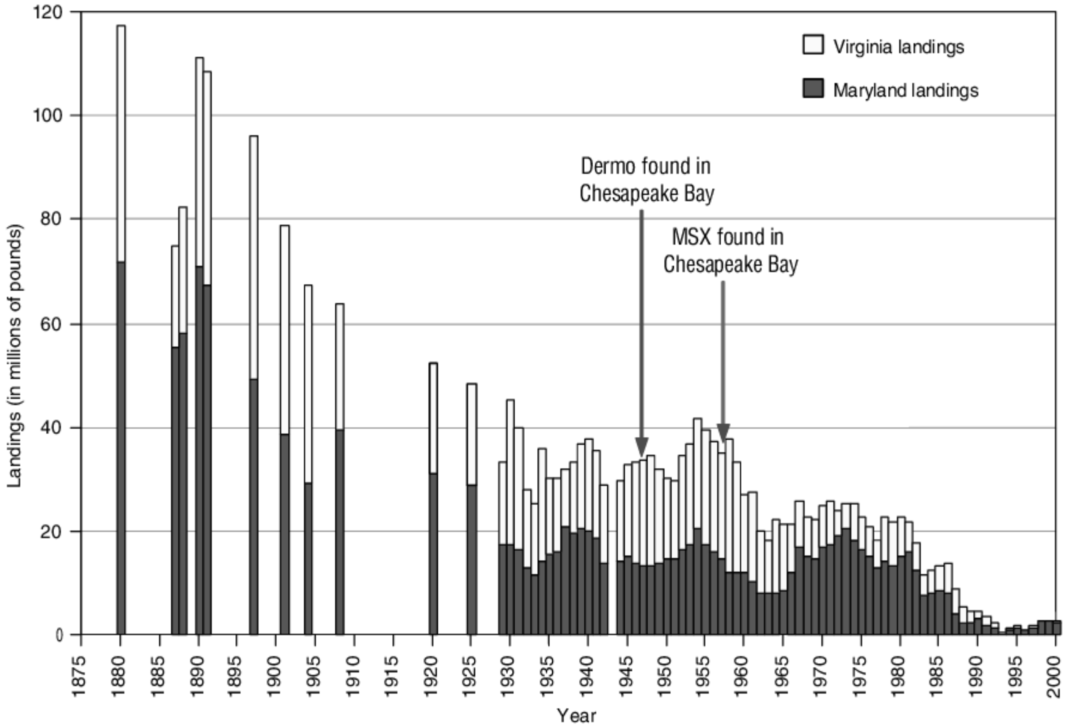


Figure 2-2. History of Commercial Landings in the Chesapeake Bay.
Sources: Data from Chesapeake Bay Program,
http://www.chesapeakebay.net/daa/historicaldb/livingresourcesmain.htm; and
National Marine Fisheries Service, http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html

River and end the sometimes lethal confrontations between Virginia and Maryland watermen and, at times, marine police from either state.

By the early 1900s, total oyster harvests were less than half of the peak years in the late 1800s, and seemed somewhat stable. In Virginia, this harvest equated to about 4 million bushels of oysters/yr (Virginia Department of Environmental Quality 2000). By this time, however, most of the complex three-dimensional structure of all oyster bars had been destroyed. Woods et al. (2004) documented a loss of 0.47 m in height on average from once-emergent reefs in the James River. Intensive and mechanized fishing effectively leveled the profile of the oyster bars in Chesapeake Bay (Rothschild et al. 1994). Many oyster bars had been entirely lost, especially those in shallower waters due to destructive harvest practices.

By the early 1930s, public oyster harvest levels began to decline again, although Virginia harvests, buoyed by private industry, increased between 1930 and 1959 prior to MSX introduction in the late 1950's. The private leasehold fishery in VA, which was almost entirely dependent on James River seed, compensated for the dip in public ground harvest that occurred in the 1940's. The public fishery continued to decrease steadily through the early 1970s, when harvest levels seemed to stabilize, though at a much lower level than the early 1900s, largely due to state-run "repletion" programs and the availability of affordable "seed" oysters. Harvests in both states decreased precipitously following the spread of Dermo in the 1980s. At this time, even though far reduced from the peak harvest levels of prior years, the oyster fishery was still the most important fishery in the Chesapeake Bay. For example, the 1987 Virginia oyster harvest had a dockside gross value of almost $12 million, most of which came from private lease productivity.

> 'Sustainable shellfish harvests have been achieved elsewhere through a mixture of protected areas for important populations, cooperative fishery management, user rights, and the use of aquaculture to reduce harvests of wild stocks.' (Beck et al. 2011)

Current oyster harvests Chesapeake Bay-wide declined precipitously after the expansion of Dermo in the 1980s to less than 100,000 bushels/yr in Virginia waters and about 500,000 bushels/yr in Maryland waters, for a total dockside value of approximately $10 million. To summarize the impact of overfishing, in 1904, Virginia's public ground harvest was about 7.6 million bushels of oysters; by 1930, the public ground harvest was approximately 1 million bushels; by 1957, the harvest was about 586,000 bushels; and a steady decline has continued. Today's public ground harvest is on average less than 40,000 bushels of oysters/yr in Virginia, though it can increase when a sanctuary area is opened to well over 80,000 bushels (VMRC 2004,2005,2006,2007,2008,2009). [Currently, Virginia does not establish large, permanent sanctuaries. Sanctuaries in Virginia are either part of a rotating system where areas are set aside for a number of years and then opened for harvest or small distinct areas within otherwise open harvest grounds. Section 4.5 further describes sanctuary designations.] It is important to note that the vast majority of this decline occurred before either of the two diseases, Dermo and MSX, which had a significant negative impact on the Chesapeake Bay oyster populations (pre-1949), were discovered in the Chesapeake Bay, and subsequently took their toll on the native oyster.

2.1.4.1 Public Fishery Augmentation

Due to the commercial value of the oyster and the ability of oyster harvests to provide income, employment, and other economic benefits to the Chesapeake Bay region, there is a public interest in fishery restoration. In addition to ecosystem restoration, Virginia and Maryland both also have a keen interest in augmenting the public fishery in their respective states and have undertaken efforts to do so.

USACE is authorized by Section 704(b) of the Water Resources Development Act of 1986, as amended by Section 505 of WRDA 1996, Section 342 of WRDA 2000, Section 113 of the Fiscal Year 2002 Energy and Water Development Appropriations Act, Section 126 of the Fiscal Year 2006 Energy and Water Development Appropriations Act, and Section 5021 of WRDA 2007, to construct oyster restoration projects "to conserve fish and wildlife" for ecosystem restoration and can include sanctuaries and harvest reserves. However, to fulfill the USACE ecosystem restoration mission, all proposed restoration in the master plan is to be constructed within permanent sanctuary, with the exception of spat-on-shell production areas. These areas may be incorporated for ecosystem restoration stock enhancement efforts and would serve as a key component of the genetic rehabilitation strategy that seeks to promote the development of disease resistance in wild oyster stock.

To be consistent with USACE ecosystem restoration policies, the benefits of USACE projects must be sustainable; therefore, although WRDA provides USACE the capability to include harvest reserves in restoration plans, any destructive harvesting practices would not be compatible with sites established for ecosystem restoration. Permanent sanctuaries, which are oyster restoration areas where no commercial or recreational harvest of oysters will ever take place, are an important component of the master plan's recommendations.

At this time, USACE does not have information that justifies federal investment in other management approaches such as harvest reserves or replenishment of wild harvest areas to achieve ecosystem restoration goals. USACE is undertaking additional investigations into the costs and benefits of sanctuaries and harvest reserves. Future tributary plan development which will include applicable NEPA analyses and documentation will incorporate the findings of these investigations. Inclusion of management approaches other than sanctuaries will be considered in specific tributary plans, if justified. On the basis of current science and policy, USACE does support the efforts of others in establishing harvest reserves within proximity of sanctuaries to provide near-term support to the seafood industry and establish a diverse network of oyster resources. USACE can implement projects that are focused on fishery restoration, but the local sponsors must bear the full financial responsibility for any deviations from USACE selected plans which focus on ecosystem restoration.

In the case of many Virginia tributaries, spat-on-shell production areas will not be directly constructed by USACE, since an extensive private oyster leasehold system is already in place that could provide such services via the private sector.

2.2 SIGNIFICANCE OF NATIVE OYSTERS

Oysters are considered keystone organisms in the ecology of Chesapeake Bay both for the habitat they create, their water filtering capacity and the important role they play in the Bay's "resilience"; or, its ability to manage stress and maintain its integrity upon negative impacts. Oysters have also historically been an important commercial resource supporting an economically important fishery and are of great cultural value to many residents of the Bay area.

Years of overharvesting, habitat destruction, pollution, and disease-induced mortalities have severely impacted oyster populations throughout the Bay. The population of native oysters has declined to a small fraction of its historical abundance, and restoration efforts undertaken to date have failed to reverse the decline. Sections 1.3 and 5.4.4.3 provides details on past restoration efforts.

> Oysters are considered a keystone species and ecosystem engineers. Keystone species are defined as a species whose impacts on its community or ecosystem are large, and much larger than would be expected from its abundance (Meffe et al. 1997).

2.2.1 INSTITUTIONAL RECOGNITION

Significance based on institutional recognition is defined by the importance of an environmental resource being acknowledged in the laws, adopted plans, and other policy statements of public agencies, tribes, or private groups. Native oysters in the Chesapeake Bay have institutional significance by virtue of their inclusion in federal, state, and county government plans and policies.

The Chesapeake Bay Program (CBP) began in 1983 with the goal of restoring the Bay to its former health and productivity using an ecosystem management strategy. The signatory members of the program were Maryland, Pennsylvania, Virginia, the District of Columbia, and EPA, but many other agencies and stakeholders have joined the effort. CBP identified oyster restoration as a key component for improving the health of the Bay and established specific management goals in its 1987, 1994, and 2000 agreements. The most recent agreement, known as *Chesapeake 2000*, established the goal of attaining a standing oyster population that is 10 times greater than the 1994 baseline by the year 2010.

The following initiatives exemplify the institutional significance afforded oyster restoration, which all outline the most recent restoration measures drawn up to guide government agency and private organization efforts:

- Chesapeake Bay Program Oyster Master Plan (CBP 2004a)
- Virginia Blue Ribbon Oyster Panel Report (Virginia Blue Ribbon Oyster Panel 2007)
- Chesapeake Bay Action Plan (2008)
- Maryland Oyster Advisory Commission Report (OAC 2009)
- Executive Order 13508 - Chesapeake Bay Restoration and Protection (E.O. 13508 2009)
- MD Oyster Restoration and Aquaculture Development Plan (MDNR 2009)
- Programmatic EIS to Evaluate Oyster Restoration Alternatives, including the Proposed Action of Introducing the Oyster Species *Crassostrea ariakensis* (USACE 2009)

In January 2005, the Chesapeake Bay Program's Executive Council adopted the Chesapeake Bay Oyster Management Plan (OMP) to provide a general framework and specific guidance for restoring and managing the Bay's native oyster resource.

On May 12, 2009, President Barack Obama issued Executive Order 13508, *Chesapeake Bay Protection and Restoration*. The "Strategy for Protecting and Restoring the Chesapeake Bay Watershed" (May 2010) was developed in response to the executive order, which declared the Chesapeake Bay a national treasure and ushered in a new era of shared Federal leadership, action and accountability. Under this plan, NOAA and USACE are committed 'to launch a Bay-wide oyster restoration strategy in close collaboration with Maryland and Virginia and the Potomac River Fisheries Commission that focuses on priority tributaries, supports expansion of commercial aquaculture and bolsters research on oyster stock, habitat and restoration progress.' The E.O. Strategy has identified an oyster outcome of restoring 'native oyster habitat and populations in 20 out of 35 to 40 candidate tributaries by 2025.' The master plan will play an integral role in USACE and NOAA's efforts.

2.2.2 Public Recognition

Significance based on public recognition is defined as some segment of the general public that considers the resource or effect to be important. Public recognition may be manifest in controversy, with support or opposition expressed in any number of formal or informal ways.

The importance of the native oyster as a resource to both the people of the Chesapeake Bay area and the Bay itself and to the organisms that reside within it has been recognized locally, regionally, and nationally. The need to restore the native oyster throughout the Chesapeake Bay and its tributaries has been documented for many years. A recent, large-scale public involvement effort to solicit comments on oyster restoration was conducted through the NEPA process for PEIS (USACE 2009). The PEIS electronic document was downloaded by more than 1,000 unique users and received hundreds of comments. This level of interest shows the importance of this issue to the many stakeholders concerned and affected by the decline of oysters.

There are many programs led by non-profit organizations (TNC, CBF, Chesapeake Bay Trust (CBT), ORP, etc.) that provide opportunities for the public to volunteer in oyster restoration efforts, such as CBF's oyster-gardening and "reef ball" construction program. As of 2010, nearly 4,000 households have participated in the oyster growing program, and in 2009 alone, volunteers contributed almost 20,000 hours of time to CBF oyster restoration work (CBF 2010). The amount of people and amount of hours spent volunteering for oyster restoration initiatives such as these provides evidence of public concern for this resource.

There is public recognition that native oysters are an economically important species as well. The oyster resource has supported a substantial commercial fishery in the past. During the 1958-59 oyster harvest season, watermen harvested more than 4 million bushels of market-size oysters from the Bay's Virginia waters. In the 1997-1998 harvest seasons, only 14,295 bushels were harvested commercially. There is wide public recognition that oyster decline has threatened a way of life for both oystermen and the Bay itself. Over the last 30 years, Maryland and Virginia have suffered more than $4 billion in cumulative annual losses due to the decline of oyster-related industries (NOAA as cited in CBF 2010).

2.2.3 TECHNICAL RECOGNITION

Significance in terms of technical recognition is based on scientific or other technical criteria that establish a resource's significance. While it is recognized that virtually all species and habitats are important in a community ecosystem context, limited funding and planning resources necessitate focusing on those considered significant in terms of justifying a federal interest.

Historically the oyster was a keystone species that provided a variety of ecological services in the Chesapeake Bay ecosystem. It was a primary component of the Bay's filtration system and provided rich habitat for many other species (Newell 1988). As an example of nutrient reduction (filtration) services, it is estimated that the historical population of oysters was able to filter the volume of the Chesapeake Bay every 3 days. The current population takes more than 1 year to filter the same volume of water, while point and non-point pollution has increased and further degraded the Chesapeake Bay (Newell 1988).

Oyster bars clean the water around them, with each adult oyster filtering up to 50 gallons of water a day (Luckenbach 2009). By making the water clearer, oysters help sun light penetrate to the bottom, which allows SAV to grow, adding oxygen to the water, trapping sediment, and providing essential habitat for other Bay species, such as juvenile crabs. Oysters, if restored to historic levels, would make a significant contribution to increasing water quality throughout the Chesapeake Bay.

Grabowski and Peterson (2007) have identified seven categories of ecosystem services provided by oysters:

(1) production of oysters,
(2) water filtration and concentration of biodeposits (largely as they affect local water quality),
(3) provision of habitat for epibenthic fishes (and other vertebrates and invertebrates, as cited in Coen et a1. 1999) (ASMFC 2007),
(4) sequestration of carbon,
(5) augmentation of fishery resources in general,
(6) stabilization of benthic or intertidal habitat (e.g. marsh), and
(7) increase of landscape diversity
(see also reviews by Coen et a1. 1999, Coen and Luckenbach 2000, ASMFC 2007).

Oysters are recognized as being on the decline globally and functionally extinct in many regions. Native oyster bars in 40 ecoregions, including 144 bays were recently investigated (Beck et al. 2011). Beck et al. (2011) determined that "oyster bars are at less than 10 percent of their prior abundance in most bays (70 percent) and ecoregions (63 percent)" and that oysters "are functionally extinct -- in that they lack any significant ecosystem role and remain at less than one percent of prior abundances in many bays (37 percent) and ecoregions (28 percent) -- particularly in North America, Australia and Europe." Within this context, Chesapeake Bay oyster resources were classified as "poor". On average, the analysis estimates that 85 percent of oyster bar ecosystems have been lost globally, with the recognition that this is a conservative estimate.

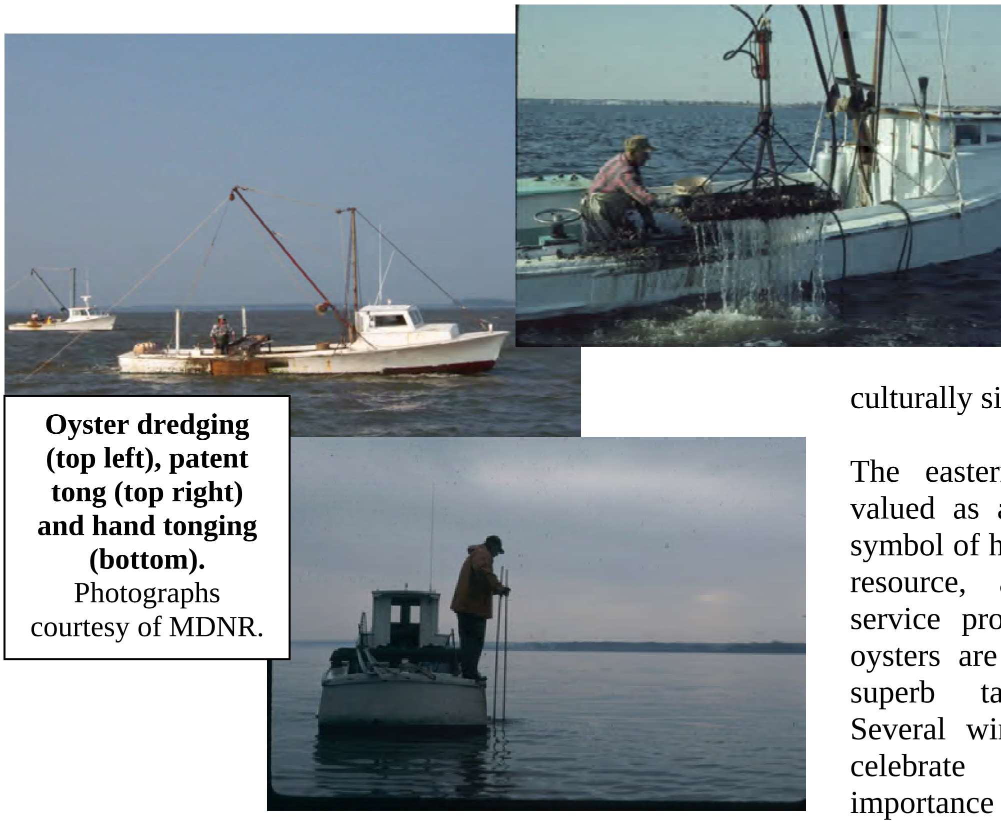
Figure 2-3. Oyster Bar Depicting Faunal Community
Illustration by Alice Jane Lippson from Lippson and Lippson (1997).

The master plan is proposing to construct permanent oyster sanctuaries. As designated sanctuaries, these protected bars will be able to continue to grow as three-dimensional structures. These bar structures are critical habitat not only for oysters, but also for fish, crabs, and other species. Bars can have 50 times the surface area of flat bottom, and a wide variety of animals—including worms, sponges, snails, sea squirts, small crabs, and baby fishes—live on the oysters or hide from predators in the bars crevices (VA DEQ 2009). The benefits of sanctuaries are further discussed in Section 4.5.

2.2.4 Cultural and Historical Significance

The following section is adapted from Paolisso and Dery (2008):

Oystering has been a central component and driver of social and economic development in the Chesapeake Bay region. From the colonial period to the 20^{th} century, oyster harvests supported a vibrant regional industry that included primary harvesters (including growers), processors, and retailers in addition to secondary industries, fishing communities, and a culinary culture centered on the bivalve. The eastern oyster was as an important food resource for Native Americans and early European settlers, and the Bay's oyster fishery developed into a large export industry during the 1800s, when the Chesapeake oyster fishery became the largest in the world (NRC 2004). Towns such as Crisfield on Maryland's Eastern Shore were established and prospered solely on the basis of the abundance of oysters in local waters. The oyster became widely recognized as an important cultural symbol of the Chesapeake Bay region.



Oyster dredging (top left), patent tong (top right) and hand tonging (bottom). Photographs courtesy of MDNR.

Although the devastation of eastern oyster populations has had a serious impact on the primacy of the oyster as a resource, the shellfish remains a culturally significant species.

The eastern oyster is highly valued as a source of food, a symbol of heritage, an economic resource, and an ecological service provider. Chesapeake oysters are renowned for their superb taste and texture. Several winter oyster festivals celebrate the culinary importance of this treasured food. During oyster season, the shellfish is on countless restaurant menus in the area, although restaurant owners increasingly rely on oysters imported from other regions. Imported oysters are still prepared with classic Chesapeake recipes, like cornmeal fritters and oysters casino. Seafood houses throughout the region serve a variety of oyster dishes.

The fisheries of the Bay figure prominently in the heritage of the region, as evidenced by the declaration of a skipjack as the Maryland State Boat in 1985 (Chapter 788, Acts of 1985; Code State Government Article, sec. 13-312). Skipjacks are shallow draft, single mast, large-sail workboats used to dredge oysters. Today, there are about a dozen skipjacks remaining from a fleet that once numbered almost 1,000 boats (National Trust for Historic Preservation 2011). The Chesapeake Bay skipjack fleet was the last commercial fishing fleet powered by sail in North America. Some of the skipjacks that remain are privately owned and continue to be used for dredging, while others are on display in museums or are used for educational programs and heritage tourism. The *Rebecca T. Ruark*, a national historic landmark and the oldest vessel in the

Chesapeake Bay skipjack fleet at 117 years old, still sails commercially on historic charters (Murphy 2005). The Chesapeake Heritage Conservancy Program offers educational programs aboard the *Martha Lewis*, and the *Flora Price* serves as a floating classroom. Every year on Labor Day weekend, many of the remaining skipjacks gather at Deal Island, Maryland, for the annual skipjack races.

2.2.5 ECONOMIC SIGNIFICANCE

The natural and cultural resources of the Chesapeake Bay are essential components of the economy of both Maryland and Virginia. A wide variety of resource-dependent commercial and recreational activities are significant for the regional economy as well as the well-being of its citizens (Paolisso and Dery 2008).

The oyster fishery is an important part of the larger Chesapeake Bay seafood industry. The oyster has a direct value as food source for consumers and as a product for the industry that catches, grows, processes, and sells the shellfish (Lipton et al. 2005). In the late 19th century, the Chesapeake Bay oyster fishery became a major source of oysters for North America and a major economic engine for communities, businesses, and local governments throughout the watershed. In the 1890s, there were some 4,500 boats of assorted size in the fishery (Wennersten 2001). There is extensive literature on the oyster fishery, detailing the various harvesting practices used (e.g., diving, dredging under sail or power, tonging either by hand or with hydraulics), harvest levels, changes in regulations, and the special role of the Chesapeake's once-great fleet of skipjacks, (Blackstone 2001, Byron 1977, Peffer 1979, Vojtech 1993, Paolisso and Dery 2008).

Commercial landings of oysters in Chesapeake Bay declined steadily beginning in the late 19th Century. Oyster harvests stabilized for several decades (through the late 1970s) before beginning a further decline through the 1990s. Section 4.7 discusses cultural and socioeconomic issues related to oysters in more detail. Based on recent oyster surcharges and licenses sold in Maryland and Virginia, there are approximately 500 to 600 watermen employed as oyster fishermen (see Table 4-7). Aquaculture in Virginia, supported 53 full and 81 part-time jobs as of 2010. Much of the oyster processing industry has been lost. According to Murray (2002), virtually all of Virginia's processed oyster production is now from oysters harvested from other states, principally the Gulf of Mexico. The same is true of Maryland-based oyster processors.

Photograph provided by USACE-Norfolk.

Oysters also have an indirect value derived from the ecological services they provide. Oyster bars provide habitat for other commercially valuable species (e.g., blue crab). The oysters' contribution to improving water quality can lead to an increase in recreational activities such as boating or swimming, and a reduction in the costs of water quality improvement measures.

3.0 RESTORATION VISION

USACE envisions the return of self-sustainable oyster populations to the Chesapeake Bay. Self-sustainable implies that the resource will require no further assistance or inputs. This will not be an easy task and it will require focused and dedicated funding and political and public will. It will require the use of sanctuaries and the observance of sanctuary regulations by all. Oysters are an important resource to the ecosystem, the economy, and the culture of the Chesapeake Bay region. They are also a critical component of comprehensive Chesapeake Bay restoration and are worth the investment and energy.

> "New thinking and approaches are needed to ensure that oyster bars are managed not only for fisheries production but also as fundamental ecological components of bays and coasts and for the return of other associated critical ecosystem services" (Beck et al. 2011).

USACE proposes that self-sustainability is feasible, but not in the near-term. Only after habitat has been widely restored and broodstocks with some ability to tolerate diseases have been established will it be achieved. This will likely take multiple decades to achieve. Beck et al. (2011) recognized that recovery will take time and quick returns on restoration investments are unlikely. Setbacks are to be expected as the techniques to construct large-scale restoration are just being developed. In the near-term, sustainable oyster bars and populations will provide valuable ecosystem benefits that are a necessary stepping stone to ultimate self-sustainability. Sustainable bars provide a high degree of diverse functions and benefits, but require some type of periodic attention or inputs, whether it is additional seeding or substrate, to remain viable.

The master plan calls for a large-scale approach to oyster restoration on a tributary basis. This is different from past efforts that have spread resources into small allotments across many tributaries. There is increased risk to "putting all your eggs in one basket," but a concentration of resources is necessary to have an impact on depleted oyster populations and reverse the severe loss of broodstock and habitat. Past restoration efforts have failed to impact population levels because the habitat and broodstock returned to the Bay were too little and were scattered over too large an area. USACE envisions construction of significant acreage (potentially 25 to 100 acres, dependent on available resources) in one to two tributaries per year until restoration targets are reached for those tributaries. Monitoring of these bars will determine when enough habitat has been constructed to reach restoration goals. For larger tributaries, it will likely take multiple years to reach identified targets. These concepts are expanded upon in the scale discussion of Section 5.4.

One final critical component of large-scale oyster restoration that must be recognized is watershed management. Land and water are closely tied together by numerous miles of shoreline in the Chesapeake Bay watershed. If oyster restoration is going to be successful, pollutant inputs from watersheds cannot increase. Additionally, excess nutrients are the main driver of increasing CO_2 (i.e. acidity) in the Bay (Waldbusser et al. 2011, Nash 2012) and has the potential to impact the dissolution rate and ability of oysters to form shells. Improved watershed management is necessary to provide suitable estuarine conditions for restored oyster populations (Beck et al. 2011).

Although, this master plan was developed to guide USACE's long-term oyster restoration activities, large-scale oyster restoration in the Chesapeake Bay will only succeed with the cooperation of all agencies and organizations involved. Resources and skills must be leveraged to achieve the most from restoration dollars. The greatest achievements will be made by joining the capabilities of government agencies and private organizations in a collaborative manner to pursue restoration activities.

3.1 CONCEPTUAL MODEL FOR OYSTER RESTORATION

Conceptual models are descriptions of the general functional relationships among essential components of an ecosystem. They tell the story of "how the system works" and, in the case of ecosystem restoration, how restoration actions aim to alter those processes or attributes for the betterment of the system. Conceptual models are particularly useful tools in guiding plan formulation. Formulating an effective ecosystem restoration project requires an understanding of: (1) the underlying causes of degradation, (2) how causal mechanisms influence components, and (3) how the effects may be reversed through intervention. These elements form the nucleus of a conceptual model applied to project formulation (Fischenich 2008). Figure 3.1 presents a conceptual model developed by USACE and its partners for oyster restoration in the Chesapeake Bay and shows the relationships among critical factors in oyster restoration considered in the master plan. The interrelationships among the factors in this model are described in the sections that follow.

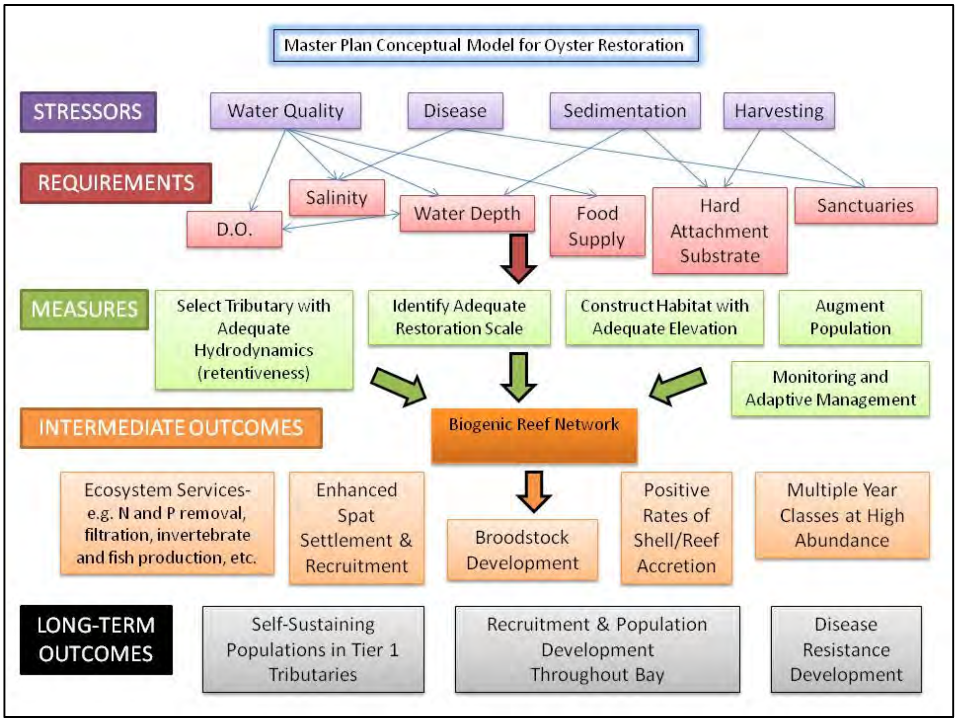


Figure 3-1. Conceptual Model for Oyster Restoration in the Chesapeake Bay.

3.2 GOALS AND OBJECTIVES

A goal is a statement of the overall purpose of an effort. An objective is a more specific statement of the intended purpose of a study or alternative. The Chesapeake 2000 agreement established the following goal: "By 2010, achieve a tenfold increase in native oysters in the Chesapeake Bay." Although this ambitious goal was not achieved, it helped to highlight the need for large-scale oyster restoration in the Bay. Through a series of meetings and discussions, the interagency group for the master plan (including USACE, MDNR, VMRC, and the collaborating agencies) developed a specific goal and objectives for the master plan. Ideally, planning objectives are specific, flexible, and measureable.

Restoration, by definition, involves reestablishing a self-sustaining habitat that closely resembles natural conditions in terms of structure and function. Restoration for oysters in this project means reestablishing self-sustaining populations of oysters that closely resemble oyster bars prior to widespread degradation and that provide the ecological functions that these bars once provided. Specifically, the long-term goal or vision of restoration of this master plan is as follows:

> *Restore an abundant, self-sustaining oyster population throughout the Chesapeake Bay that performs important ecological functions (e.g. bar community habitat, nutrient cycling, spatial connectivity, and water filtration), and contributes to an oyster fishery.*

The master plan has been undertaken to ensure that oyster restoration implemented by USACE is conducted in a logical, cost-effective manner, with the greatest potential for success in achieving the restoration goal. The master plan presents a strategic plan for pursuing wide-scale restoration throughout the Bay that complements the states' oyster restoration programs as well as other Bay-wide restoration efforts and future uses of the Chesapeake Bay.

In establishing the goals and objectives for the master plan, USACE, the project sponsors, and the collaborating agencies recognized the strong influence of salinity on restoration and the fact that some objectives can be achieved in the near term and others will take longer to achieve. Ecosystem benefits will be immediately achieved upon completion of restoration projects and will increase as oysters grow and the reef community develops (Rodney and Paynter 2006; Paynter et al. 2010). As part of the restoration strategy, it will be necessary to measure the response of the ecosystem (pelagic fish, benthic conditions, water quality, etc.) to large-scale restoration and further identify larval transport connections within and among tributaries within the Chesapeake Bay.

Dredged shell placement, Chesapeake Bay. USACE-Baltimore.

Population goals of sustainability are expected to take longer to achieve. It is further anticipated that the timeframe will vary depending on the salinity zone within which restoration takes place. The primary differences between low salinity and high salinity waters which will impact the restoration timeframe and the level of restoration effort are decreased recruitment in low salinity areas and the greater potential for the development of disease resistance in high salinity waters (Carnegie and Burreson 2011).

In low salinity waters, where recruitment is naturally lower and broodstock is currently depleted so extensively that recruitment is essentially non-existent, the near-term strategy will focus on achieving population longevity as a necessary step toward achieving long-range goals. Restoration efforts will be developed to restore broodstock populations and larval transport pathways throughout the system. The low salinity strategy may require restoring more bar structure to provide the same recruitment as high salinity areas, more initial spat-on-shell augmentation of the population to build broodstock, and more intensive adaptive management based on monitoring. This more intensive manipulation and management will be required before oyster populations become self-sustaining in low salinity areas. It is uncertain whether low salinity populations that are not regularly challenged by MSX or severe Dermo infections are able to develop disease resistance, but if so, it will likely take longer to develop compared to high salinity areas. This will leave low salinity areas more prone to disease in dry years.

In high salinity areas, the need for seed plantings should be much reduced compared to low salinity waters because of natural recruitment. Development of disease resistance is occurring in high salinity waters (Carnegie and Burreson 2011). This is a significant development that will reduce mortality, but is also projected to reduce the effort (and thus costs) needed to restore populations in high salinity waters compared to low salinity. The main focus of high salinity restoration will be to construct substrate.

In other words, the near-term goal is to achieve *sustainability*, even if it is a managed sustainability; *self-sustainability*, where the oyster population functions on its own, is a long-range goal. The time required for near-term objectives to be met cannot be defined precisely but is expected to be a matter of years for high salinity areas and years to decades for lower salinity areas. Long-term self-sustainability is expected to require decades to develop in low or high salinity.

Long-Range Objective

Low and High Salinity:
Restore self-sustaining oyster sanctuary populations throughout the historic range of oysters in the Chesapeake Bay in areas/tributaries that previously supported oysters and meet the minimum criteria for dissolved oxygen, salinity, and depth and that are connected to one another on multiple scales (within and among tributaries) to ensure the population's resilience in the face of natural and anthropogenic environmental variation, disease, and predation.

Near-Term Ecological Restoration Objectives

HABITAT FOR OYSTERS

Low Salinity:
Restore native oyster abundance (area and density) in key areas/tributaries throughout the historic range of oysters in the Chesapeake Bay. Focus on restoring and maintaining habitat and broodstock, with efforts directed to restoring larval transport connections and recruitment.

High Salinity:
Restore self-sustaining native oyster abundance (area and density) in key areas/tributaries throughout the historic range of oysters in the Chesapeake Bay. Focus on restoring and maintaining habitat.

Low and High Salinity:
Restore resilience of native oyster population to natural and anthropogenic environmental variations and disease.

Create a network of oyster bar sources and sinks in different salinity and hydrographic zones that are linked through larval transport and are stable and resilient over time.

HABITAT FOR REEF COMMUNITY

Low and High Salinity:
Restore native oyster populations in key areas/tributaries throughout the historic range of oysters in the Chesapeake Bay with bar/reef characteristics similar to undegraded oyster habitat.

ECOLOGICAL SERVICES

Low and High Salinity:
Restore native oyster populations that provide ecological services typical of undegraded oyster habitat including, but not limited to 1) support a diverse bar community including macrofauna, epifauna, and demersal fish, and 2) water filtration and nutrient sequestration.

Fisheries Management Objective

Low and High Salinity:
Restore oyster spawning/habitat sanctuaries in multiple tributaries within the Chesapeake Bay and targeted areas within tributaries that export larvae outside the sanctuary boundaries and provide a larval source to harvest grounds.

3.3 CONSISTENCY WITH OTHER CHESAPEAKE BAY OYSTER RESTORATION PLANS

Oyster restoration in the Chesapeake Bay has long been a priority of state and Federal agencies, municipalities, and non-governmental organizations and has been the recent focus of a number of reports and plans. The master plan is unique in that it proposes strategies for accomplishing large-scale restoration, which has been a recommendation in many of the recent oyster plans listed below. While recognizing that oyster restoration is just one critical element of an overall program to restore living resources throughout the Chesapeake Bay, the master plan is intended to lay out a comprehensive, coordinated approach directed toward ecosystem restoration.

The master plan is also intended to be consistent with and support to the maximum extent practicable the goals and objectives described in these various oyster restoration plans of other organizations. Many of these organizations established oyster restoration goals in partnership with other organizations or separately for individual plans. The team conducted an analysis of the following plans to consider the consistency of the specific goal of the master plan with other plans:

- 2004 Chesapeake Bay Program's *Oyster Management Plan* (OMP) (CBP 2004a)
- 2007 Virginia Blue Ribbon Oyster Panel Recommendations (VA Blue Ribbon Oyster Panel 2007)
- 2008 *Chesapeake Bay Action Plan* (CBP 2008)
- 2008 Maryland Oyster Advisory Commission Recommendations (OAC 2009)
- 2009 Executive Order 13508 – *Chesapeake Bay Protection and Restoration* and 202(g) Report (E.O. 13508 2009)
- 2009 *Maryland Oyster Restoration Aquaculture Development Plan* (MDNR 2009
- Native oyster restoration goals of the 2009 *Programmatic EIS to Evaluate Oyster Restoration Alternatives, including the Proposed Action of Introduction of the Oyster Species Crassostrea ariakensis* (USACE 2009)

A summary matrix of the goals and objectives stated in these plans is provided in Table 3-1. The master plan goal and objectives are consistent with all of the goals in these plans to the extent that they overlap with USACE ecosystem restoration authorities. The following goals or objectives from the various plans are particularly relevant to the master plan:

- A restored oyster resource can be described as abundant, self-sustaining, occurring over a wide range throughout the Chesapeake Bay, performing important ecological roles and supporting an oyster fishery (CBP 2004a).

- Establish functional oyster sanctuaries throughout the Chesapeake Bay comprising 10 percent of the historical oyster habitat in the Chesapeake Bay (Chesapeake Bay 2000 Agreement and the CBP 2004a).

- Undertake all individual restoration projects with clearly defined, specific objectives that can be evaluated. Incorporate monitoring for adaptive management and systematic investigations that will improve our ability to achieve our objectives as integral parts of restoration projects (Chesapeake Bay 2000 Agreement and CBP 2004a).

- Using the best available models for larval dispersal, designate large sanctuaries within each rotational harvest area (Virginia Blue Ribbon Oyster Panel 2007).

- Focusing ecological restoration efforts in a large-scale, interconnected fashion (river system-wide) as the strategy most likely to allow large populations of oysters to persist in the face of disease and other stressors (OAC 2009).

- Reversing habitat degradation and loss must be a primary focus for both ecologic and economic conditions. The continued degradation of Bay water quality from land-based management decisions will further impede Maryland's ability to restore oysters to the Bay (OAC 2009).

- A restored oyster population will strengthen science and benefit the wide-ranging goals of the Executive Order as outlined for the Sustainable Fisheries, Protect and Restore Vital Habitat, Protect and Restore Water Quality, Maintain Healthy Watersheds, and Foster Chesapeake Stewardship Goal Implementation Teams (E.O. 13508 2009).

Buoys marking sanctuary boundaries.

Lynnhaven River oysters. Spat are visible on shells above. Photographs provided by USACE-Norfolk.

Table 3-1. Summary of Chesapeake Bay Oyster Restoration Plans

Goal/ Objective	CBP OMP	VA Blue Ribbon	Chesapeake Bay Action Plan (CAP)	MD Oyster Advisory Commission (OAC)	Restore the Chesapeake Bay Executive Order 13508- Draft Strategy and 202(g) Report	MD Oyster Restoration and Aquaculture Development Plan	Programmatic EIS to Evaluate Oyster Restoration Alternatives, including the Proposed Action of Introducing the Oyster Species Crassostrea ariakensis (PEIS)	Native Oyster Restoration Master Plan
Date	*2004*	*May 2007*	*2008*	*2009*	*May 2009*	*December 2009*	*2009*	*2012*
Lead Agencies	CBP (EPA), MDNR, VMRC	VMRC	CBP (EPA), MDNR, VMRC	MDNR	EPA with Depts of Ag (Ag, USFS), Commerce, (NOAA), Defense (USACE, Navy), Homeland Security, Interior (USGS, NPS, USFWS), and Transportation, PRFC, PA, MD, VA, NY, WV, DE, and DC	MDNR	USACE, MDNR, VMRC, PRFC, NOAA, USFWS, EPA, ASMFC	COE (Lead Agency), MDNR, VMRC, & NOAA, USFWS, EPA, TNC, CBF
Overarching Goal/ Strategy	The purpose of the Oyster Management Plan (OMP) is to provide both a general framework and specific guidance for implementing a strategic, coordinated, multi-partner management effort. The OMP proposes to guide, focus, and coordinate the multiple partners in rebuilding the native oyster population in Chesapeake Bay. Management strategies are defined according to three salinity zones.	Four over-arching issues must be addressed to realize improvements in native oyster populations and move us toward meeting ecological and economic goals: 1) increased oyster production for both population growth and harvest, 2) improved and expanded oyster habitat and substrate, 3) establishment of a harvest policy that is based on sustainability of the fishery, and 4) improved water quality. Develop management plans for all river systems, Bay regions, and seaside coastal embayment, that describes objectives for system. Establish harvest 'triggers' based on science. Incorporate hydro modeling in decision making.	Four primary components: 1.a strategic framework that unifies CBP's existing planning documents and clarifies how CBP partners will pursue the restoration and protection goals for the Bay and its watershed; 2. an activity integration plan with comprehensive, quality assured data for 2007 that identifies and catalogues CBP partners' implementation activities and corresponding resources; 3. dashboards, and 4. an adaptive management process that begins to identify how this information and analysis will provide critical input to CBP partners' actions, emphasis, and future priorities.	Large-scale sanctuaries and an industry focused on aquaculture.	Recognizes the Chesapeake Bay as a national treasure and calls on the federal government to lead a renewed effort to restore and protect the nation's largest estuary and its watershed. 202g report for habitats focuses on ways to better achieve CAP goals 1 and 2. Specific to oysters- Commit to a (new) comprehensive, bay-wide, ecological oyster restoration strategy to repopulate the Bay with healthy, self-sustaining native reefs. NOAA, USACE, and other federal agencies will coordinate with Maryland, Virginia, and the Potomac River Fisheries Commission with a goal to recover oyster reefs and establish self-sustaining oyster reef sanctuaries in 20 key tributaries throughout the Bay by 2020.	1. Establish an expanding and sustainable population of native oysters in significant portions of Ches Bay and its tributaries. 2. Establish a private aquaculture industry that emerges as a major economic contributor to Maryland while maintaining a more targeted and scientifically managed wild oyster fishery.	Establish an oyster population that reaches a level of abundance in Chesapeake Bay that would support sustainable harvests comparable to harvest levels during the period 1920–1970. [Approximately, average annual harvest of 5 million market size oysters over several decades.]	Within the Authorities of the Corps of Engineers, the goal of native oyster restoration is to restore an abundant, self-sustaining oyster population throughout the Chesapeake Bay that performs important ecological functions (e.g. reef community, nutrient cycling, spatial connectivity, water filtration) and contributes to an oyster fishery. Restoration, by definition, involves reestablishing a self-sustaining habitat that closely resembles a natural condition in terms of structure and function. Restoration for oysters in this project means reestablishing self-sustaining populations of oysters that closely resemble previously existing oyster reefs and provide the ecological functions that these
Ecological Restoration	Evaluate the use of sanctuaries to obtain optimum ecological and economic benefits. Establish a network of oyster sanctuaries. Outlines steps for identifying sanctuaries. Objective 1- Increase oyster populations to levels that restore important ecological functions, including: water filtration and nutrient cycling; aquatic reef community structure; and adequate broodstock to sustain regional populations. 1b- Conserve/protect sanctuaries.	Development and Implementation of a New Management Strategy for Restoration Activities and Focus Ecological Improvements- Establish large permanent oyster sanctuaries within rotational harvest areas using larval dispersal and biology. Establish ecologically relevant, measurable goals, for each of the targeted systems, for the upcoming three years, and develop implementation plans accordingly.	Goal 1- Protect and restore fisheries. Strategies for achieving a healthy and sustainable native oyster stock include: establish, enhance, and seed oyster reefs; establish a network of permanent sanctuaries throughout the Bay;	Focus on large-scale, interconnected (river system wide) sanctuaries. Views sanctuaries as regions sufficiently large to contain a diversity of oyster habitats and brood stock populations to seed them. Discusses factors to consider in identifying sites and adaptive management in three distinct regions.	Implement a bay-wide oyster restoration strategy which prioritizes tributaries for ecological restoration with the greatest likelihood of success and long-term sustainability. Work with States to substantially increase a network of permanent sanctuaries in ecologically viable areas throughout the Bay. Identify, establish, enhance, and seed oyster sanctuaries. Recommends that USACE would contribute to planning and constructing reefs and to overall program support.	Significantly increase Maryland's network of oyster sanctuaries . Of 36,000 ac of remaining quality habitat (in MD), increase amount of habitat protected as sanctuaries from 9% to 24%.	A need exists to restore the ecological role of oysters in the Bay and the economic benefits of a commercial fishery through native oyster restoration and/or an ecologically compatible nonnative oyster species that would restore these lost functions.	Restore abundant, self-sustaining oyster populations in priority areas/tributaries throughout the Chesapeake Bay that perform important ecological functions (e.g. reef community, nutrient cycling, spatial connectivity, water filtration)

Table 3-1 (continued). Summary of Chesapeake Bay Oyster Restoration Plans

Goal/ Objective	CBP OMP	VA Blue Ribbon	Chesapeake Bay Action Plan (CAP)	MD Oyster Advisory Commission (OAC)	Restore the Chesapeake Bay Executive Order 13508- Draft Strategy and 202(g) Report	MD Oyster Restoration and Aquaculture Development Plan	Programmatic EIS to Evaluate Oyster Restoration Alternatives, including the Proposed Action of Introducing the Oyster Species Crassostrea ariakensis (PEIS)	Native Oyster Restoration Master Plan
Fisheries Management	Control fishing effort (overall goal to reduce) using special management areas. Evaluate the use of harvest reserves to obtain optimum ecological and economic benefits. Discusses modifications to state repletion programs. Objective 2: Achieve a sustainable oyster fishery through a combination of harvest from public oyster grounds and private aquaculture.	Development and Implementation of a New Management Strategy for Oyster Harvest and Enhance VMRC's Efforts to Restore the Oyster Fishery. - Continue shell planting and maintain public grounds. Establish rotational harvest areas. Establish maximum size limit and return largest oysters to sanctuaries. Establish harvest season date. Consider controlling fishing effort with a control date and limited entry in certain areas. Low salinity areas should be designated for a put and take fishery.	Goal 1: Protect and Restore Fisheries- Restore, enhance and protect the finfish, shellfish and other living resources, their habitats and ecological relationships to sustain all fisheries and provide for a balanced ecosystem. Desired results include 1. Effective Fisheries Ecosystem-based Planning and Management and 2. increased oyster abundance. CBP recognizes that successful efforts to reduce nutrient loads, improve water quality, re-establish submerged aquatic vegetation, and restore migratory fish spawning habitat should bring about healthier, more abundant stocks of fish, crabs, and oysters, ultimately leading to higher fisheries yields from the Bay.	Implement new plan based on maximum fishing mortality rates. Improve annual population and habitat surveys. Achieve more accurate harvest reporting. Develop new management concepts for the reemergence of a large oyster fishery based on private sector principles of investment and ownership. Revise the structure of county oyster committees to reflect modern communications, joint decision making, and reduced industry size.	Support ecosystem-based fisheries management approaches through establishment of interjurisdictional Baywide strategies, comprehensive stock assessments, and evaluation of alternative approaches to improve fisheries management, including quota-based management, limited access programs, and gear-restricted areas. Conduct a socio-economic assessment to determine what ecosystem services are most valuable to the people and communities in the Bay watershed.	Support a more focused and scientifically managed wild fishery. Identify areas off limits to leasing. This proposal will maintain 167,720 acres of natural oyster bars for the wild oyster fishery, including 76% of the Bay's remaining quality oyster habitat.	A need exists to restore the ecological role of oysters in the Bay and the economic benefits of a commercial fishery through native oyster restoration and/or an ecologically compatible nonnative oyster species that would restore these lost functions.	Restore an abundant, self-sustaining oyster population throughout the Chesapeake Bay that contributes to an oyster fishery.
Disease Management	Obj 3- Reduce the impacts of disease on oyster populations. Obj 4- Develop disease resistant strains. Outlines a disease strategy.	Reduce or eliminate transplantation of diseased seed.	Strategies for achieving a healthy and sustainable native oyster stock include: develop disease resistant oysters.	The protection of 'survivor' oysters and their progeny, resulting in longterm development (multidecadal) of genetically based disease tolerance. The prevention of the spread of disease.	Expand efforts to achieve natural disease resistance.	Manage against oyster disease.	Do not introduce a non-native oyster. Promote development of disease resistance. Use 'revolving broodstock approach'. Spat production in hatcheries generated from wild *C. virginica*.	Use trap estuaries to promote the development of disease resistance. Use disease resistance seed or broodstock for stocking needs. Described in detail in Section 5.
Habitat	1A- Rehabilitate habitat by utilizing appropriate bottom type; consider the influence of environmental conditions; and, increase oyster biomass.	Focus on three dimensional features.	Goal 2- Protect and restore vital aquatic habitats- Restore those habitats and natural areas that are vital to the survival and diversity of the living resources of the Bay and its rivers.	The reestablishment of three dimensional reef structures which significantly elevates oysters above the bottom. Creation of a linked system (through larval dispersal) of oyster habitats at a scale that is resilient in the face of climatic variability and change.	Promote the protection of key species and their key habitats in a way that integrates landscapes and waterways, consolidates best available information, develops a strategic ranking, and supports efforts such as the new Atlantic Coast Fish Habitat Partnership and Atlantic Coast Joint Venture (migratory birds). Protect valuable land and water habitats through permit reviews and consultation under existing authorities including the CWA, Fish and Wildlife Coordination Act, Endangered Species Act, Magnuson-Stevens Fishery Conservation and Management Act, Coastal Zone Management Act, and the Lacey Act.	Rehabilitate oyster bar habitat.	Expand oyster habitat restoration efforts. Recognizes that continuing loss of hard hard-bottom substrate in the Bay may be the greatest obstacle to enhancing the Bay-wide oyster population.	Restoration for oysters in this master plan means reestablishing self-sustaining populations of oysters that closely resemble previously existing oyster reefs and provide the ecological functions that these reefs once provided. (This will include alternative substrates and three dimensional reefs.)

Table 3-1 (continued). Summary of Chesapeake Bay Oyster Restoration Plans

Goal/ Objective	CBP OMP	VA Blue Ribbon	Chesapeake Bay Action Plan (CAP)	MD Oyster Advisory Commission (OAC)	Restore the Chesapeake Bay Executive Order 13508- Draft Strategy and 202(g) Report	MD Oyster Restoration and Aquaculture Development Plan	Programmatic EIS to Evaluate Oyster Restoration Alternatives, including the Proposed Action of Introducing the Oyster Species Crassostrea ariakensis (PEIS)	Native Oyster Restoration Master Plan
Materials (Seed and substrate)	Evaluate use of alternate substrate. Develop and implement techniques to locate and recover buried shell or shell with layers of sedimentation. Track genetic background of broodstocks. Utilize hatchery-produced seed to augment natural reproduction, reduce disease effects and increase biomass. Obj 4- Increase hatchery production.	Continue shell planting. Expand hatchery production through expansion of private hatchery capacity. Expand spat on shell production. Continue testing alternate substrates including concrete.	Increase hatchery production.	Increase and diversify sources of disease-free seed (including public hatcheries) and identify new sources of substrate. Supports fossil shell dredging at Man-O-War Shoal.	Increase hatchery production for purposes of re-seeding oyster sanctuary sites.	Dredge thinly buried shell to surface. Place dredged, clean shell. Place alternate substrate. Dredge deeply buried shell to surface and aggregate. Increase hatchery production.	Expanded restoration will necessarily involve placing various kinds of substrate on the bottom of the Bay or manipulating the existing bottom substrate. Expand hatchery production.	Focus on providing habitat with sufficient relief off bottom. Use best available and most cost-effective materials to construct habitat including fossil shell, reclaimed shell, and alternate substrates.
Prevention of illegal harvests	Supports strengthening the enforcement of closure areas. Evaluate various additional enforcement measures- increased staff, make penalties and fines more severe, additional enforcement staff, add points to license system for violations, buoys, physical deterrents, citizens call line, etc.	Enforcement of Virginia's Oyster Restoration Plan- Enforce fines and revoke fishing licences. Expand enforcement resources if necessary to maintain optimum level of enforcement. Incorporate concrete structures in reef building.	Strategies for achieving a healthy and sustainable native oyster stock include: enforce oyster management laws and regulations.	Increase enforcement for protection of public and private oyster resources with penalties significant enough to deter theft. The use of very large closed areas will simplify and make more manageable the control of illegal harvest activities.	NOAA will explore possibility of establishing marine protected areas.	Enhance law enforcement. Incorporate enforcement reforms including a collaborative effort with federal partners to install a network of radars and cameras to monitor sanctuaries and prevent poaching.	Implement restrictive oyster haresting management regimes.	
Water Quality		Finance Water Quality improvements- endorses the need for a long term dedicated funding source for water quality improvements in the Chesapeake Bay. A long term commitment must address sources of nitrogen pollution from sewage treatment plants, storm water and agricultural runoff, and atmospheric deposition.	Goal 3- Protect and restore water quality. Waters are considered healthy when their chemical and physical attributes support the ecological needs for robust populations of living resources such as fish, crabs, and oysters.	All agencies focus on 'down-stream' implications of their decisions.	Assess impact of environmental contaminants such as heavy metals, PCBs, PAHs, and endocrine disruptor compounds on the health of fish, wildlife, and plants. Additionally, other parts of E.O. focus on water quality (Section 202a and c).		Recognized relationship of oyster habitat and water quality. Investigated the effects of recommended actions on other components of the ecosystem and water quality of Chesapeake Bay.	Restore abundant, self-sustaining oyster populations in priority areas/tributaries throughout the Chesapeake Bay that provide nutrient cycling, water filtration/clarification, and other ecosystem benefits.

Table 3-1 (continued). Summary of Chesapeake Bay Oyster Restoration Plans

Goal/ Objective	CBP OMP	VA Blue Ribbon	Chesapeake Bay Action Plan (CAP)	MD Oyster Advisory Commission (OAC)	Restore the Chesapeake Bay Executive Order 13508- Draft Strategy and 202(g) Report	MD Oyster Restoration and Aquaculture Development Plan	Programmatic EIS to Evaluate Oyster Restoration Alternatives, including the Proposed Action of Introducing the Oyster Species Crassostrea ariakensis (PEIS)	Native Oyster Restoration Master Plan
Aquaculture	Evaluate impediments to aquaculture. Discusses recommendations for supporting the growth of aquaculture industry.	Enhance the Role of Aquaculture to support economic goals. Expand aquaculture training. Continue development of disease resistant strains including wild strains. Establish aquaculture zones.	Strategies for achieving a healthy and sustainable native oyster stock include: support aquaculture.	Revise restrictive laws and regulations that currently inhibit private cultivation of shellfish including a streamlined and timely permitting process. Consolidate the authority for aquaculture and permitting into a single state agency. Attract private capital for aquaculture development. Increase legal protection of private property for growers. Develop and implement a transparent and balanced transition strategy for existing commercial watermen from the wild fishery to aquaculture. Established aquaculture enterprise zones (AEZ) and industry management areas (IMa). Support and expand industry training projects. Identifying startup funding and insurance programs to reduce the barrier to entry and risk.	Support aquaculture development to facilitate the ability of waterman and the oyster industry to adapt to focused ecological restoration efforts.	Shift commercial production to aquaculture. Increase areas open to leasing for oyster aquaculture and streamline the permitting process, including 95,525 ac of formerly off-limit natural oyster bars. Establish aquaculture enterprise zones (pre-approved aquaculture lease areas)- first are near Broomes Island in Patuxent River.	Establish and/or expand State-assisted, managed or regulated aquaculture operations in Maryland and Virginia using native oysters. Expand technical support and training to watermen.	
Estimate of funding needs		Increase state funding to $2.5 M/yr.		$40 M annually			$350-$600 million over 10 years	See Section 5 for estimates of tributary costs.
Proposed funding sources		Seek federal funds and leverage funds to bolster state funds.		2009 state capital funds, federal crab disaster funding, annual state and federal support. Provides list of recommendations for financial assistance programs for aquaculture.	Greater federal and state commitments to supporting oyster sanctuaries will accelerate these efforts. Rebuilding reefs and stocking them with oysters is a long-term process that will require significant funding and the participation and commitment of federal and state agencies, academia, industry, nongovernmental organizations and partnerships, and the public.		Recognized the need for increased federal and state funding.	Leverage federal dollars in collaboration with States and partners.
Predation Controls		Improve Understanding of Management Options for the Cownose Rays- supports s responsible and sustainable fishery on cow-nose rays and expanded research focused on population control and predation deterrents.					Use spat-on-shell because less vulnerable to predation.	

Table 3-1 (continued). Summary of Chesapeake Bay Oyster Restoration Plans

Goal/ Objective	CBP OMP	VA Blue Ribbon	Chesapeake Bay Action Plan (CAP)	MD Oyster Advisory Commission (OAC)	Restore the Chesapeake Bay Executive Order 13508- Draft Strategy and 202(g) Report	MD Oyster Restoration and Aquaculture Development Plan	Programmatic EIS to Evaluate Oyster Restoration Alternatives, including the Proposed Action of Introducing the Oyster Species Crassostrea ariakensis (PEIS)	Native Oyster Restoration Master Plan
Population Goal	1C- Achieve a tenfold increase in oyster biomass by 2010, relative to a 1994 baseline.				Mentions 2010 goal, but otherwise does not specify a population goal.		Establish an oyster population that reaches a level of abundance in Chesapeake Bay that would support sustainable harvests comparable to harvest levels during the period 1920–1970.	
Identified Sites		Targeted areas for continued near-term investment in oyster restoration for ecological restoration- Eastern Shore seaside coastal bays; the Lynnhaven River; the Great Wicomico River; and, the PiankatankRiver. Rotational harvest area should be est. in Rap, followed by Potomac River tributaries, Tangier and Pocomoke Sounds, and the lower James River.		Three regions: 1) limited recruitment with low mortality- Severn, Magothy, and South Rivers for large-scale sanctuaries, 2) recurrent recruitment with high mortality- Honga and St. Mary's Rivers, and 3) variable salinity, recruitment, and mortality- Choptank River.		Proposed new sanctuaries include entire rivers such as Little Choptank. Other proposed sanctuaries include Magothy River, Chester River, the area between the mouths of the Patapsco and Back rivers bounded by the main channel, Upper St. Mary's River, Point Lookout, Upper Patuxent River, the mainstem portion and lower tributaries of the Choptank River and area between main channel and shore from Hooper Strait to Smith Island.		See Section 5 for Tier 1 tributaries.
Monitoring/ Data management	Conduct consistent monitoring programs.		Strategies for achieving a healthy and sustainable native oyster stock include: monitor the status of the Chesapeake Bay stock		Develop a geo-referenced oyster database for modeling and management purposes. Conduct comprehensive bay-wide monitoring and assessment using common metrics, data, and analysis tools for evaluating restoration progress, establishing best practices, and applying adaptive management.		Extensive monitoring and management will be required as part of restoration.	Include pre- and post-construction monitoring to assess natural recruitment, population and condition, mortality, water quality, etc. Heavily incorporate adaptive management to achieve sustainable reefs.
Miscellaneous	Develop a database to track oyster restoration projects and monitoring results. Incorporate latest stock assessment in plans.	Focus funding of strategies and decision making on 1:1 return investment ratio.		Measure success on decadal time scales. Proposes intermediate (5-yr assessment) short-term goals.	Integrate oyster restoration with other habitat restoration projects such as living shorelines.			
				Provides extensive list of law enforcement and policy recommendations.	Support science and modeling to advance understanding of the Bay ecosystem, including long-term multispecies monitoring to inform decision making for fisheries, wildlife, and aquatic and terrestrial habitats.			
					Make data easily accessible to resource managers through existing web-enabled technologies and provide training and technical assistance in the use of spatial tools for decision-making.			

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4.0 EXISTING CONDITIONS

The Chesapeake Bay watershed is an incredibly complex ecosystem, with more than 3,600 species of flora and fauna and a human population exceeding 16 million. The diversity of habitats supports economic, recreational, and educational resources. In order for large-scale oyster restoration to be successful, the current conditions (physical, chemical, social, etc.) of the Bay need to be understood and incorporated into the plan development. Additionally it is important to have an understanding of potential resources that could be affected by large-scale oyster restoration. This section summarizes current Bay conditions and resources.

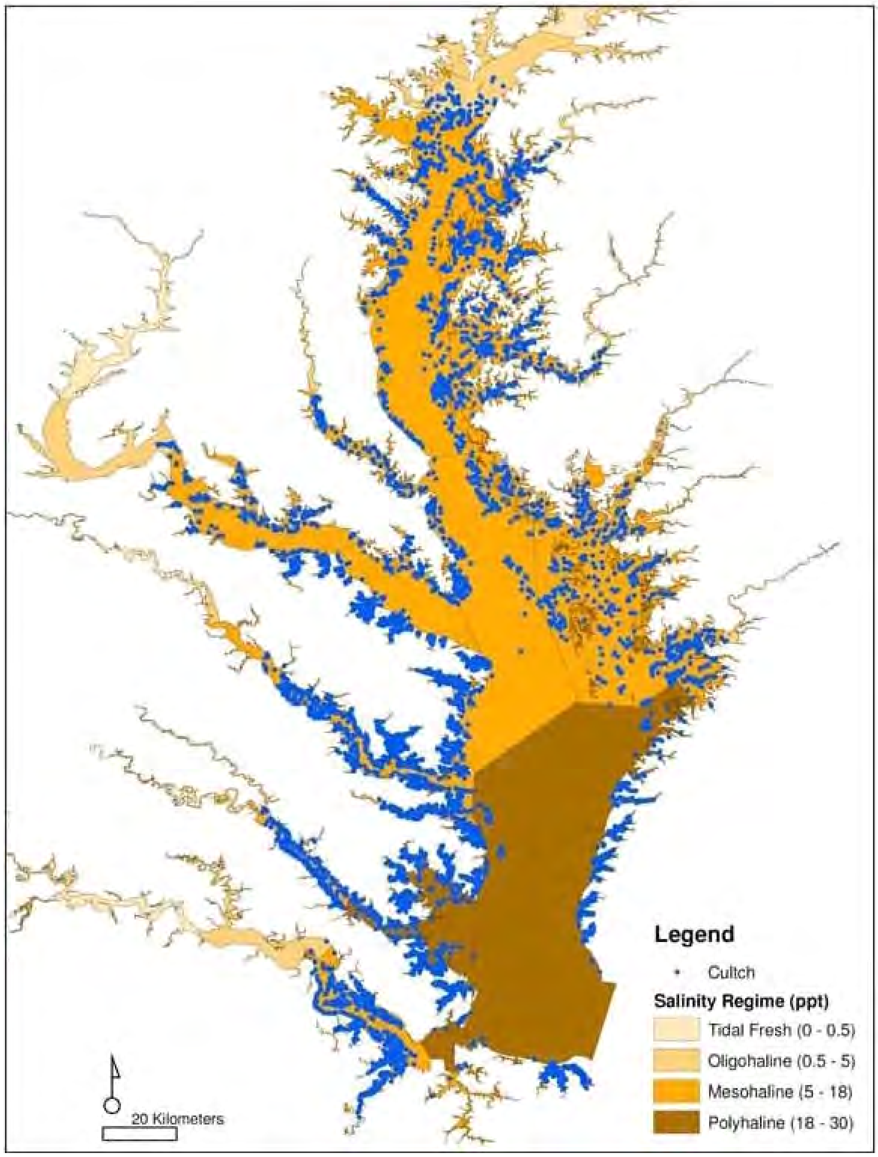


Figure 4-1. Distribution of Oyster Cultch in Chesapeake Bay with Salinity

Important commercial and recreational species include blue crab, oyster, striped bass, and numerous species of waterfowl. Figure 4-1 shows the distribution of oyster of the eastern oyster cultch compared to the salinity regime in Chesapeake Bay. The Bay is a major resting ground along the Atlantic Migratory Bird Flyway.

The surface area of Chesapeake Bay is approximately 3,225 square miles (8,386 km^2). The watershed spans 64,000 square miles and includes parts of six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) and the District of Columbia.

One hundred fifty rivers and streams empty into the Bay; the James, York, and Rappahannock Rivers in Virginia, and the Potomac and Susquehanna Rivers in Maryland are the largest.

Smaller tributaries that historically supported oysters include, but are not limited to the Patuxent and Severn Rivers on Maryland's western shore, the Chester and Choptank Rivers on Maryland's eastern shore, and the Great Wicomico and Lynnhaven Rivers in Virginia. Salinity determines the potential geographic limit of oysters within the Bay. Oysters are not commonly found at salinities lower than 5 parts per thousand and occur most commonly at higher Bay salinities (Kennedy 1996). Figure 4-2 shows the locations of the smaller tributaries considered in the master plan.

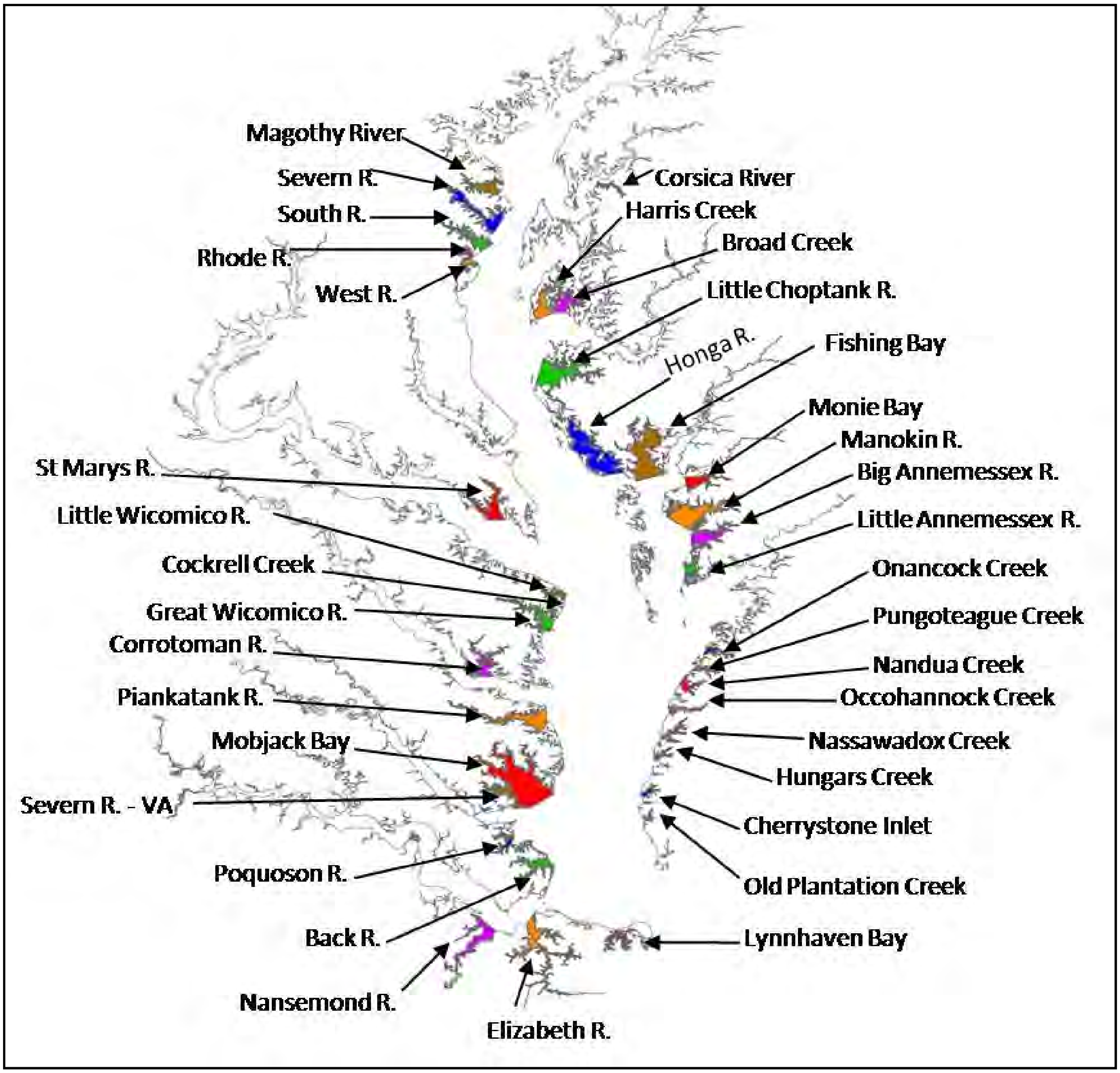


Figure 4-2. Tributaries of Interest

The protection and restoration of the Bay's resources is considered vital to its future. This section presents general descriptions of the Bay environments that could be impacted from native oyster restoration activities. For the purpose of discussing the environment, the Bay is divided into three regions as follows:

- Upper Bay—The region of the Bay and its tributaries above the Chesapeake Bay Bridge.
- Middle Bay—The region of the Bay and its tributaries from the Chesapeake Bay Bridge south to the Virginia state line.
- Lower Bay—The region of the Bay and its tributaries south of the Virginia state line.

Where practical, information for an environmental resource category is summarized separately for each of the three regions. In some instances it is not practical to make these distinctions, either because the information does not lend itself to those separations (e.g., geology) or because the source information did not use those geographic separations.

For each region, the information presented focuses on the portions of the Bay most likely to be impacted from native oyster restoration. As a result, the focus is on the water resources of the Bay where oyster restoration could occur. Physical, biological, and chemical properties and existing conditions of Maryland and Virginia tributaries, respectively, are presented for tributaries where native oyster restoration potential will be evaluated.

4.1 PHYSICAL CONDITIONS OF THE CHESAPEAKE BAY

Approximately one half of the water in the Chesapeake Bay comes from the 150 major rivers and streams in the Chesapeake drainage basin, and the other half of the water enters the Bay at Cape Henry from the Atlantic Ocean (CBP 2004b). The general climate of the Chesapeake Bay region is characterized as moderate with an average precipitation of 44 inches/yr. The Bay is oriented in a north-south direction and its tidal shoreline is approximately 14,000 miles in length (Leatherman et al. 1995). Because the Bay covers a wide latitudinal area, the physical conditions of the Bay vary according to geographical region. The physical conditions of particular concern include bathymetry, water levels, wind conditions, wave conditions, and tidal currents. Each tributary will have its own unique hydrodynamics and currents that are driven by tides, tributary shape and size, freshwater input, benthic structures, and winds. These forces influence oyster larval transport within and between tributaries, as well as local flows over an individual bar. The hydrodynamics and currents control the delivery rate and retention of planktonic oyster larvae and suspended food material to suspension-feeding oysters, as well as sediment, thereby affecting the recruitment, growth, and survival of oysters, and oyster bar habitat quality. On the individual bar scale, flow velocity affects recruitment, growth, condition, and mortality (Lenihan 1999). Flow impacts sedimentation and burial of the bar habitat, which can contribute to mortality (Lenihan 1999).

Table 4-1 a and b provides the drainage basin, length, depth, and tidal range for each of the tributaries of interest in Maryland and Virginia, respectively. Table 4-1c provides explanatory information for Table 4-1a and b.

Table 4-1a. Physical Properties of Maryland Tributaries

Tributary	*Salinity*	*Length (Miles)*	*Drainage Basin* (mi^2)	*Historic Oyster Habitat (acres)*	*Dissolved Oxygen*	*Maximum Depth (feet)*	*Tidal Mean Range (feet)*	*Chlorophyll a*	*Water Clarity*
Magothy River	Low Mesohaline	12.5	44.4	228	Poor-Good	-10	0.89	Very Poor	Very Poor
Severn River	High Mesohaline	18.97	80.8	1,980	Poor-Good	-16	0.88	Very Poor	Very Poor
South River	High Mesohaline	10.45	66.1	1,057	Poor-Good	-8	0.96	Very Poor	Very Poor
Rhode River	High Mesohaline	2.75	7.87	84	Good	-3	0.98	Very Poor	Very Poor
West River	High Mesohaline	n/d	31	136	Good	-3	0.9	Very Poor	Very Poor
Chester River	Low and High Mesohaline	49.6	368	12,747	Good	-20	1.63	Very Poor-Poor	Very Poor
lower Chester	High Mesohaline	7	36	6,344	Good	-18	1.19	Very Poor-Poor	Very Poor
upper Chester	Low Mesohaline	42.6	36	6,404	Good	-20	1.5	Very Poor	Very Poor
Corsica River	Low Mesohaline	6.1	39.5	190	Good	-13	1.6	Very Poor	Very Poor
Eastern Bay	High Mesohaline	n/a	38.6	17,358	Poor-Good	-23	1.05	Very Poor	Very Poor-Poor
lower Eastern Bay	High Mesohaline	n/a	40	8,288	Poor-Good	-23	1.1	Very Poor	Very Poor-Poor
upper Eastern Bay	High Mesohaline	n/a	36	9,070	Good	-18	1.4	Very Poor	Very Poor
Choptank River	Oligohaline, Low and High Mesohaline	160.5	1,004	20,995	Good	-25	1.9	Very Poor	Very Poor-Good
lower Choptank	High Mesohaline	10	52	16,057	Good	-25	1.6	Very Poor	Poor-Good
upper Choptank	Oligohaline, Low and High Mesohaline	56.1	38	4,938	Good	-25	1.7	Very Poor	Very Poor-Poor
Harris Creek	High Mesohaline	6.82	37.5	3,479	Good	-10	n/d	Very Poor	Poor
Broad Creek	High Mesohaline	9.49	24.9	2,569	Good	-9	1.4	Very Poor	Poor
Little Choptank	High Mesohaline	7.45	108.8	4,092	Poor	-14	1.3	Very Poor-Poor	Poor
Honga River	High Mesohaline	15.48	82.4	5,163	Poor-Good	-16	n/d	Very Poor-Poor	Very Poor
Potomac River	Tidal Fresh, Oligohaline, Low and High Mesohaline	383	14,679	10,808	Poor-Good	-27	1.88	Very Poor-Poor	Very Poor
lower Potomac	High Mesohaline	28.5	130	991	Poor-Good	-25	1.3	Very Poor-Poor	Very Poor-Poor
middle Potomac	High Mesohaline	17.9	109	9,817	Good	-14	1.8	Very Poor	Very Poor
upper Potomac	Low Mesohaline	15.7	56	0	Good	-27	1.5	Very Poor	Very Poor
St. Mary's River	High Mesohaline	27.06	85.3	2,461	Poor	-9	n/d	Very Poor	Very Poor
Tangier Sound	Polyhaline, High Mesohaline	n/a	158	20,192	Poor-Good	-31	1.6	Very Poor-Poor	Very Poor-Poor
lower Tangier	Polyhaline	n/a	99	9,963	Poor	-31	1.86	Very Poor-Poor	Very Poor-Poor
upper Tangier	Low Mesohaline	n/a	59	10,229	Good	-27	2.1	Very Poor	Very Poor
Fishing Bay	Low Mesohaline	n/d	203.2	4,434	Good	-9	2.05	Very Poor	Very Poor
Nanticoke River	Low Mesohaline	64.3	169.5	857	Good-Excellent	-16	1.33	Very Poor-Good	Very Poor
Monie Bay	Low Mesohaline	n/d	46.2	392	Good	-11	2.3	Very Poor-Poor	Very Poor
Manokin River	High Mesohaline	9.99	116.1	4,869	Good	-12	2.1	Very Poor	Very Poor
Big Annemessex River	High Mesohaline	11.7	46.5	1,220	Good	-5	2.02	Poor	Very Poor
Little Annemessex River	Polyhaline	5.16	80.7	0	Good	-4	1.86	Poor	Very Poor-Poor
Patuxent River	Oligohaline, Low	115	957	5,662	Poor-Good	-39	1.71	Very Poor	Very Poor
lower Patuxent	High Mesohaline	17.2	23	4,188	Poor-Good	-39	1.7	Very Poor	Very Poor
upper Patuxent	High Mesohaline	28.2	19	1,474	Good	-16	1.24	Very Poor	Very Poor
MD Mainstem - Upper	Low Mesohaline	25.5	164	21,461	Good	-22	1.65	Poor-Good	Very Poor-Good
MD Mainstem - Middle East	High Mesohaline	17.8	180	25,178	Poor-Good	-52	1.1	Very Poor	Very Poor-Poor
MD Mainstem - Middle West	High Mesohaline	32.3	230	21,385	Poor-Good	-34	1	Very Poor	Very Poor-Poor
MD Mainstem - Lower East	High Mesohaline	22.6	205	16,841	Poor	-49	1.2	Poor	Very Poor-Poor
MD Mainstem - Lower West	High Mesohaline	7.7	164	8,664	Poor-Good	-29	1	Poor	Very Poor-Poor

Table 4-1b. Physical Properties of Virginia Tributaries

Tributary	*Salinity*	*Length* (*Miles*)	*Drainage Basin* (*mi²*)	*Historic Oyster Habitat* (*acres*)	*Dissolved Oxygen*	*Maximum Depth* (*feet*)	*Tidal Mean Range* (*feet*)	*Chlorophyll a*	*Water Clarity*
Little Wicomico River	Polyhaline	12.77	18.1	206	Poor-Good	-36	0.8	Poor	Very Poor-Poor
Cockrell Creek	High Mesohaline	4.07	12.5	23	Good	-56	n/d	Poor	Very Poor
Great Wicomico River	High Mesohaline	15.2	62.7	2,479	Good	-46	1.15	Poor	Very Poor
Rappahannock River	Tidal Fresh, Oligohaline, Low and High Mesohaline	184	2,848	40,127	Good	-22	1.76	Very Poor-Poor	Very Poor
lower Rappahannock River	High Mesohaline	8	30	13,703	Good	-22	1.28	Very Poor-Poor	Very Poor
middle Rappahannock River	High Mesohaline	19	51	23,904	Good	-22	1.74	Very Poor-Poor	Very Poor
upper Rappahannock River	Low and High Mesohaline	12	24	2,520	Good	-22	2.1	Very Poor	Very Poor
Corrotoman River	High Mesohaline	2.93	87.9	2,757	Poor	-52	1.3	Very Poor	Very Poor
Piankatank River	Polyhaline	21.39	118.6	7,097	Poor-Good	-26	1.25	Poor	Very Poor
Mobjack Bay	Polyhaline	n/d	116.7	8,866	Good	-23	2.4	Very Poor	Very Poor
Severn River	Polyhaline	1.72	41.7	193	Good	-26	n/d	Very Poor	Very Poor
York River	Tidal Fresh, Oligohaline, Polyhaline, High Mesohaline	40	2,670	11,986	Good	-23	2.83	Very Poor	Very Poor
lower York River	Polyhaline	12	84	11,226	Good	-23	2.24	Very Poor	Very Poor
upper York River	Polyhaline, High Mesohaline	9	28	760	Good	-23	2.5	Very Poor	Very Poor
Poquoson River	Polyhaline	11.65	64.4	180	Good	-10	n/d	Very Poor	Very Poor
Back River	Polyhaline	2.07	69.6	182	Good	-13	2.3	Very Poor	Very Poor
Pocomoke Sound	Polyhaline, High Mesohaline	n/a	328.2	31,576	Good	-27	2.31	Very Poor-Poor	Very Poor-Poor
Onancock Creek	Polyhaline	5.32	36.4	0	Good	-26	1.8	Very Poor	Very Poor
Pungoteague Creek	Polyhaline	8.36	44.7	91	Good	-36	1.76	Very Poor	Very Poor
Nandua Creek	Polyhaline	4.6	28.6	0	Good	-16	n/d	Very Poor	Very Poor
Occohannock Creek	High Mesohaline	10.99	36.2	130	Good	-52	1.7	Very Poor	Very Poor
Nassawaddox Creek	Polyhaline	12.17	33.6	166	Good	-10	n/d	Very Poor	Very Poor
Hungars Creek	Polyhaline	6.23	36.5	0	Good	-26	n/d	Very Poor	Poor
Cherrystone Inlet	Polyhaline	8.44	44.9	0	Good	-36	n/d	Very Poor	Poor
Old Plantation Creek	Polyhaline	4.8	4.3	0	Good	n/d	n/d	Very Poor	Poor
James River	Polyhaline, Low and High Mesohaline	410	10,432	30,393	Good	-27	2.46	Very Poor-Good	Very Poor-Poor
lower James River	Polyhaline	12	53	9,578	Good	-27	2.6	Very Poor-Poor	Very Poor
upper James River	Tidal Fresh, Oligohaline, Polyhaline, Low and High Mesohaline	17	73	20,815	Good	-27	2.26	Poor-Good	Very Poor-Poor
Elizabeth River	Polyhaline	11.03	143.9	2,860	Poor-Good	n/d	2.79	Very Poor-Good	Very Poor
Nansemond River	Polyhaline	22.84	224.5	1,173	Good	-20	2.93	Poor	Very Poor
Lynnhaven Bay	Polyhaline	n/d	64.6	990	Very Good	-16	1.66	Poor	Very Poor-Poor

Table 4-1c. Explanatory Information for Table 4-1 a and b

PHYSICAL
Salinity, Dissolved Oxygen, Chlorophyll a and Water Clarity - Salinity zones are defined as- Polyhaline- 18-25 ppt; high mesohaline 12-18 ppt; low mesohaline 5-12; oligohaline 0.5-5 ppt, and tidal fresh 0 to 0.5 ppt. Index scores from CBP threshold comparison by Eco-Check (NOAA and UMCES 2012). Dissolved Oxygen-- Score is determined by how often (% of sampling times) dissolved oxygen levels were above or below the threshold between June and September 2010. Chlorophyll a-- Score is how often chlorophyll a concentrations were above or below threshold concentrations between March and September 2010. Water clarity-- Score is how often water clarity was above or below threshold concentrations from March to November 2010. Poor = 0-19%, Poor = 20-59%, Good = 60-99%, and Very Good = 100% (http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2010/indicators/). The following tributaries also have numerical data available through CBP Monitoring Stations (http://www.chesapeakebay.net/data): DO, chlorophyll a, and water clarity- Magothy, Severn, South, Rhode, West, Little Choptank, Big Annemessex, Fishing Bay, Manokin, Great Wicomico, Corrotoman, Piankatank, Mobjack, Poquoson, Back, and Elizabeth; chlorophyll a and water clarity- upper Rappahannock, middle Rappahannock, lower Rappahannock, upper York, lower York, upper James, lower James.
Length (Stream Miles) - Calculated by The National Hydrography Dataset (NHD). (VA) U/L James, U/M/L Rappahannock, and U/L York Rivers data based on Final Report Larval Transport Maps 2009 boundaries.
Drainage Basin - MD: This file (SWSUB8) is a statewide digital watershed file. This file depicts the State with 138 separate watersheds each with an 8-digit numeric code This file was created primarily for State and Federal agency use. The creation of this file goes back many years and involved several State and Federal agencies. This file was derived from a more detailed watershed file (Maryland's Third-Order Watershed). The U.S. Natural Resources Conservation Service (NRCS) redefined the third order watersheds creating the HUC14 file. The SUB1998 file contains all of the HUC14 Watersheds and some added watersheds to maintain water quality sampling sites. VA: The hydrologic unit (HU) data (HUC12) was download from the USDA Geospatial Data Gateway and called the Watershed Boundary Dataset (WBD). This new dataset at 1:24,000 scale is a greatly expanded version of the hydrologic units created in the mid-1970's by the U.S. Geological Survey under the sponsorship of the Water Resources Council. The WBD is a complete set of hydrologic units from new watershed and subwatersheds less than 10,000 acres to entire river systems draining large hydrologic unit regions, all attributed by a standard nomenclature. U/L James, U/M/L Rappahannock, U/L York Rivers data based on Final Report Larval Transport Maps 2009 boundaries and not watershed boundaries.
Historic Oyster Habitat - Polygon delineation of Maryland oyster bottom as surveyed by C.C. Yates in Maryland (Yates 1913) plus those surveyed by Baylor in Virginia in 1892-1893 (Baylor 1895). To create this compilation, the "baylor_grds" file was appended to the "Yatesbrs" file by using the "union" function in the Editor toolbox in ArcGIS version 9.3. All of the associated attributes are from the "Yatesbrs" file. For the attributes associated with the Baylor grounds survey, see the file "baylor_grds." This file was created for planning purposes.
Maximum Depth - This dataset contains bathymetric one meter low water contours for the mainstem Chesapeake Bay. The contours were generated by ArcInfo using surveys from the National Oceanic and Atmospheric Administration (NOAA) Hydrographic Survey Data CD-ROM. The one meter low water contours were generated by interpolating the Hydrographic surveys (~3.5 million soundings) and generating contours.
Tidal Mean Range - Calculated from data found at http://tidesandcurrents.noaa.gov/tides09/tab2ec2c.html.

4.1.1 SEDIMENT

Sediment erosion is a natural process influenced by geology, soil characteristics, land cover, topography, and climate. Natural sediment transport processes can be affected by anthropogenic land disturbances. Table 4-2 a and b provide land use in each tributary of interest. There are four primary sources of sediments to the Bay. Explanatory information for Table 4-2a and b is provided in Table 4-2c. The relative importance of each varies throughout the watershed:

- Input from main rivers, smaller tributaries, and streams in the watershed,

- Erosion from shorelines and coastal marshes (shoreline erosion),
- Ocean input at the mouth of the Bay, and
- Internal biogenic production of skeletal and organic material (minor source).

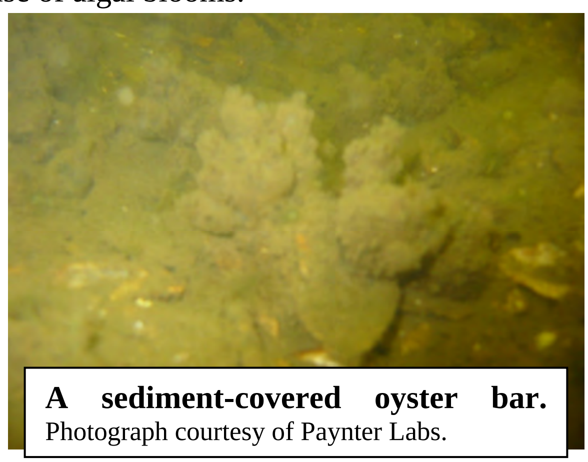
Bottom sedimentation at natural or accelerated rates is of concern because it impairs shell production that would otherwise compensate for this. Sedimentation eliminates important oyster habitat. Adult oysters can feed in heavily sedimented waters but feeding is most efficient in water that contains little suspended matter. Eggs and larvae can be killed by high sedimentation rates (Kennedy 1991).

Before European settlement, forests covered about 95 percent of the Bay watershed. Forests act as filters, capturing rainfall, trapping nutrients, and reducing stormwater runoff. Forests also protect soil from erosion and stabilize stream banks. Forests are now concentrated in the Appalachian region of Pennsylvania and West Virginia and account for 58 percent of the total land area in the watershed (CBP 2010c). Agriculture comprises 22 percent and urban/suburban lands make-up 9% of the watershed. Wetlands account for about 4 percent of the total land area; the remaining is open water and other land uses.

Sedimentation of the Bay bottom eliminates oyster habitat.

Eroded sediments from upland and riverine sources enter the Bay in quantities considerably greater than natural levels as a consequence of human activities and landscape alterations. Urban development and population growth affect oysters because impervious surfaces created by roads, parking lots, buildings, and other structures result in increased runoff, which alters salinity patterns, increases sediment loading, and contributes to nutrient enrichment within the Bay. Increased nutrients are a leading cause of algal blooms.

Phosphorus adsorbed to fine-grained sediments contributes to eutrophication. This phosphorus largely originates from fertilizer and human and animal waste, but becomes adsorbed to sediment while traveling to the Bay. Municipal and industrial wastewater treatment facilities accounted for 21 percent of the total nitrogen load delivered to the Bay in 2001. More than 300 municipal wastewater facilities and 58 industrial facilities collectively add 59 million pounds of nitrogen to Chesapeake Bay each year.



A sediment-covered oyster bar. Photograph courtesy of Paynter Labs.

Table 4-2a. Community Characteristics of Maryland Tributaries

Tributary	*Land Use*			*Archeological and Historic Resources*	*Minority Population (%)*	*Population of Children (%)*	*Low Income Population (%)*	*Bordering Counties*	*Oyster Sanctuary (Acres)*	*Commercial Navigation*
	Urban Lands	Agricultural	Forest							
Magothy River	55.5%	2.0%	22.3%	0	20.5%	30.9%	5.0%	Anne Arundel	5,360	No
Severn River	47.7%	7.3%	30.0%	11	20.5%	30.9%	5.0%	Anne Arundel	7,205	Yes
South River	33.5%	13.0%	39.4%	1	20.5%	30.9%	5.0%	Anne Arundel	2,032	No
Rhode River	20.5%	15.5%	35.8%	0	20.5%	30.9%	5.0%	Anne Arundel	0	No
West River	16.3%	27.8%	37.2%	3	20.5%	30.9%	5.0%	Anne Arundel	0	Yes
Chester River	2.8%	39.8%	21.0%	3	14.7%	20.4%	7.6%	Queen Anne's, Talbot, Kent	30,749	Yes
lower Chester	5.0%	26.0%	12.0%	0	22.9%	15.9%	9.6%	Kent, Queen Anne's	20,854	Yes
upper Chester	3.0%	64.0%	31.0%	3	14.7%	20.4%	7.6%	Queen Anne's, Talbot, Kent	9,895	Yes
Corsica River	0.3%	29.2%	20.1%	0	10.4%	29.4%	6.1%	Queen Anne's	1,257	Yes
Eastern Bay	13.3%	38.3%	8.7%	13	13.3%	21.3%	7.2%		13,753	Yes
lower Eastern Bay	14.5%	23.7%	8.6%	3	13.3%	21.3%	7.2%	Queen Anne's, Talbot	6,327	Yes
upper Eastern Bay	12.0%	52.8%	8.8%	10	13.3%	21.3%	7.2%		7,426	No
Choptank River	5.5%	26.7%	15.0%	11	18.3%	21.9%	9.9%	Caroline, Dorchester, Queen Anne's, Talbot	25,081	Yes
lower Choptank	10.0%	34.0%	13.0%	0	24.3%	22.8%	11.1%	Dorchester, Talbot	8,924	Yes
upper Choptank	8.0%	58.0%	28.0%	0	18.3%	21.9%	9.9%	Caroline, Dorchester, Queen Anne's, Talbot	16,156	Yes
Harris Creek	9.2%	28.1%	12.6%	10	16.0%	25.2%	8.3%	Talbot	4,302	No
Broad Creek	0.1%	0.8%	10.0%	1	43.9%	23.4%	23.0%	Somerset	0	No
Little Choptank	0.4%	12.9%	11.4%	0	29.7%	27.5%	13.7%	Dorchester	8,837	Yes
Honga River	0.1%	0.4%	6.7%	0	29.7%	27.5%	13.7%	Dorchester	694	Yes
Potomac River	8.6%	42.3%	33.6%	14	26.4%	24.4%	7.0%	18 bordering MD and VA counties	3,491	Yes
lower Potomac	11.0%	14.8%	37.3%	3	27.2%	25.0%	15.3%	St. Mary's, MD and Northumberland, Westmoreland, VA	0	Yes
middle Potomac	11.0%	14.8%	37.3%	6	28.4%	28.4%	14.5%	Charles, St. Mary's, MD and Westmoreland,VA	3,491	Yes
upper Potomac	11.0%	14.8%	37.3%	1	29.5%	23.2%	15.2%	Charles, MD and King George, Westmoreland, VA	0	Yes
St. Mary's River	19.2%	15.6%	46.5%	4	19.1%	33.5%	7.7%	St. Mary's	1,228	Yes
Tangier Sound	2.8%	0.7%	1.3%	2	30.2%	20.6%	16.6%	Dorchester, Somerset, Wicomico	6,237	Yes
lower Tangier	2.1%	0.6%	1.3%	1	43.9%	23.4%	23.0%	Somerset	356	Yes
upper Tangier	3.4%	0.7%	1.3%	1	30.2%	20.6%	16.6%	Dorchester, Somerset, Wicomico	5,881	Yes
Fishing Bay	0.5%	9.0%	20.9%	0	29.7%	27.5%	13.7%	Dorchester	0	Yes
Nanticoke River	6.0%	36.5%	43.0%	7	31.3%	28.4%	15.5%	Kent and Sussex Co., DE and Dorchester and Wicomico Co., MD	9,702	Yes
Monie Bay	2.7%	14.8%	30.9%	0	43.9%	23.4%	23.0%	Somerset	492	Yes
Manokin River	0.4%	10.4%	18.3%	2	43.9%	23.4%	23.0%	Somerset	15,057	Yes
Big Annemessex River	1.5%	10.1%	17.1%	5	43.9%	23.4%	23.0%	Somerset	648	Yes
Little Annemessex River	2.7%	0.8%	1.7%	0	43.9%	23.4%	23.0%	Somerset	0	Yes
Patuxent River	23.6%	22.2%	44.3%	6	32.5%	24.6%	5.9%	Anne Arundel, Calvert, Charles, Howard, Montgomery, Prince Georges, St. Mary's	9,855	Yes
lower Patuxent	21.0%	19.7%	43.4%	4	17.6%	31.6%	6.1%	Calvert, St. Mary's	619	Yes
upper Patuxent	26.2%	24.6%	45.2%	2	19.9%	29.7%	7.4%	Calvert, Charles, Prince Georges, St. Mary's	9,236	No
MD Mainstem - Upper	29.2%	20.9%	21.7%	2	19.9%	20.2%	7.3%	Anne Arundel, Harford, Kent, Queen Anne's	8,043	Yes
MD Mainstem - Middle East	9.4%	32.5%	11.9%	1	24.6%	18.6%	9.5%	Dorchester, Talbot, Queen Anne's	24,712	Yes
MD Mainstem - Middle West	36.7%	11.7%	38.7%	2	18.6%	31.3%	5.7%	Anne Arundel, Calvert, St. Mary's	2,455	Yes
MD Mainstem - Lower East	1.6%	3.7%	10.5%	1	37.3%	23.4%	18.4%	Dorchester, Somerset	3,792	Yes
MD Mainstem - Lower West	17.3%	18.5%	40.8%	1	23.5%	26.1%	10.0%	St. Mary's, MD and Northumberland, VA	38,294	Yes

Table 4-2b. Community Characteristics of Virginia Tributaries

Tributary	*Land Use*			*Archeological and Historic Resources*	*Minority Population (%)*	*Population of Children (%)*	*Low Income Population (%)*	*Bordering Counties*	*Oyster Sanctuary (Acres)*	*Commercial Navigation*
	Urban Lands	Agricultural	Forest							
Little Wicomico River	4.0%	10.0%	19.0%	9, 29	26.8%	22.2%	13.6%	Northumberland	0	No
Cockrell Creek	4.0%	10.0%	19.0%	3, 10	26.8%	22.2%	13.6%	Northumberland	0	No
Great Wicomico River	4.0%	10.0%	19.0%	18, 60	26.8%	22.2%	13.6%	Northumberland	80	Yes
Rappahannock River	1.0%	31.0%	57.0%	1948, 1961	29.9%	22.5%	11.1%	Stafford, Spotsylvania, Fredericksburg City, Caroline, King George, Essex, Westmoreland, Richmond, Middlesex, Lancaster	48	Yes
lower Rappahannock River	1.0%	31.0%	57.0%	2,7	23.9%	16.7%	12.8%	Middlesex, Lancaster	35	Yes
middle Rappahannock River	1.0%	31.0%	57.0%	17,8	31.0%	17.8%	14.3%	Middlesex, Lancaster, Essex, Richmond	10	Yes
upper Rappahannock River	1.0%	31.0%	57.0%	15,4	38.1%	24.5%	15.7%	Richmond, Essex	3	Yes
Corrotoman River	1.0%	31.0%	57.0%	127, 264	26.4%	21.9%	12.9%	Lancaster	2	No
Piankatank River	4.0%	10.0%	19.0%	69, 73	15.0%	23.5%	9.6%	Mathews Gloucester Middlesex	7	Yes
Mobjack Bay	4.0%	10.0%	19.0%	183, 180	12.6%	24.6%	8.3%	Mathews, Gloucester	3	Yes
Severn River	4.0%	10.0%	19.0%	n/d	12.9%	28.2%	8.4%	Gloucester	0	No
York River	2.0%	22.0%	64.0%	2378, 2463	19.5%	22.7%	7.2%	King William, New Kent, King and Queen, Hanover, Gloucester, York, Louisa, Caroline, Spotsylvania, Orange	42	Yes
lower York River	2.0%	22.0%	64.0%	108,18	23.6%	21.2%	9.3%	Poquoson, Hampton, York, Northampton, Mathews, Gloucester	25	Yes
upper York River	2.0%	22.0%	64.0%	31,25	20.9%	21.9%	7.2%	York, New Kent, King William, King and Queen, James City, Gloucester	17	Yes
Poquoson River	4.0%	10.0%	19.0%	138, 149	13.1%	26.2%	4.4%	Poquoson City,York	1	No
Back River	4.0%	10.0%	19.0%	79, 111	29.1%	26.8%	9.9%	Hampton, Poquoson City	1	Yes
Pocomoke Sound	4.0%	10.0%	19.0%	7, 14	30.7%	22.6%	16.8%	Accomack, Somerset, Worcester	8	Yes
Onancock Creek	4.0%	10.0%	19.0%	22, 26	30.8%	29.0%	16.8%	Accomack	0	Yes
Pungoteague Creek	4.0%	10.0%	19.0%	59, 18	30.8%	29.0%	16.8%	Accomack	1	No
Nandua Creek	4.0%	10.0%	19.0%	94, 9	30.8%	29.0%	16.8%	Accomack	0	Yes
Occohannock Creek	4.0%	10.0%	19.0%	115, 38	35.4%	29.0%	18.8%	Accomack, Northampton	0	No
Nassawaddox Creek	4.0%	10.0%	19.0%	44, 83	40.0%	28.9%	20.8%	Northampton	0	No
Hungars Creek	4.0%	10.0%	19.0%	65, 93	40.0%	28.9%	20.8%	Northampton	0	No
Cherrystone Inlet	4.0%	10.0%	19.0%	178, 92	40.0%	28.9%	20.8%	Northampton	0	No
Old Plantation Creek	4.0%	10.0%	19.0%	n/d	40.0%	28.9%	20.8%	Northampton	0	No
James River	5.0%	16.0%	71.0%	4244, 3567	44.1%	23.2%	11.9%	39 bordering VA counties	2	Yes
lower James River	5.0%	16.0%	71.0%	14,24	46.1%	25.3%	17.0%	Suffolk, Portsmouth, Norfolk, Newport News, Hampton, Isle of Wight	1	Yes
upper James River	5.0%	16.0%	71.0%	49,12	34.9%	22.8%	9.8%	Newport News, Surry, James City, Isle of Wight	1	Yes
Elizabeth River	5.0%	16.0%	71.0%	186, 2187	53.4%	34.1%	16.8%	Portsmouth, Norfolk	14 sites	Yes
Nansemond River	5.0%	16.0%	71.0%	397, 404	44.4%	34.6%	10.9%	Suffolk	0	Yes
Lynnhaven Bay	4.0%	10.0%	19.0%	138, 235	28.8%	32.6%	6.6%	Virginia Beach	57	Yes

Table 4-2c. Explanatory Information for Table 4-2 a and b

COMMUNITY
Land Use - MD: Calculated using each Drainage Basin (Watershed) using MARYLAND LAND USE\LAND COVER 2002 CLASSIFICATION SCHEME. Level 2 U.S.G.S. Classification of land use/landcover for each Maryland County and Baltimore City. Initially developed using high altitude aerial photography and satellite imagery. Urban land use categories were further refined using parcel data from MDPropertyView. VA: Data is based on Virginia major watershed classification as defined by the VA Department of Conservation and Recreation. The urban, agricultural, and forest data was retrieved from the following website: http://www.cnr.vt.edu/PLT/watersheds.html and is based upon USGS National Land Cover Dataset.
Archeological and Historic Resources - MD: This column was calculated using the data set that contains the locations and basic attributes of sites, buildings, objects, structures, and districts listed on the National Register of Historic Places (NRHP). VA: Cultural and Historic Resources - information listed as number of sites categorized by Archaeologic\Architecture in the watershed. Source: Virginia Department of Historic Resources 2008. U/L James, U/M/L Rappahannock, and U/L York Rivers data based on Final Report Larval Transport Maps 2009 boundaries.
Minority Population %, Population of Children % and Low Income Population % - MD: Calculated using United States - Data Sets - American FactFinder (http://factfinder.census.gov/servlet/DatasetMainPageServlet) by selecting all surrounding counties and finding the average. VA: Calculated using U.S. Census Bureau State and County Quickfacts (http://quickfacts.census.gov/qfd/states/51000.html) by selecting all surrounding counties and finding the average.
Bordering Counties - Selecting all counties that intersect the Drainage Basin (Watershed). VA: U/L James, U/M/L Rappahannock, and U/L York Rivers data based on Final Report Larval Transport Maps 2009 boundaries.
Oyster Sanctuary (Acres**) -** MD: Sanctuary acreage provided by MDNR in December 2010. VA: Elizabeth River data compiled by USACE Norfolk District. York River data: source article in the DailyPress.com 2/25/10 U/L James, U/M/L Rappahannock, and U/L York Rivers data based on Final Report Larval Transport Maps 2009 boundaries.
Commercial Navigation - Visualization analysis by drainage basin using a data set representing channel alignments maintained by the USACE - Baltimore and Norfolk Districts.

Contaminants harmful or toxic to aquatic life bind to fine-grained sediments in urban and industrial areas. Fine-grained sediments can remain suspended in Bay waters for extended periods of time because settlement is impeded by organic matter flocculant from eutrophication. Oysters are currently too few to filter all the sediments. This contributes to reduced water clarity and limits growth of SAV.

Wave resuspension of bottom sediments and shoreline erosion are a major source of suspended sediments in shallow water areas. Generally, wave energies can move bottom sediments down to about a 6-foot depth. Historically, large populations of oysters filtered suspended sediments out of Bay waters, and greater expanses of SAV may have reduced wave resuspension of bottom materials. Figure 4-3 shows the extent of SAV habitat as categorized by the CBP. For comparison, Figure 4-4 portrays the historic range of oyster habitat in 1916, following decades of harvest.

Between 1970 and 1990, the human population in the Chesapeake Bay region grew by 21 percent, and housing density increased by 49 percent to accommodate the new residents. From 1990 through 2000, the human population in the Chesapeake Bay watershed increased 8 percent, and the amount of impervious cover (land impenetrable to water) increased 41 percent. In 2008, population of the Bay watershed was recorded to be 16,883,751. The population is expected to grow to 20 million by 2030 (CBP 2010a). This population increase will bring additional development that is likely to exacerbate the problems of heavy erosion and sedimentation in the Bay; however, some of these increases may be offset by efforts to reduce and remove nutrients.

Agriculture and timber production can cause increased upland erosion and delivery of sediments to streams. Sediment inputs to the rivers of the Bay watershed from agriculture and forestry sources peaked in the late 1800s/early 1900s and have since declined substantially as a consequence of natural forest recovery and implementation of soil conservation management practices (Curtin et al. 2001). Monitoring (River Input Monitoring Program) data from major rivers entering tidal waters of Chesapeake Bay provides long-term trends (1985-2008). Suspended sediment concentration at the Susquehanna, Patuxent, Potomac, and Choptank Rivers, which includes the two largest tributaries to Chesapeake Bay, has trended downward. There was not a significant trend for the James, Rappahannock, Mattaponi (a tributary to the York) and Appomattox Rivers. The Pamunkey River in Virginia is the only site monitored that shows an increasing trend in suspended sediment concentrations (CBP 2010b).

The Maryland Shore Erosion Task Force states that approximately 31 percent of Maryland's shoreline is eroding (MDNR 2000). Shoreline erosion of the banks and coastal marshes of the Chesapeake Bay is a large source of fine-grained sediment, particularly in the middle Bay. However, the amount of sediment material is difficult to quantify because sediment loads vary greatly depending on the region and location. It is likely that shoreline erosion will become an increasing source of sediment given that sea level is currently rising and is expected to continue to rise (USGS 2003). Approximately, 1,000 miles of Maryland's 7,000 miles bay shoreline are artificially stabilized, not including the large Bay islands (Smith, Poplar, etc.). This includes over 500 miles of riprap, about 375 miles of bulkheads, and 9 miles of breakwaters. Stabilization seems to be concentrated in the Middle Bay, but occurs throughout. More than 3,000 acres of wetlands are projected to be lost to erosion from 2006 through 2056, not including large islands. This does not account for sea-level rise rate increases. About 975 acres of cultural resources are vulnerable to loss from erosion over the same time period. In total, approximately 12,000 acres of mainland shoreline have been identified as being vulnerable to erosion (USACE and MDNR 2010).

Although eroding shorelines do contribute sediment to the Bay, it is important to note that shorelines with erosional conditions are natural to much of the Bay. Sediment from eroding shorelines is critical to maintenance and creation of shallow water and shoreline habitats. Stabilization of eroding shorelines often leads to accelerated downdrift erosion, increased water depth alongshore, and loss of beach. In addition, eroding shoreline sediment typically contains only limited quantities of biologically available nutrients in contrast to eroding topsoil and nutrients delivered from artificial fertilizers, animal waste, and human waste.

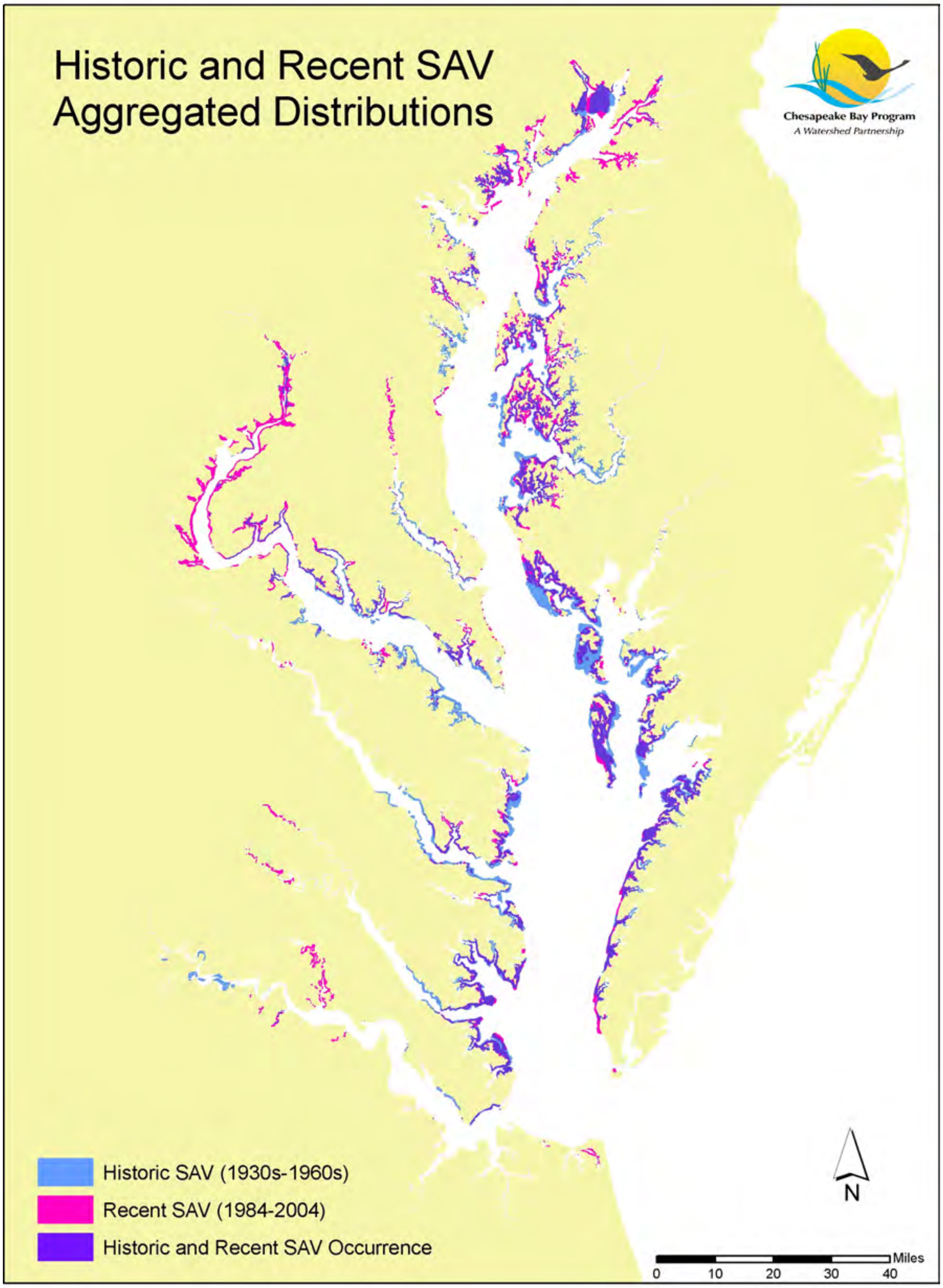


Figure 4-3. Submerged Aquatic Vegetation in the Chesapeake Bay (VIMS 2009)

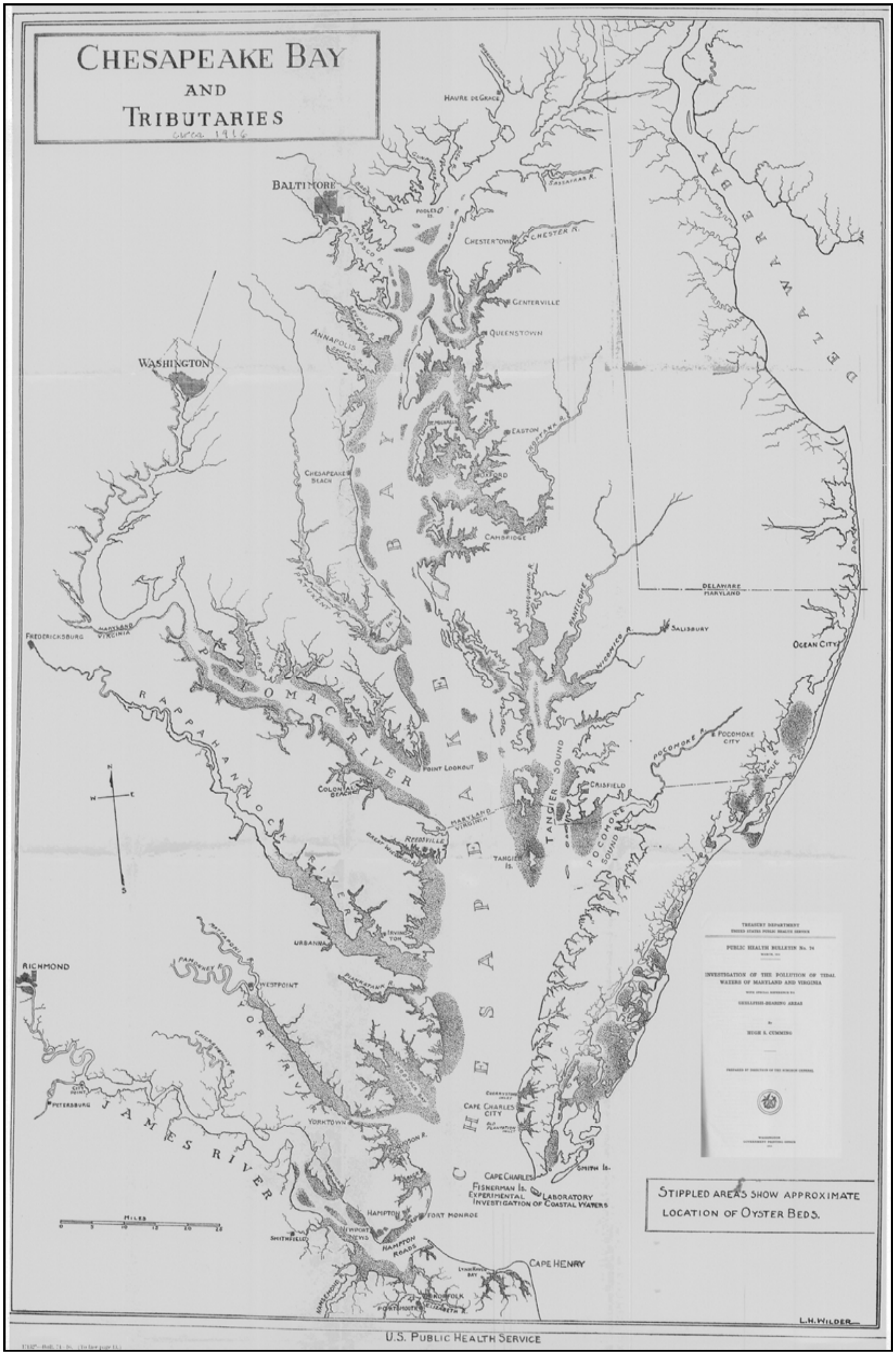


Figure 4-4. Approximate Historic Range of Chesapeake Bay Oyster Bars in 1916

4.1.1.1 Upper Bay

In the upper Bay, the Susquehanna River is the dominant source of sediment influx, supplying over 80 percent of the total sediment load in the area north of Annapolis (SRBC 2001). This northern area of the Bay contains the mainstem estuarine turbidity maximum zone (ETM zone) and is a region where most of the fine-grained particulate matter from the Susquehanna is trapped and deposited. All major tributaries as well as the mainstem have an ETM zone, characterized by high turbidity. The mainstem's ETM zone is an important site of sediment deposition because it acts as a barrier for southward sediment transport of material introduced into the Bay from the Susquehanna (USGS 2003). Generally, fine-grained river-borne sediment in the ETM zone escapes only during extreme hydrologic events (USGS 2003).

> Oyster growth must be greater than sedimentation rates for oysters to survive.

4.1.1.2 Middle Bay

In the middle Bay, the majority of sediment influx comes from shoreline erosion or is produced internally by biological processes. As mentioned previously, shoreline erosion is a significant problem in this region.

4.1.1.3 Lower Bay

In the Virginia portion of the Bay, shoreline erosion, nonpoint watershed sources, and influx from the ocean are the dominant sediment sources. Large quantities of sediment are produced from coastal erosion of headlands along the Bay margins and from the Atlantic Ocean through the mouth of the Bay due to ocean currents and tidal effects (USGS 2003).

4.1.1.4 Impact of Sediment on Oyster Bars

Sediment is a significant threat to oysters. Sediment effectively smothers oysters. Oyster growth must be greater than sedimentation rates in order for oysters to survive. Studies by DeAlteris (1988) estimate that Wreck Shoal in the James River grew vertically at a rate of 50 cm per century (0.5 cm/yr) until 1855 and that this rate of rise kept pace with both sea level rise and the deposition of new sediment. An evaluation of twenty-seven plantings on Maryland sanctuaries where salinity is typically less than 12 ppt, identified that oyster growth is sufficient to outpace sedimentation (Paynter et al. 2010). The most comprehensive Chesapeake Bay data set for sedimentation is the total suspended solids (TSS) monitoring performed by CBP (map and data available in Appendix C-5). Average bottom TSS (g/m^3) and long-term deposition (gm^{-2}/d) were computed for the stations in the data set. The long-term deposition rates are less than average oyster growing rates, suggesting that healthy oysters can handle the sedimentation rates. However, monitoring of restored oyster bars shows that sedimentation is a problem. Sedimentation at natural or anthropogenically accelerated rates is a problem if shell production is low. It is likely that the CBP monitoring data is not reflective of conditions on oyster bars because the monitoring stations, for the most part, are located in deep water and in the channels, rather than in shallow areas where oysters grow. Further, coarse sediment would have settled in shallow areas prior to reaching the channels.

4.2 WATER QUALITY

Water quality in Chesapeake Bay is influenced by the characteristics of its watershed and by the interaction of physical, chemical, biological, and anthropogenic processes. The watershed drains a large area encompassing 64,000 square miles of streams, rivers, and land within parts of six states. The waters that flow into the Bay carry effluent from wastewater treatment plants and septic systems as well as nutrients, sediment, and toxic substances from a variety of anthropogenic sources, such as agricultural lands, industrial discharges, automobile emissions, and power-generating facilities. Toxic substances and contaminants are not a major threat to the Bay-wide population, but can pose local problems, particularly in urban areas.

Except for a few deep troughs associated with the ancient bed of the Susquehanna River, Chesapeake Bay is shallow, averaging 6.5 meters deep. This shallowness makes the Bay's waters sensitive to temperature fluctuations, mixing events, and interactions with the sediments (Jasinski 2003).

Physical processes in Chesapeake Bay control the seasonal distribution of salinity, temperature, and dissolved oxygen (DO), and play an important role in determining water quality. Temperature and salinity are the two main environmental factors affecting survival, growth, and reproduction of oysters (Shumway 1996; NRC 2004). During spring and summer, surface and shallow waters are warmer and fresher than deeper waters; therefore, the water column stratifies into a two-layer system. The zone of change between those two layers is called the pycnocline. The strength of the stratification depends on river flow: the larger the volume of the incoming fresh water, the stronger the stratification. The deeper, more saline water moves up the Bay from the Atlantic Ocean. During autumn, vertical mixing occurs rapidly due to cooling and sinking of the surface waters and the passage of weather fronts.

Oysters both affect water quality and are affected by water quality.

The oxygen content or the DO concentration of Chesapeake Bay waters largely determines water quality and its suitability for the Bay's flora and fauna. Increased algal growth and sediment runoff also contribute to reducing water clarity in Chesapeake Bay. These processes suggest three good indicators of water quality in the Bay that are discussed below: DO concentration, chlorophyll a concentration, and water clarity.

4.2.1 *SALINITY AND TEMPERATURE*

Eastern oysters can tolerate a wide range of salinity- thriving in the mesohaline waters, becoming less abundant toward the head of the Bay and in upper regions of the Bay tributaries. Salinity influences growth, development, reproduction, feeding activity, predation, and disease pressure.

The Eastern oyster is accustomed to water temperatures ranging annually from -2ºC to 36ºC, and salinity ranging annually from 5 to 40 ppt, although most major populations occur in salinities between 10 and 30 ppt. Although able to withstand extreme temperatures, the rate of temperature change has been shown to have a great effect on adult oysters. That is, the slower the rate of temperature increases, the lower the upper lethal temperature (Shumway 1996). Adult and spat have the greatest ability to withstand extreme temperatures, followed by veliger larvae and then zygotes (Kennedy 1991).

Oysters are capable of withstanding wide salinity fluctuations, with greater tolerance at reduced temperatures. Adult oysters can survive salinities between 0 and 36+ ppt, but various life stages have narrower salinity ranges (Kennedy 1991), survival time is reduced below 2 ppt, and optimal ranges exist for all stages. Many investigators have attempted to define the temperature and salinity tolerance limits and optimum ranges, with considerable variability in results (Shumway, 1996). Table 4-3 summarizes the results of various investigations focused on defining optimal salinity for the oyster's life stages. Differences in methodology (laboratory versus field observations), acclimation conditions (Davis 1958; Davis and Calabrese 1964), and geographically associated genetic traits (Barber and Mann 1994; Dittman et al. 1998) all contribute to observed variations in optimum ranges, making it difficult and risky to define limits that apply to all populations. In addition, food and turbidity can confound the interpretation of field observations, especially in the case of salinity, as food availability is often limiting at low-salinity sites. Gunter (1950, 1953) showed that the eastern oyster could survive salinities as low as 2 ppt for a month, and even fresh water for several days when water temperatures were low. Self-sustaining populations have been identified in areas with salinities as low as 0.2 to 3.5 ppt for five consecutive months annually (Butler 1952). Spat survived salinities of 1.4 to 4.2 pt in the lower Laguna Madre, Texas, during periods of flood and reduced salinities (Breuer 1962). Long-term exposure to high salinities can also inhibit oyster populations. Open ocean waters can support oysters, but they usually do not reproduce or grow well under these conditions. Loosanoff (1953) determined that juvenile oysters could tolerate reduced salinities as well as adult oysters. In a study in the Chesapeake Bay, Chanley (1958) identified that juvenile oysters less than 1 year old survived 5 ppt. The effect of salinity on mortality rate is highly dependent on ambient temperature as evidenced by variable survival during spring floods and heavy rains (Shumway 1996). Loosanoff (1948) demonstrated that Long Island Sound oysters survived in freshwater and low salinity (3 ppt) for 70 and 115 d (days) at water temperatures between 8 and 12 C. However, all oysters died within 15 d at higher temperatures (between 23 and 27 C). Some evidence suggests that oysters conditioned to low salinity and temperatures have an increased ability to survive low salinities (Andrews et al. 1959).

Optimum salinity and the salinity range for the development of oyster eggs into straight-hinge larvae is influenced by the salinity experienced by the parents during gametogenesis. That is, parents acclimated to higher salinities will produce zygotes that develop optimally at higher salinities; and the opposite for parents acclimated to lower salinities (Kennedy 1991). Low salinity oysters are typically smaller in size than those grown at higher salinities (Shumway 1996).

Larval development occurs over a narrower range of temperatures and salinities than those suitable for adult oysters (Shumway 1996). Various studies have identified a suitable salinity range for successful development of oyster larvae from 5.6 to 7.5 ppt through 30 to 33 ppt (Hopkins 1932; Butler 1949a, b; Loosanoff 1948, 1953; Amemiya 1926; Prytherch 1934 as referenced by Shumway 1996). Investigations by Davis (1958) and David and Calabrese (1964)

Table 4-3. Suitable Salinity Ranges by Oyster Life Stage

Life stage	*Salinity (ppt)*	*Reference*
Eggs	12.5-35[1]	Davis 1958
	7.5-22.5[2]	Davis 1958
Larvae	12.5-27[1]	Davis 1958
	8-39 (10-29 optimal)[3]	Mann et al. 1991
Spat	15-22.5	Chanley 1958
Adults- survival	0-36+	Kennedy 1991
Feeding	5+	Kennedy 1991
Growth	12+	Kennedy 1991
	>5 (12-27 optimal)[3]	Mann et al. 1991
Gametogenesis	7.5-30+	Kennedy 1991
Spawning	10+	Kennedy 1991
	>8[3]	Mann et al. 1991
Commercial Production[4]	0-42.5	Ingle and Dawson 1950, 1953
Typical Population Range[4]	5-40.0	Galtsoff 1964, Wallace 1966
	1.2-36.6	Menzel et al. 1966
	1.5-39	Amemiya 1926
Minimum for Survival[4]	7.5	Loosanoff 1953
	7	Wells 1961
	4-5.0	Arnold 1868, Ryder 1885, Belding 1912, Loosanoff 1932
Optimum Range (varies geographically)[4]	14-28	Moore 1900, Butler 1949c, Chanley 1958, Galtsoff 1964
	15-18	Shumway 1996
Development of straight-hinge larvae[4]	7.5 to 22.5 (eggs conditioned at 8.7 ppt)	Davis 1958
	12.5-35 (eggs conditioned at 26-27 ppt)	Davis 1958
Release of gametes	>5-10	Kennedy 1996

[1] Adults acclimated to 26-27 ppt; optimal egg development at 22.5 ppt and optimal larval growth at 17.5 ppt.
[2] Adults acclimated to 9 ppt; optimal egg development at 10-15 ppt, some normal development at 7.5 ppt.
[3] Mann et al. (1991)
[4] As referenced by Shumway (1996)
Table 4-3 is reproduced from Kennedy (1991) with addition of Mann et al. (1991) and Shumway (1996) data.

suggest that larval development is governed by the salinity at which the parent eastern oysters undergo gametogenesis (see Table 4-3). Further, their work showed that the degree and rapidity of salinity change is likely more important than actual salinity under field conditions. As with adults, the effect of reduced salinities on larvae was to reduce the range of temperature tolerance (Davis and Calabrese 1964).

Unlike most of the other physical characteristics listed, salinity varies from the head to the mouth of the Bay, and with depth, as well as seasonally and annually based upon freshwater input from the watershed. Annual precipitation varies and determines whether wet, dry, or normal hydrologic conditions exist in the watershed in any given year. Seasonally, melting snow and spring rains typically drive salinity down through spring and into summer. Summer dry conditions then result in salinities rising through summer and into the fall.

Salinity is a significant control on survival of oysters because it largely controls the distribution of the oyster diseases, dermo and MSX. Recruitment is higher in high salinity waters, but there is also a higher prevalence and infection rate of disease. High salinities favor disease. Disease pressure is reduced in lower salinity waters, but so is recruitment. Further, disease pressure is increased Baywide in dry years when there is less freshwater discharge into the Bay and salinities are elevated, as opposed to wet years when salinity is decreased.

Historically, the region's climate has tended to shift between wet and dry conditions over several years. That is, wet or dry years tended to occur in clusters through time. During the last 10 years, however, rainfall patterns have shifted between wet and dry years more randomly with clusters of dry years in 1999, 2001, and 2002 and wet years in 2003 and 2004. These unpredictable changes in climate are expected to become more prevalent as average global temperatures rise, following the current trend (Jones and Moberg 2003). Hurricanes and severe tropical storms strike the Chesapeake Bay area during some years. Storms that cause large-scale oyster mortality are relatively rare but can have important population-level effects when they occur. For example, nearly all oysters north of the Chesapeake Bay Bridge died due to the prolonged reduction in salinity (CRC 1977) along with the reduction in DO and an influx of sediment and pollutants following the landfall of Tropical Storm Agnes in 1972 (USACE 2009).

As evidenced with Agnes, huge influxes of freshwater during storm events that can kill oysters. Oysters become inactive at salinities less than 4 ppt (Haven et al. 1977). The length of time that oysters can survive at these reduced salinities depends most on water temperature, but also genetics and conditioning (Haven et al. 1977). Oysters can survive reduced salinities for 2 to 3 months in cooler months (less than 5.5°C), but as temperatures rise (21 to 27°C), Haven et al. (1977) document that 3 weeks is about the longest oysters can survive (Andrews et al. 1959). It is important to note that freshets are much more likely to occur during months where oysters are not metabolically active, and that adults are capable of tolerating freshets during the colder months of the year far more aptly than juveniles. Regardless, juveniles have much higher survival rates during a colder month freshet than a warmer month event. Freshets kill oyster larvae outright, and oyster larvae are typically in the water column only during the summer months when the chance for a freshet is small.

Low salinity conditions do have a benefit of reducing or eliminating oyster diseases and competitors. However, areas that have consistently low salinity reduce the opportunities to promote the development of disease resistance in the local population.

Further discussion of how salinity and temperature are considered in the master plan is available in the Physiochemical White Paper in Appendix C-1.

4.2.2 DISSOLVED OXYGEN

During the spring and summer, as organisms consume increasingly more oxygen, the oxygen content decreases in bottom waters. As stratification persists, the concentration of oxygen in bottom waters may decrease to less than is needed for organisms to function (i.e., the water becomes hypoxic). This process occurs naturally in many estuaries, but in Chesapeake Bay it is exacerbated by excess nutrients from anthropogenic sources (Kemp et al. 2005). The extent of hypoxic (<2.0 mg/L) and anoxic (<0.2 mg/L) waters has far surpassed natural conditions and continues to worsen with eutrophication (Karlsen et al. 2000; Cronin and Vann 2003). Recent investigations suggest that the Bay has become more susceptible to the oxygen-depleting effects of nutrient loading than it was in the 1950's and 1960's (Hagy et al. 2004). A possible explanation for this is that the Bay has lost its buffering capabilities once provided by extensive populations of filter feeders and aquatic grasses (Wicks et al. 2007).

> Low salinity areas with the risk of an occasional freshet can be important sites for oyster restoration in terms of accumulating biomass.

In recent years, the magnitude of spring flows has been most closely tied to the volume of anoxic water that develops in the Bay. Hypoxic waters generally occur in Chesapeake Bay during the summer of each year in deep areas of the mainstem and at the mouths of the major tributaries. The volume of hypoxic water in Chesapeake Bay varies monthly with changes in hydrology (rainfall) and with seasonal changes in water temperature. Years with little precipitation and minimal river flow show less intense hypoxia than years with greater precipitation and river flow. Also, as water temperature increases during the summer months, hypoxia becomes more prevalent.

From 1985 to 2006, during the period June through September, on average 1.44 percent of the volume of the mainstem was anoxic, and 5.25 percent was hypoxic (D. Jasinski, USEPA CBP, pers. comm., USACE 2009). Data throughout the Bay suggest a general decreasing trend in DO since 1985; and, the Bay experienced extensive hypoxia from 2003 to 2005. Water quality monitoring performed by CBP between 2008 to 2010 indicate that 38 percent of the combined volume of open-water, deep-water and deep-channel water of the Bay and its tidal tributaries met DO standards during the summer months. This is a decrease of 1 percent from the 2009 assessment (CBP 2012a). The DO standards or thresholds are those defined by the Eco-Check program to develop the Chesapeake Bay Ecosystem Health Report Card (NOAA and UMCES 2012). The DO thresholds were originally defined as ambient water quality criteria by the USEPA (USEPA 2003a). Table 4-4 summarizes relevant CBP water quality goals and established thresholds.

> Discrete, severe, low DO events have the potential to be deadly and can be more important than seasonal averages.

Table 4-4. Chesapeake Bay Water Quality Goals and Thresholds

Indicator	CBP Goal	Threshold		
Dissolved Oxygen	100% of Chesapeake Bay and its tidal tributaries meet Clean Water Act standards for DO	**Designated Use**	**Threshold (mg/L)**	**Season**
		Open water fish and shellfish use	≥ 5	June-September
		Deep water seasonal fish and shellfish use	≥3	June-September
		Deep-channel seasonal refuse use	≥1	June-September
Water Clarity	100% of Chesapeake Bay to meet thresholds for water clarity. Typically, visibility to a depth >0.65 to 2 m (depending on salinity) during underwater bay grass growing season is acceptable.	**Salinity Regime**	**Relative Status Threshold (mg/L)**	**Season**
		Tidal-fresh	≥ 0.85	April-October
		Oligohaline	≥ 0.65	April-October
		Mesohaline	≥ 1.63	April-October
		Polyhaline	≥ 2.0	March-November
Chlorophyll-*a*	100% of Chesapeake Bay tidal waters to be below threshold concentrations of chlorophyll-*a* that are acceptable to underwater Bay grasses.	**Salinity Regime**	**Spring Threshold (March, April, May) (ug/L)**	**Summer Threshold (July, August, September) (ug/L)**
		Tidal-fresh	≤ 14	≤ 12
		Oligohaline	≤ 20.9	≤ 9.5
		Mesohaline	≤ 6.2	≤ 7.7
		Polyhaline	≤ 2.8	≤ 4.5

Impaired water quality in Chesapeake Bay is linked to nutrient over-enrichment and high concentrations of suspended sediment. Forest clearing, agricultural practices, human waste, animal waste, air pollution, and urban development contribute large amounts of nutrients and sediment that are transported to the Bay by its tributaries. Excess nutrients stimulate the growth of phytoplankton populations. When the increasingly abundant phytoplankton (i.e., an algal bloom) die, large amounts of organic matter sink to the bottom. The presence of excess organic matter on the bottom increases the demand for DO, which is required for bacterial decomposition of the organic matter. This increased oxygen demand hastens the seasonal oxygen depletion in the bottom waters of the Bay.

It is generally recognized that oxygen concentrations of less than 5 milligrams per liter (mg/L) of water affect the behavior and survival of fish (EPA 2003, CBP 2007b). Concentrations below 2 mg/L are considered to be hypoxic and affect the structure, distribution, and productivity of benthic organisms, including oysters (Widdows et al. 1989; Baker and Mann 1992, 1994; Baird et al. 2004; Stickle et al. 1989; Kirby and Miller 2005; Lenihan and Peterson 1998). Frequent hypoxic events result in benthic populations dominated by fewer, short-lived species. Persistent hypoxia and anoxia (a complete absence of oxygen) can result in mass mortality of benthic organisms and often in the complete elimination of the macrofauna. For example, Seliger et al. (1985) documented a catastrophic anoxic episode in the Bay that occurred in 1984. As a result of an unusual combination of factors that together contributed to oxygen depletion, oxygen levels at water depths greater than five meters dropped to 0 mg/L beginning in June of that year, followed by total mortality of shellfish and associated fauna at depths greater than six meters. Subsequent studies conducted from 1986 to 1988 in the Choptank River specifically to investigate relationships between DO levels and oyster mortality found no significant correlation, possibly because DO levels never declined or persisted to the extent that occurred in 1984.

Sessile estuarine organisms such as oysters have adapted to variable environmental conditions that typically occur in estuaries and are capable of surviving short episodes of hypoxia. Also, the fact that oyster bars in the Bay are located in shallow areas reduces their exposure to seasonal hypoxia in deeper waters (R. Mann, VIMS, pers. comm., USACE 2009).

Virginia considers the potentially deleterious effects of hypoxia in planning its oyster restoration and enhancement programs. Virginia routinely limits the placement of shell for restoration to shallower areas where oysters once were present; locations where low DO may be an issue, as identified during Virginia's fall oyster surveys, are avoided when placing shell (J. Wesson, VMRC, pers. comm., USACE 2009). According to Kennedy (1991), the minimum habitat requirement recommended for adult oysters is greater than 1 mg/L. Adult oysters can survive prolonged anoxia but larval oysters are more vulnerable to this condition. DO concentrations of greater than 5 mg/L are recommended for oyster survival (EPA 2003; CBP 2007a). DO at levels that do not cause mortality of oysters may cause stress that contributes to increases in mortality from other causes. For example, Anderson et al. (1998) documented immune suppression and consequent increased mortality from Dermo among oysters that experienced hypoxia. Hypoxia also affects the behavior of a variety of predators of benthos and influences the trophic transfer of energy from benthos to fish (Nestlerode and Diaz 1998, Baird et al. 2004).

> O_2 concentrations less than 5 mg/L are recognized to affect the behavior and survival of fish.

4.2.3 CHLOROPHYLL-A

The concentration of chlorophyll *a* in a water sample is used as an indicator of the amount of phytoplankton present. Large concentrations of chlorophyll *a* usually result from the presence of excess nutrients that contribute to increases in phytoplankton populations and have been linked to decreased water clarity, hypoxia, and changes in the structure of plankton communities in Chesapeake Bay. Harmful algal blooms may result from the altered community composition. When phytoplankton (i.e. and algal bloom) die large amounts of organic matter sink to the bottom which increases the demand for DO (required for bacterial decomposition of the organic matter). This increased oxygen demand hastens seasonal oxygen depletion with can negatively impact oyster reproduction and growth. Recent CBP data show decreasing trends for chlorophyll *a* concentrations (i.e., decreasing phytoplankton populations) in the upper portion of many tributaries, such as the Patuxent, Potomac, York, James, Choptank, Nanticoke, and Pocomoke Rivers, and in the smaller tributaries of the upper western shore of Maryland, but increasing trends in the Rappahannock River, lower Choptank River, and Tangier Sound (CBP 2004d). In 2010, 22 percent of mid-channel tidal waters met the threshold concentrations set for chlorophyll-a, a decrease of 7 percent from 2008 (CBP 2012b). The Chesapeake Bay Program goal for chlorophyll-a and thresholds are summarized in Table 4-4. Thresholds were initially defined by Lacouture et al. (2006) and Buchanan et al. (2005).

4.2.4 WATER CLARITY

Clear water, which allows light to pass freely, is important for the growth of SAV. Water clarity decreases with algal blooms and large volumes of sediment runoff. Increases in water clarity have been observed to occur with increases in filter feeding organisms such as oysters. For example, during the summer of 2004, water clarity in the Magothy River reached an all-time high value concurrent with a dramatic increase in the population of the dark false mussel (*Mytilopsis leucophaeta*), a small filter-feeding shellfish (MDNR 2004). Loosanoff (1948) observed that poor water clarity can negatively impact oysters by inhibiting their feeding, growth and reproduction.

Water clarity is usually low in the upper Bay (above 39ºN latitude). The lower Bay generally has the clearest waters. Water clarity is also low in most of the tributaries. Recent CBP data show a trend toward decreasing water clarity in many tributaries, including the Patuxent, Potomac, York, James, and Choptank Rivers, the smaller tributaries of the lower Eastern Shore of Maryland, Tangier Sound, and the mainstem of the Bay. In 2010, 18 percent of tidal waters met or exceeded thresholds for mid-channel water clarity, a decrease of 12 percent from 2009 (CBP 2012c). The Chesapeake Bay Program goal for water clarity and thresholds are summarized in Table 4-4. It is also important to consider nutrient levels, as well, because of the impacts nitrogen and phosphorus have on DO and water clarity. Thresholds were initially defined by Lacouture et al. (2006) and Buchanan et al. (2005).

4.2.5 POTENTIAL CONTAMINANTS OF CONCERN

Toxic contaminants enter the Chesapeake Bay and its tributaries by wastewater, agriculture, stormwater, and air pollution. Common organic contaminants include polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), organophosphate pesticides (OPs), and organochlorine pesticides. Heavy metals and endocrine disrupters are other contaminants that have the potential to harm oysters. Many contaminants will bind to sediments and persist in the Bay environment. Bioaccumulation is also a problem and can lead to contaminants moving through the food web. Although prevalent throughout the Bay system, toxics typically cause local water quality problems, particularly in urban watersheds. The percent of urban land use for each tributary is provided in Table 4-2 a and b. Due to the tributary level scale of the master plan investigation, contaminants were not considered in detail, but should be evaluated on a local level during tributary plan development.

4.3 AQUATIC RESOURCES

The Chesapeake Bay provides a wide range of habitats for thousands of different aquatic species, including finfish, shellfish, benthic invertebrates, and SAV. Habitats are the places where plants and animals live, where they feed, find shelter, and reproduce. Bay habitats of critical importance to aquatic organisms include oyster beds, SAV beds, and tidal marsh. A summary of these resources is provided in Table 4-5a and b for Maryland and Virginia tributaries, respectively. Table 4-5c provides explanatory information for Table 4-5a and b.

The Bay's aquatic resources are part of a complex food web, with phytoplankton and zooplankton at the base of the food chain, and large finfish species, waterbirds, marine mammals, and humans at higher trophic levels. Many aquatic species are commercially important, such as Atlantic menhaden (*Brevoortia tyrannus*), blue crab (*Callinectes sapidus*), and striped bass (*Morone saxatilis*). The Chesapeake Bay is a very productive and ecologically important ecosystem, which produces 500 million pounds of harvested seafood per year (CBP 2004b).

Aquatic resources in the Bay are protected at the Federal level under a number of environmental protection statutes including the Endangered Species Act, Fish and Wildlife Coordination Act, Anadromous Fish Conservation Act, The Magnuson Stevens Fishery Conservation and Management Act, and Emergency Wetlands Resources Act. The State of Maryland protects species and their habitats through several additional statutes including the Non-Game and Endangered Species Conservation Act, Chesapeake Bay Critical Area Law, Non-tidal Wetlands Protection Act, and Tidal Wetlands Act. The Commonwealth of Virginia has analogous environmental protection laws including the Chesapeake Bay Preservation Act, Virginia Wetlands Act, Virginia Endangered Species Act, and Endangered Plant and Insect Species Act.

Under these statutes, aquatic resources of the Chesapeake Bay are monitored and protected by a number of Federal, state, and public entities. USFWS biologists at the USFWS Chesapeake Bay Field Office work to protect endangered and threatened species, freshwater and anadromous fish, and wildlife habitats in the District of Columbia, Delaware, Maryland, and Virginia. The National Marine Fisheries Service Office for Law Enforcement is dedicated to the enforcement of laws that protect and conserve living marine resources and their natural habitat. USACE assists Federal, state, and local agencies in preparing environmental analyses, complying with environmental requirements, conserving natural resources, and implementing pollution prevention measures within the Bay region. MDNR and Virginia Department of Environmental Quality (VADEQ) preserve, protect, and restore their respective state's natural resources through law enforcement, monitoring, education, and management.

Table 4-5a. Biological Properties of Maryland Tributaries

Tributary	*Rare, Threatened, Endangered Species*	*Benthic Index of Biotic Integrity (IBI) Scores*	*Wetlands (Acres)*	*Submerged Aquatic Vegetation (Acres)*
Magothy River	1	Very Poor	640	83
Severn River	1	Very Poor	2,048	326
South River	1	Very Poor	1,792	8
Rhode River	1	Very Poor	192	0
West River	1	Very Poor	512	0
Chester River	9	Poor-Good	5,538	131
lower Chester River	8	Poor-Good	1,624	112
upper Chester River	9	Poor	3,914	19
Corsica River	7	Poor	2,048	0
Eastern Bay	8	Poor	6,217	58
lower Eastern Bay	8	Poor	3,536	0
upper Eastern Bay	8	Poor	2,681	58
Choptank River	12	Poor	30,084	1,111
lower Choptank River	8	Poor	2,514	469
upper Choptank River	12	Poor	7,090	0
Broad Creek	4	Poor	1,472	501
Harris Creek	4	Poor	1,216	0
Little Choptank	6	Poor	17,792	141
Honga River	6	Poor	15,296	2,497
Potomac River	7	Poor	4,421	618
lower Potomac River	4	Poor	686	14
middle Potomac River	7	Poor	2,623	107
upper Potomac River	5	Poor	601	11
St. Mary's River	3	Poor	511	486
Tangier Sound	9	Poor	29,732	6,730
lower Tangier Sound	4	Poor	2,397	5,825
upper Tangier Sound	9	Poor	27,335	905
Fishing Bay	6	Poor	49,920	0
Nanticoke River	12	Poor	120	0
Monie Bay	4	Poor	5,824	0
Manokin River	4	Poor	12,416	265
Big Annemessex River	4	Poor	6,464	611
Little Annemessex River	4	Poor	3,584	327
Patuxent River	10	Poor	3,401	39
lower Patuxent	5	Poor	377	25
upper Patuxent	7	Poor	3,024	14
MD Mainstem - Upper	15	Good	944	78
MD Mainstem - Middle East	12	Poor	4,395	473
MD Mainstem - Middle West	6	Poor	1,447	0
MD Mainstem - Lower East	9	Poor	9,348	604
MD Mainstem - Lower West	4	Poor	1,260	3

Table 4-5b. Biological Properties of Virginia Tributaries

Tributary	***Rare, Threatened, Endangered Species***	***Benthic Index of Biotic Integrity (IBI) Scores***	***Wetlands** (Acres)*	***Submerged Aquatic Vegetation** (Acres)*
Little Wicomico River	3	Poor	734	n/d
Cockrell Creek	3	Poor	425	81
Great Wicomico River	3	Poor	3,055	8
Rappahannock River	11	Poor	13,043	865
lower Rappahannock River	2	Poor	165	62
middle Rappahannock River	3	Poor	110	233
upper Rappahannock River	1	Poor	20	0
Corrotoman River	2	Poor	8,984	628
Piankatank River	3	Good	7,828	291
Mobjack Bay	3	Good	34,904	4,514
Severn River	1	Good	n/d	n/d
York River	10	Poor	3,138	2,335
lower York River	7	Poor	357	974
upper York River	6	Poor	91	0
Poquoson River	1	Good	8,529	1,378
Back River	3	Good	6,403	442
Pocomoke Sound	10	Good	2,639	2,054
Onancock Creek	7	Good	7,755	706
Pungoteague Creek	7	Good	6,882	1484
Nandua Creek	7	Good	7,337	704
Occohannock Creek	7	Good	3,766	418
Nassawaddox Creek	5	Good	3,645	111
Hungars Creek	5	Good	3,647	1,178
Cherrystone Inlet	5	Good	2,957	443
Old Plantation Creek	5	Good	n/d	n/d
James River	12	Good	17,450	1,567
lower James River	10	Good	134	76
upper James River	7	Good	133	0
Elizabeth River	1	n/d	19,965	n/d
Nansemond River	5	Good	37,355	n/d
Lynnhaven Bay	5	Good	6,850	2

Table 4-5c. Explanatory Information for Table 4-5 a and b

BIOLOGICAL
Rare, Threatened, Endangered Species - The number of RTE species was determined using county-based data compiled in Landscope America in September 2012 (www.landscope.org/map). The species listed in Landscope are US ESA listed, proposed, and candidate species, plus NatureServe Imperiled (G1-G2) species. The list includes plants and animals. For large tributaries that extend past historic oyster habitat, only those counties within the study area (regions of tributaries with historic oyster habitat) were included to determine the total species count for a given tributary. (VA) U/L James, U/M/L Rappahannock, and U/L York Rivers data based on Final Report Larval Transport Maps 2009 boundaries.
Benthic Index of Biotic Integrity (IBI) Scores - Benthic IBI evaluates the health of the benthic, or bottom-dwelling community (in soft-bottomed areas only). Benthic IBI Index scores from CBP threshold comparison by Eco-Check (NOAA and UMCES 2012). Eco-check score is the overall Benthic IBI scores for each of the 15 reporting regions in 2010. Poor = 0-19%, Poor = 20-59%, Good = 60-99%, and Very Good = 100%. (http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2010/indicators/). The following tributaries also have a Chesapeake Bay Program (CBP) Monitoring Stations located in them that enable a numeric Benthic Index of Biotic Integrity (BIBI) score to be calculated (http://www.chesapeakebay.net/data): Magothy, Severn, South, West, Little Choptank, Honga, St. Mary's, Big Annemessex, Little Annemessex, Manokin, upper Rappahannock, middle Rappahannock, lower Rappahannock, Corrotoman, upper York, lower York, Poquoson, Back, Occohannock Creek, upper James, lower James, Elizabeth, and Nansemond.
Wetlands - National Wetlands Inventory data.This data set represents the extent, approximate location and type of wetlands and deepwater habitats in the conterminous United States. These data delineate the areal extent of wetlands and surface waters as defined by Cowardin et al. (1979). Themes included are Wetlands, Deepwater habitats, Hydrography, Surface water, Swamps, marshes, bogs, fens. VA: U/L James, U/M/L Rappahannock, and U/L York Rivers data based on Final Report Larval Transport Maps 2009 boundaries.
SAV - The Chesapeake Bay SAV Coverage was mapped by VIMS from aerial photography to assess water quality in the Bay VIMS (2009). Each area of SAV was traced onto 1:24,000 USGS quadrangles and classified into one of four density classes by the percentage of cover. The SAV beds were then digitized and converted into GIS coverage. The annual SAV aerial photographic monitoring program provides a comprehensive and accurate measure of change in SAV relative abundance that has been used to link improving water quality to increases in bay living resources. Data is available for several years: 1980, 1984-1987 and 1989-2009. These data are also available through the Chesapeake Bay Program or VIMS. VA: U/L James, U/M/L Rappahannock, and U/L York Rivers data based on Final Report Larval Transport Maps 2009 boundaries.

In addition to these Federal and state entities, numerous partnerships and non-profit agencies assist in the protection and monitoring of the aquatic resources of the Bay. The most notable example is the Chesapeake Bay Program, which is a regional partnership whose mission is to protect the Bay's living resources and their habitats, and restore degraded habitats. The program's Executive Council (governed by the governors of Maryland, Pennsylvania, and Virginia; the administrator of the EPA; the mayor of the District of Columbia; and the chair of the Chesapeake Bay Commission) establishes the policy direction for the restoration and protection of the Chesapeake Bay and its living resources.

A complete inventory of Bay resources was beyond the scope of this document. For the master plan analyses, emphasis was placed on key commercially and ecologically important species including benthic invertebrates, clams, blue crabs, fish, phytoplankton, zooplankton, and SAV. Site-specific aquatic resource investigations may be required once specific project locations are selected for oyster restoration.

4.4 EASTERN OYSTERS

The eastern oyster occurs subtidally throughout the Bay and is also intertidal (emergent) in the southern edges of the Bay, mostly in water depths ranging from 6 to 30 feet. Oysters tolerate a wide range of salinities from 5 to 30 ppt, although salinities must remain at or above 9 ppt for successful reproduction.

Oyster bars and reefs are formed by the continual attachment of individual oysters. Early studies in Maryland (Stevenson 1894) identified that oyster bars occurred mainly on sides of channels in Chesapeake Bay and its tributaries and extend usually in the direction of the current. With sea level rise during the Holocene, oyster bars developed as paleochannels were submerged. Smith et al. (2003) determined that historic oyster habitat was associated with hard (previously terrestrial) land features (terraces and scarps). As depositional processes continued with sea level rise, some oyster bars proved to be successional and were buried with sediment. Table 4-1a and b provides the historical acreages of oyster habitat for each of the tributaries of interest. Bar morphology and height alters flow and ultimately impacts oyster growth, recruitment, condition, sedimentation, burial, and mortality. Two historical bar morphologies have been documented (Woods et al. 2004) in the Chesapeake Bay, a northern style and a southern style. The northern style was dominant across most of the Chesapeake Bay (specifically, the York River and tributaries to the north). Northern-style bars exhibited little relief, but were elevated from surrounding soft sediments (Smith et al. 2003). Relief was centered along and parallel to the channel edge (Woods et al. 2004). The southern style was found in the James River and southward along the eastern seaboard. Southern-style bars had significant relief, and although many were shoal-like, they were often emergent (Woods et al. 2004). The lower James River bars were long, fairly wide (bar base), and shoal-like and oriented at right angles to the current. The largest bar stretched 3 kilometers (km) (Woods et al. 2004).

Oysters can affect other organisms by changing the physical and chemical environment of the Bay ecosystem.

Historical accounts by Winslow (1882) noted that the shape and area of bars varied and normally exhibited an elongated shape with the longest dimension in the direction of the current (Kennedy and Sanford 1999). Bars mapped by Winslow in Tangier Sound ranged in area from 0.168 km^2 (41.5 acres) to 7.043 km^2 (1,740.4 acres), in length from 704 meters to 8,334 meters (2310 feet to 27,343 feet); and in width from 185 meters to 2,315 meters (607 feet to 7,595 ft) (McCormick-Ray 1998). Bed width-to-length ratios of the Tangier Sound beds were all less than 0.4 with the exception of one bed (ranging from 0.03 to 1) indicating that the beds were long and narrow, but that widths vary greatly among and within beds (McCormick-Ray 1998).

The eastern oyster provides a variety of ecological services within the Chesapeake Bay ecosystem including improved water clarity via filter feeding, and oyster bar and bar habitat for fish and other species in the Bay. Oysters can affect other organisms by changing the physical and chemical environment of the Bay ecosystem. Oysters filter water while feeding, thereby removing sediment and other particles from the water and depositing it on the bottom in pellets called pseudo-feces. Filtration by large numbers of oysters can reduce the time that sediment remains suspended in the water column and increase the clarity of the filtered water. Oysters' pseudo-feces are rich in nutrients and, therefore, help to support primary production among bottom-dwelling organisms in areas immediately surrounding oyster bars and reefs. Local nutrient enrichment also stimulates the exchange of various forms of nitrogen and nitrogen compounds from one part of the system to another (Newell et al. 2002). In addition to filtering suspended particles, large populations of oysters create bars and reefs of accumulated shell that are unique among kinds of habitat in Chesapeake Bay. Successive generations of oysters growing on the shells of previous generations gradually accrete large, three-dimensional structures that can compensate for sedimentation, if the rate of growth of the oyster bar or bar exceeds the rate of sedimentation.

The elevated structure of an oyster bar provides habitat for oyster spat, barnacles, mussels, hydroids, nudibranchs, and algae. These communities support blue crabs and finfish, such as oyster toadfish (*Opsanus tau*), naked goby (*Gobiosoma bosci*), striped blenny (*Chasmodes bosquianus*), Atlantic croaker (*Micropogonias undulatus*), summer flounder (*Paralichthys dentatus*), striped bass (*Morone saxatilis*), white perch (*Morone americana*), and spotted sea trout (*Cynoscion nebulosus*).

In addition to its ecological functions, the eastern oyster provides an important commercial fishery. For hundreds of years, oysters were among the most abundant bivalves and the most commercially important fishery resources in the Bay. Harvests peaked in the late 1800s but remained plentiful enough in the Chesapeake Bay through the 1st half of the 20th century to provide seasonal harvests in the millions of bushels. During the 1950s, approximately 35 million bushels of oysters were harvested annually. Oyster landings in the Chesapeake Bay have experienced a 95 percent decline since 1980, and are estimated to be at their lowest recorded level (Kennedy 1991). Oyster harvests are now tallied in terms of thousands of bushels. The Bay's oyster population is now estimated to be less than 1 percent of its size during the 1800s (Newell 1988). Figure 4-4, presented previously, depicts the historic oyster habitat as identified in 1916, following decades of harvest. Figure 1-2 in Section 1 documented the location and extent of the habitat identified by the Yates and Baylor surveys.

Major factors believed to have contributed to the decline of oysters include intense fishing pressure, mechanical destruction of habitat, siltation of optimal substrate, and stock over-fishing (refers to a level of fishing intensity at which the magnitude of harvest results in a reduction in the reproductive capacity of the stock) (Rothschild et al. 1994), as well as declining water quality and disease. Dredging for oysters began to degrade the physical integrity of centuries-old bars and reefs (DeAlteris 1988) by breaking off shell and oysters that were too small to harvest, thereby reducing the population and the habitat available for future production and harvest. In fact, current oyster harvests show that much of what was classified as productive oyster bottom at the turn of the century is no longer capable of producing oysters (Smith et al. 2005). Declining water quality, particularly suspended solids and eutrophication, have further limited the quality and quantity of available habitat.

4.4.1 DISEASE

There are at least 14 different diseases and parasites documented for the eastern oyster; however, oyster diseases caused by two waterborne parasites (MSX (*Haplosporidium nelsoni*) and Dermo (*Perkinsus marinus*)) are among the most important factors affecting oyster populations and their restoration in the Chesapeake Bay. Chesapeake Bay oyster populations had no resistance to these diseases which were first identified in the mid-20th Century. Dermo is dominant in the region today and is responsible for substantially and consistently more oyster mortality Bay-wide than MSX (CBP 2007a). These diseases have severely reduced the abundance of Eastern oyster populations along the East Coast of the United States (Ford and Tripp 1996).

Both MSX and Dermo are transmitted through the water column to other oysters. The mechanisms of Dermo transmission and infection are well established. Dermo is spread when infected oysters release *Perkinsus marinus* into the water column for healthy oysters to ingest. MSX transmission and infection, however, is not well defined. It is believed that an intermediate host is involved with MSX transmissions because laboratory attempts to transmit MSX from infected to healthy oysters have been unsuccessful (Ewart and Ford 1993).

Disease caused by Dermo and MSX are among the most important factors affecting oyster populations and restoration in the Bay. Recent evidence shows that high salinity oyster populations exposed to consistent disease pressure are developing disease resistance.

MSX thrives in higher salinity waters (greater than 12 ppt) and is particularly prevalent and widespread in dry years. Dermo tolerates lower salinity and infections are not always fatal. Dermo typically infects oyster by two years of age whereas MSX is often contracted by oysters less than one year old (Andrews and Hewatt 1957; Ford and Tripp 1996), High mortality rates caused by these diseases not only remove oysters potentially available for harvest, but also reduce the number of large, highly reproductive oysters that are left to propagate. Overall, oyster populations in the Bay are now strongly controlled by disease pressure (Ford and Tripp 1996) in addition to being negatively affected by harvest, degraded oyster habitat, poor water quality, and complex interactions among these factors (Hargis 1999; NRC 2004).

4.4.1.1 Evidence of the Development of Disease Resistance

There is definitive evidence that oysters can develop resistance to disease in general (Needler and Logie 1947) and MSX and Dermo in particular (Carnegie and Burreson 2011; Andrews and Hewatt 1957; Bushek and Allen 1996**;** Haskin and Ford 1979**).** Despite the increasing prevalence in the Bay of the parasites that are responsible for the two diseases and continued significant disease mortality, there are strong indications that disease resistance is developing in populations, especially those that are exposed to greater disease prevalence and intensity in the higher salinity waters, and where adults that have developed resistance are not harvested (Malmquist 2009, Carnegie and Burreson 2011). Available evidence suggests that the current high levels of resistance in present-day Delaware Bay stocks was achieved after extensive MSX-caused mortalities occurred on seed beds in the upper Bay during two drought years in the mid-1980s (USACE 2009). A number of papers suggest that some localized oyster stocks in the Chesapeake Bay show selective survival despite disease pressure (Andrews 1968; Burreson 1991; Ragone-Calvo et al. 2003; Carnegie and Burreson 2011). Specifically, Carnegie and Burreson (2011) highlighted resistance in oysters in the lower Rappahannock River, and at sites in the James and York Rivers. The CBP's 2007 oyster disease meeting recognized disease resistance developing in native populations. Most recently, a unique, 50-year dataset collected by researchers at VIMS shows that Chesapeake Bay oysters are developing resistance to the pair of diseases. Ryan Carnegie, a VIMS research scientist in the Shellfish Pathology Laboratory, indicates that while disease "continues to be a major killer of oysters," fewer oysters are becoming infected by the diseases. Carnegie says “decreased disease in the wild despite favorable conditions for the parasites is a clear sign of increasing resistance among our native oysters due to long-term exposure” (Malmquist 2009).

The CBP’s oyster disease meeting recommended that a cost-effective and defensible strategy to allow disease resistance to develop “would begin with leaving natural oyster populations alone, creating sanctuaries and enforcing harvest moratoria to allow populations a chance to expand, and disease resistance to evolve.” “Natural oyster sanctuaries are valuable in particular because presumptively disease-resistant broodstock will be given more opportunity to spawn in the absence of harvest pressure. Sanctuary populations over time should grow to be enriched for such larger, resistant oysters, which should be viewed as key spawners. Sanctuary bars should also be viewed as important repositories for natural genetic diversity. Selection and siting of sanctuaries should reflect an understanding of oyster dispersal patterns, and metapopulation structure. Some effort should be directed toward setting aside existing productive bars, or portions thereof, rather than only creating new habitats and designating them as sanctuaries” (CBP 2007a).

4.4.2 REPRODUCTION

Following external fertilization, oysters go through a series of larval stages lasting 2 to 3 weeks until the spat ‘sets’ on hard substrate in the benthos (Kennedy 1996). Initially, non-feeding trochophore larva develops followed by planktotrophic veliger and pediveliger larvae. Oyster larvae are able to move vertically in the water column by swimming (~1 to 10 mm/s); horizontal movement is driven by tidal currents (greater than 1m/s) (North et al. 2008). Larval swimming speeds increase with larval size and have also been shown to vary with temperature and salinity (Hidu and Haskin 1978). Investigations to better understand how well oyster larvae are able to control their distribution are ongoing (North, personal communication).

4.4.2.1 Fecundity

The oyster’s energetic investment in reproduction is prodigious, with individual females capable of producing many millions of eggs. The number of eggs produced is proportional to the size of the individual oyster (Davis and Chanley 1955). Thompson et al. (1996) reanalyzed the data of Cox (1988) to determine a relationship between numbers of eggs and dry tissue weight. They estimated fecundity values varying from 2 million eggs for a 0.3 g dry weight oyster (about 4 cm long) to 45 million eggs for a 1 g dry weight oyster (about 7 cm long). Galtsoff (1930) counted the eggs released by individual eastern oysters and found that a single female could produce from 15 to 115 million eggs in one spawning. He estimated that as many as 500 million eggs may be spawned by a female during the season. Later, Galtsoff (1964) reported values of 10 to 20 million eggs as typical for a single spawn, with occasional spawning as many as 100 million. Cox and Mann (1992) estimated fecundity in James River oysters as a mean fecundity of 4 to 9 million eggs per female, depending on body size and the sampling site.

The Eastern oyster is protandric and, as such, usually spawns as a male the first year. Andrews (1979) reported that in the James River 90 percent of oysters smaller than 35 mm shell height, and as young as 6 weeks post-settlement, functioned as males in the season in which they settled.

As individuals grow, the proportion of functional females in each size class increases, with an excess of females occurring among larger animals (Galtsoff 1964). Cox and Mann (1992) reported a significantly greater number of male than female eastern oysters from four locations in the James River. Conversely, previous data from one of these locations had demonstrated a sex ratio of approximately unity for oysters larger than 60 mm shell height (Morales-Alamo and Mann 1989). This feature of oyster biology is an important consideration for oyster restoration. Spat plantings of a uniform age will tend to be predominantly male and then turn to females with age. Providing for successful reproduction in areas with greatly diminished broodstock will likely require more than one spat planting to provide a sexually diverse population.

4.4.2.2 Physical and Biological Influences on Reproduction/Fecundity

Salinity has a significant control over reproduction. The development of eggs and larvae appears to be progressively reduced when the salinity falls below about 12 ppt and becomes negligible below about 8 ppt. Salinities below 5 or 6 ppt can inhibit gametogenesis (Butler 1949; Loosanoff 1953).

Reproduction of the eastern oyster is seasonal and largely influenced by temperature. Gametogenesis begins in the spring, and spawning occurs from late May to late September in the mid-Atlantic region (Shumway 1996; Thompson et al. 1996). Small oysters (10 to 20 mm) sometimes develop gametes, almost always sperm (NRC 2004). Under favorable growth conditions in the mid-Atlantic region, this may occur during the late summer after setting, although it is uncertain whether such individuals actually spawn or produce embryos because they do not ripen until after the normal spawning period. In the southeastern United States, sexual maturity is typically reached about 3 months after setting (NRC 2004).

Reproductive activity is seasonal and in temperate regions is generally dictated by temperature. Spawning occurs predominantly during the warm season, although other factors, such as phytoplankton blooms, may also play a role. Oysters shed their gametes directly into the water where fertilization occurs, and larval life is spent entirely in the water column. The larvae are both dispersed and concentrated by water currents and wind. At the end of the larval life, usually 2 to 3 weeks, the oysters “set.”

4.4.2.3 Larval Development and Distribution

Factors affecting larval survival and settlement include food, predation, suspended silt, and salinity, and water currents (Loosanoff and Tommers 1948; Baldwin and Newell 1991; Ulanowicz et al. 1980; Loosanoff 1959). During their 2 to 3 week planktonic stage, the young oysters pass through different stages of development, growing from fertilized eggs, to trochophore, to veligers, and finally to pediveligers, the stage at which larvae search for suitable substrate to which they will cement themselves, leaving the water column and becoming fixed on the bottom. This “settlement” of the larvae signals the end of the larval dispersal stage and the beginning of the juvenile stage. Larval circulation patterns are controlled by tides as well as freshwater flow and wind, which can change between years, months, weeks and even days. These patterns, and larval behavior responses, influence the direction and distance that larvae could be transported.

Larvae appear to migrate vertically, particularly at later stages, tending to concentrate near the bottom during the outgoing tide and rising in the water column during the incoming tide, thus increasing their chance of being retained in the estuary (Kennedy 1996; Shumway 1996). Larval mortality rates are estimated to be close to 99 percent (NRC 2004). It is important that larvae locate and settle on a suitable substrate within this 2- to 3-week period, and before they are flushed out of the area of suitable habitat.

4.4.2.4 Recruitment

Bay-wide recruitment levels are a fraction of what they were historically. For example, in the James River, larval concentrations were greater than 5,000 larvae/m^3 of water in 1950, but decreased to 300 to 800 larvae/m^3 of water as late as 1965, which was after the onset of MSX mortality but before Dermo began taking its toll (Mann and Evans 1998). This was at least a 90 percent reduction from previous years, based on the drop in spat-setting rates after MSX-induced mortalities began (Haven et al. 1981). After Dermo further devastated the already-depleted James River stocks, larval concentrations were measured in the same area as the previous study at 12 to 113 larvae/m^3 (Mann and Evans 1998). Krantz and Meritt (1977) investigated spatsets over two periods, 1939 to 1965 and 1966 to 1975, in Maryland waters. Nearly all sites in the Krantz-Meritt study showed a decrease in spatset between the two periods. The densest spatsets were recorded at >200 spat/bu (spat per bushel) during the period between 1939 and 1965, whereas, from 1966 to 1975 all spatsets were below 75 spat/bu.

4.4.3 PHYTOPLANKTON RESOURCES

> Oysters restoration has the greatest potential to reduce phytoplankton in tributaries where oysters have access to shallower, surface waters.

Typically food is not limiting to oysters in the Chesapeake Bay as phytoplankton is overly abundant. However, the size of available phytoplankton resources can affect oyster food availability. Oysters filter particles greater than 4 microns at near 100 percent efficiency (Landgon and Newell 1996) and provide near zero filtration of particles less than 2 microns (picoplankton). Historically, large oyster population may have been more dependent on other sources of food such as allochthonous detritus (fragments of organic materials and other small particles from the land), higher organic content of resuspended sediment, or on a higher primary production rate resulting from much tighter nutrient recycling and increased light penetration than is present today (Newell et al. 2005). As eutrophication has increased, the phytoplankton community has shifted to smaller planktonic species and has exhibited an increase in dinoflagellates at the expense of diatoms. Under present-day eutrophic conditions in the Bay, the relative biomass of picoplankton, which are largely unavailable to oysters, increases to around 20 percent of total phytoplankton biomass during the warmer summer months when oyster filtration is greatest. The inability of oysters to remove this portion of the phytoplankton community may limit the effect of oyster filtration on phytoplankton biomass (Fulford et al. 2007). Further, the removal of larger phytoplankton species by oysters would be expected to increase the proportion of picoplankton in the plankton assemblage (Fulford et al. 2007). As documented by Fulford et al. (2007) for average annual climatic conditions, 63 percent of phytoplankton biomass is concentrated in the mesohaline mainstem, the mesohaline portions of the Potomac and Tangier Sound contain 5.4 and 3.1 percent, respectively, and no other segment contains greater than 2 percent of phytoplankton biomass.

Fulford et al. (2007) modeled the effects of various oyster restoration scenarios on phytoplankton populations. They recognized that the occurrence of maximum phytoplankton biomass in March or April, prior to period of maximum oyster clearance from June to September, will likely limit the effect of restoration on the size of the spring bloom or its contribution to summer hypoxia (Malone 1992). The modeling indentified that oysters had the greatest impact on phytoplankton clearance in tributaries, with little effect in the mainstem Bay. From this, they concluded that restoration will make its greatest contribution towards reducing phytoplankton biomass where oysters have access to surface-layer chl-a, when picoplankton comprise a modest proportion of summer phytoplankton biomass, and when the contribution of the spring bloom to total annual phytoplankton biomass is low.

4.4.4 ADDITIONAL FACTORS AFFECTING OYSTER BAR HEALTH

4.4.4.1 Water Flow

Proper water flow over an oyster bar is critical to maintain a sediment free bar, provide food, and remove waste products. Shellfish growth is generally higher where currents are greater, delivering food and oxygenated water and carrying away waste by-products. Smith et al. (2003) identified that scouring currents were associated with the scarps where oyster bars historically developed and that these currents likely maintained sediment free oysters and brought increased food to the bar. Northern-style bars were characterized as large patches, often parallel to channel and currents (Woods et al. 2004). Strong currents are important in development of this style of bars along the edges of channels and tops of upthrusting areas of bottom. Southern-style bars were better characterized as biogenic lumps and groin-like ridges perpendicular to current. Woods et al. (2004) proposed water flow as the major controlling factor of oyster bar success.

Some quantitative guidance is available in the scientific literature. The species profile from Stanley and Sellers (1986) for oysters identifies that sufficient water currents range from 11 to 600 cm/s. Conversely, Lenihan (1999) identified that external currents up to 10 cm/s enhance internal feeding currents, and improve the rate of particle capture on oyster bars. Seliger and Boggs (1988) determined that a bathymetric gradient ($dz/dr \times 10^3$) greater than or equal to 20 maintained sediment free oyster bars in areas surveyed in the Chester River, Broad Creek, and Tred Avon River. This equates to a 2 percent slope. (Bathymetric gradients are the slope of the Bay's floor.) Seliger and Boggs (1988) calculated the bathymetry gradients from isobaths (depth, z) by measuring the projected distances (r) normal to the isobaths, expressing the gradient as noted above.

4.5 OYSTER SANCTUARIES

Sanctuaries are an integral part of restoring significant populations of oysters to the Chesapeake Bay. Sanctuaries provide areas that are not permitted to be harvested or impacted by fishing gear. The oysters within sanctuaries are protected to not only provide ecosystem benefits, but to provide larvae from mature oysters that have survived disease challenges. It is critical to develop populations of oysters that have survived disease so that they can pass that disease tolerance on to future generations.

A recent study by The Nature Conservancy and UC-Santa Cruz recommends that any oyster bars with less than 10 percent of their former abundance be closed to further harvesting until the oysters can build up their numbers again unless the harvesting can be shown to not impact bar structure (Beck et al. 2011).

Further, various negative impacts to oysters resulting from eutrophication could be most effectively addressed via large sanctuary bars. Large bars more efficiently filter high levels of sediments, preventing bar sedimentation. Waters flowing over large bars from nearby open bottom have already been filtered to a significant extent for TSS by oysters on the edge, thereby reducing exposure of interior oysters to sedimentation. Sanctuary designation would accelerate ongoing disease resistance development in the wild oyster stocks and eliminate negative impacts from oyster fishing. Fishing, other than applying negative selection for growth and disease resistance also disturbs the bar matrix, exposing shell that would otherwise be incorporated into the bar base back into direct contact with surface waters, encouraging its dissolution and preventing its sequestering into the anoxic portion of the bar matrix.

The State of Maryland recently expanded the sanctuary network from 9 to 24 percent of oyster habitat. There are now 223,276 acres of oyster sanctuary distributed throughout nearly all the tributaries within Maryland. Of this acreage 55,533 acres are located within Yates Bar boundaries. Figure 4-5 shows the current oyster sanctuary network in Maryland.

In Virginia, the Virginia Oyster Restoration Plan, developed by VIMS and VMRC, is used to guide decisions on where to locate sanctuaries. Similar to the process in Maryland, the location of oyster sanctuaries can be codified by law. However, Virginia does not typically establish large, permanent sanctuaries, but rather employs a rotating system where areas are protected from harvest for a few years, but then opened. Virginia regulations annually specify the areas open for harvest. All areas not open for harvest and not leased are closed as sanctuaries, but have not been specifically codified as sanctuaries by law. These areas amount to thousands of acres distributed throughout the Virginia waters. In addition, there are over 100 small, three-dimensional bars, ranging from 0.5 to 2 acres in size, maintained as sanctuaries. Figure 4-6 provides the locations of these sanctuaries.

Sanctuary bars are important repositories for natural genetic diversity.

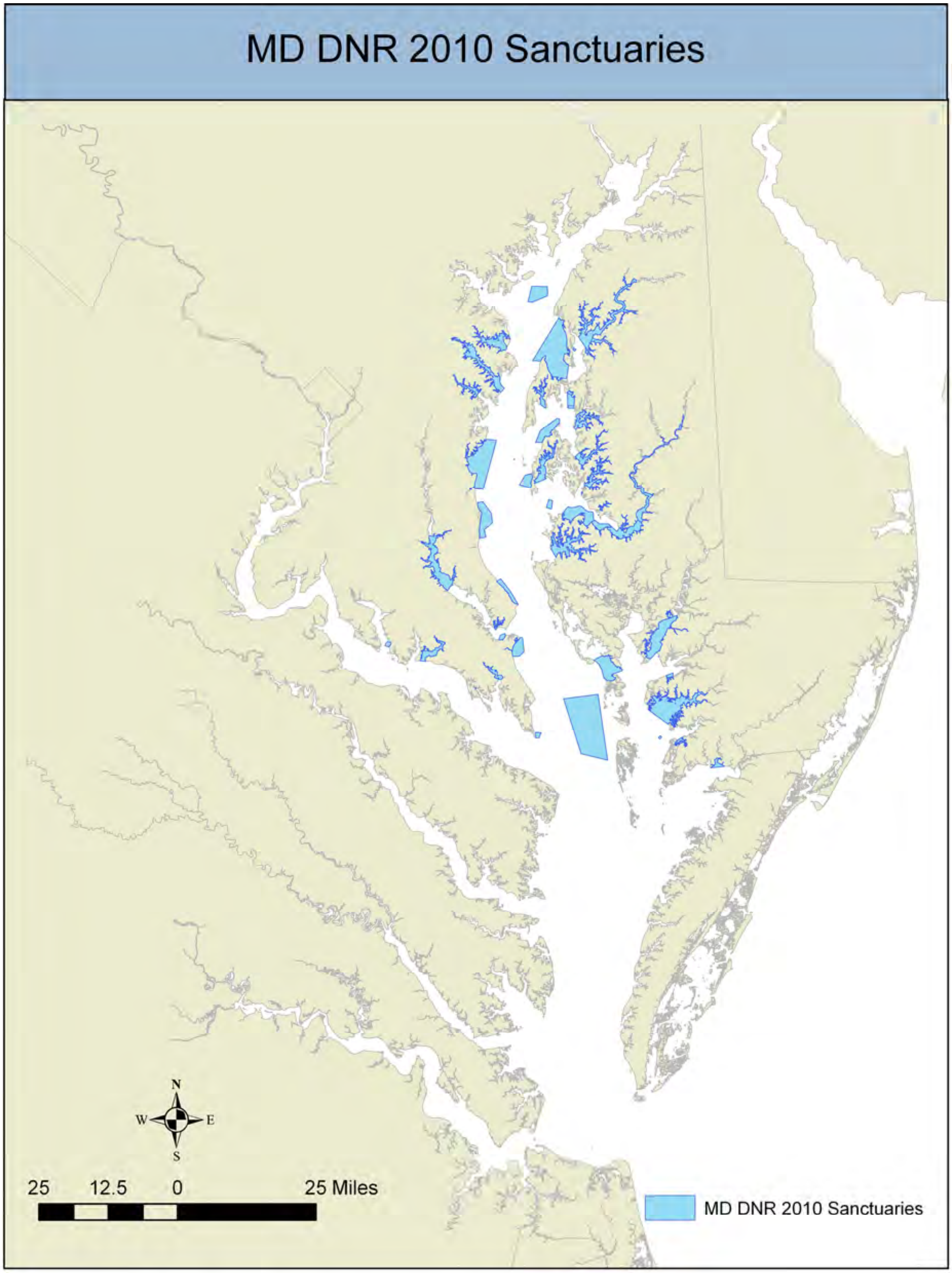


Figure 4-5. MDNR-Designated Oyster Sanctuaries

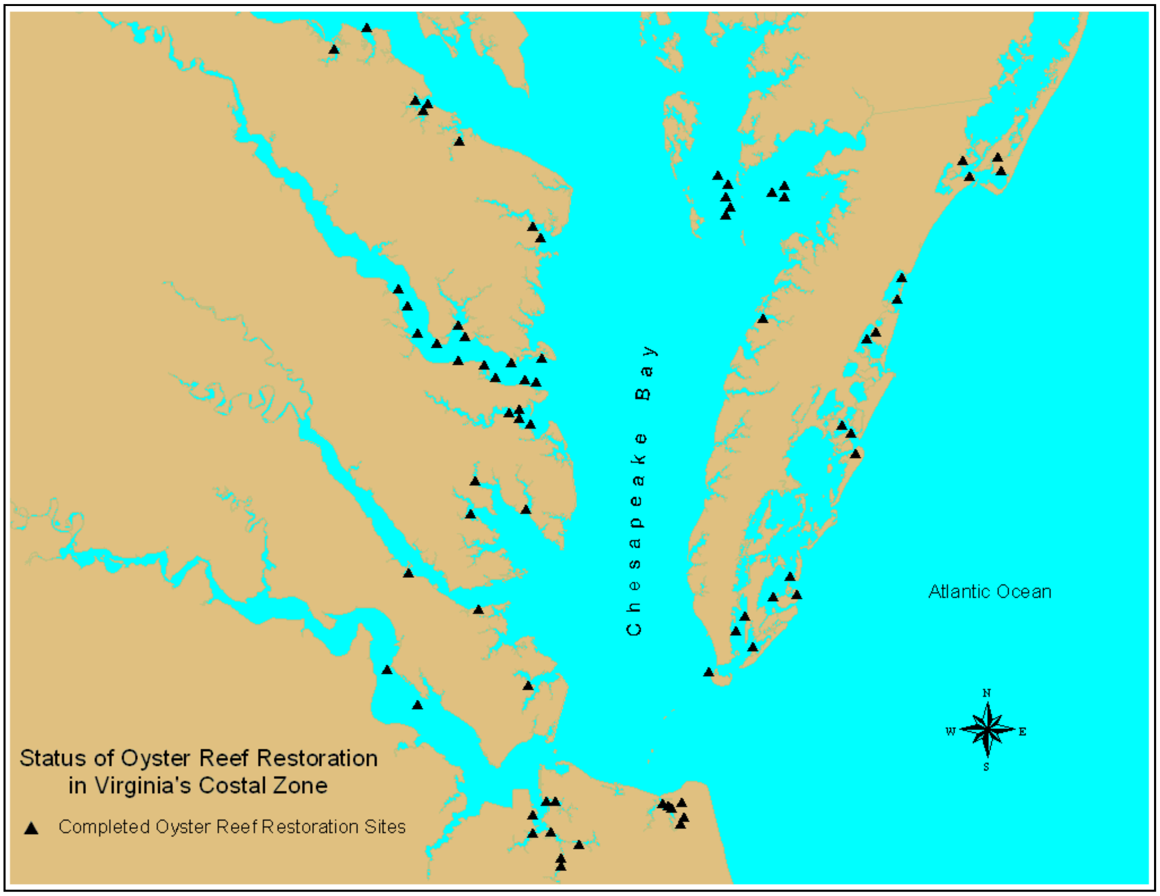


Figure 4-6. Location of Small, 3-D Sanctuaries Restored in Virginia.
Figured provided by VMRC.

4.6 POTENTIAL RISKS TO RESTORATION PROJECTS

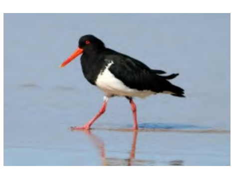
Both predation and poaching can result in serious negative effects on restored oyster habitat. Because these activities not only remove living animals but also disturb and remove shell material, they can compromise the biological and physical integrity of the bar habitat.

4.6.1 PREDATION

Oysters provide food for numerous predatory species, including flatworms, crabs, oyster drills, starfish, certain finfish, and cownose rays. A summary of oyster bar inhabitants and predators is provided in Table 4-6.

Predation on oysters is an important interaction in the Bay ecosystem. For example, blue crabs (*Callinectes sapidus*), cownose rays (*Rhinoptera bonasus*), and at least one species of bird, the American oystercatcher (*Haematopus palliatus*), prey on oysters directly. Oyster predators suffer more from exposure to the elements than do oysters. Therefore, intertidal oysters are subjected to less predation than oysters that grow subtidally. Humans are major predators of oysters, and harvest of oysters by humans has historically been biologically, economically, and culturally important in the Chesapeake Bay region (Newell 1988).

Table 4-6. Oyster Bar Predators

OYSTER BAR PREDATORS	NAME	DESCRIPTION
	Oyster Drill (*Urosalpinx cinerea; Eupleura caudata*)	A snail that bores a hole in the oyster by using its drill-like radula in conjunction with acidic secretions from a gland in its foot. It takes 8 hours for the snail to make a hole in the shell 2 mm thick. It then extends its proboscis through the hole and nibbles on the oyster tissue.
	Oyster Snail (*Odostomia sp.*)	A small cone-shaped snail. Light in color that sits on the lip of the oyster shell. It extends its proboscis inside to feed on mucous and tissue fluids.
	Boring Sponge (*Cliona sp.*)	The boring sponge is a thick, bright yellow sponge. They grow on oyster beds and other mollusk colonies throughout the Bay. It is called the "boring sponge" because it bores holes into an oyster's shell. This weakens the shell and can sometimes kill the oyster.
	Starfish (Asterias sp.)	The starfish pulls the two shells or valves of a bivalve apart with its five arms and inserts its stomach into the exposed shell cavity. As enzymes are released, the oyster is digested and absorbed by the starfish. A starfish can consume up to three adult bivalves per day and at least 15 oyster spat per day
	Cownose Ray (*Rhinoptera bonasus*)	Often observed in areas with sandy or soft bottom. Known to prey on a variety of shellfish. Often large schools. Leaves 2- to 3-foot depressions with shell fragments.
	Blue Crab (*Callinectes sapidus*)	Preys heavily on shellfish, including oysters and hard clams. Found intertidal and shallow subtidal habitats.
	Oystercatcher (*Haematopus palliatus*)	The diet of coastal oystercatchers includes estuaries bivalves (such as oysters), gastropods and polychaete worms. On rocky shores they prey upon limpets, mussels, gastropods and chitons. Other prey items include echinoderms, fish, and crabs.

Blue crabs are opportunistic predators; they exploit prey species at sizes that are most common in each of the habitats they visit (Micheli 1997). Although adult oysters are too large for blue crabs to open and prey upon (reviewed in White and Wilson 1996), they feed readily and opportunistically on juvenile oysters (Eggleston 1990).

Numerous avian species in the Chesapeake Bay watershed, such as the American oystercatcher (*Haematopus palliatus*), use benthic species including oysters and other shellfishes a primary food source. Oystercatchers were once hunted almost to extinction but are now conspicuous shorebirds found throughout the Chesapeake Bay region (from: *Status Review of the Eastern Oyster (Crassostrea virginica) Report to the National Marine Fisheries Service*, Northeast Regional Office, February 16, 2007).

A number of fish species such as black drum and cownose rays occasionally cause extensive damage to oyster beds, and diving ducks have also been documented as consumers of oyster tissue (Galtsoff 1964). Black drum have been documented to heavily impact seeded oyster bars in Louisiana in the spring (Brown et al. 2008). Cownose rays are considered an open ocean (pelagic) species, but can inhabit inshore, shallow bays, and estuaries. They prefer warm temperate and tropical waters to depths of 72 feet. Many gather in Chesapeake Bay during the summer months. Cownose rays feed on bottom-dwelling shellfish, lobster, crabs, and fish. These animals stir up the bottom sediments with their wings, thereby exposing bivalves which they then crush with their teeth and consume.

Captive cownose rays were subjected to replicate feeding trials to examine prey selectivity and ability to forage on different sizes of oysters and hard clams by Fisher (2010). Oyster trials utilized single cultchless oysters. It was observed that the adult rays used in this study were most successful preying on shellfish with shell depths less than 32 mm, which was further observed (via underwater video) to be linked to ray mouth/jaw morphology.

Although it has been considered due to high predation by the rays of commercial oyster beds, there is currently no commercial fishery for cownose rays in the Northern Atlantic. Cownose rays are considered a “pest” species by members of the shellfish industry because the rays’ feeding behavior damages commercial shellfish beds. There are many problems associated with a cownose ray fishery, including a potential decline in the population and a harvesting process that is both difficult and expensive.

Many organisms make up a healthy oyster bar community. While many of these species reside on the outer surfaces of the oyster’s shell, some species such as boring sponges and mud worms, perforate the inner shell surface causing the oyster to expend extra energy maintaining the integrity of the shell cavity.

Gastropod mollusks, primarily whelks of the genus *Busycon* and *Busycotypus*, can be significant predators on oysters and hard clams planted in subtidal areas. It has been demonstrated that the presence of the knobbed whelk (*Busycon carica*) can inhibit hard clam growth in the vicinity of the clam bed even if it cannot directly prey on the population (Nakoaka 1996). With the recent introduction of the veined rapa whelk (*Rapana venosa*) into the mid-Atlantic area, another large gastropod predator is now on the scene.

4.6.2 ILLEGAL HARVESTS

Poaching is problematic in the Chesapeake in recent years. Losses due to poaching can be as high as 5,000 to 10,000 shellfish/hr depending on harvesting method. Enforcement is difficult and poaching often goes unnoticed.

Monitoring of restored bars in Maryland from 1997-2006, showed that many of the sanctuary sites were impacted by illegal harvest (Paynter 2008). Incidentally, harvesting proved to be damaging to the oysters remaining on the bar. Harvest activity on three sites in the Choptank River resulted in well over 50 percent mortality of the remaining unharvested oysters (Paynter 2008). Recent monitoring has identified that illegal harvesting has also occurred on the Great Wicomico River sanctuaries in Virginia. Illegal removal of oysters poses one of the greatest threats to the success of restoration efforts in sanctuaries.

4.6.2.1 Laws/Regulations and Enforcement

1) Maryland - In Maryland, the Oyster Advisory Commission (OAC) 2008 Report (2009) outlined a list of law enforcement and policy recommendations that the OAC recommended that the state legislature and management agencies review and adopt via legislation or regulation to minimize illegal harvesting activities in Maryland's portion of the Chesapeake and coastal Bays.

The OAC report provided the following summary on the current status of poaching in Maryland:

> *"Currently, there is no single factor more important to the future of ecologic restoration and aquaculture than to address and dramatically reduce the ongoing illegal oyster harvesting activities. All stakeholder groups, including commercial watermen, current leaseholders and environmental organizations and government agencies, agree that illegal harvesting is a problem that needs to be resolved. The problem has been part of the oyster industry since the 1800s, leading to creation of the Oyster Navy, forerunner of today's Maryland Natural Resources Police (NRP). Unfortunately over the last seventeen years, while the NRP has lost over 40 percent of its personnel, the conservation enforcement demands placed on its staff has only increased with its state park and homeland security obligations. As such, the unit has been spread very thinly which has resulted in rampant theft of oysters in all areas of the state's waters.*
>
> *Many state authorized committees and commissions have called for NRP resources to be increased. The Fisheries Management Task Force and the Aquaculture Coordinating Council have requested additional law enforcement resources for the last two legislative sessions to "advance aquaculture". All are in agreement that without a change in current enforcement policies, increased police presence in helping to guard the bays, oyster recovery and private aquaculture efforts will likely not succeed. In addition, prosecutors and judges must understand that the illegal removal of oysters, especially those "purposely cultivated" is theft of public and/or private property. In this regard, prosecutors frequently fail to understand the severity of the crime when viewed against other criminal acts in society. Judges similarly look upon natural resource violations as minor offenses with the fines, when paid, are often set so low that they looked upon merely as a 'cost of doing business' by those who illegally harvest oysters."*

The OAC-specific recommendations to reduce poaching include:

- Prohibiting the use of power dredges in Maryland on non-leased areas unless specifically authorized by MDNR.
- Applying buffer areas around sanctuary bars.
- Holding seafood buyers responsible for possessing and/or selling undersized oysters to include ongoing inspections by NRP for compliance.
- Clearly requiring dockside vouchers for sale of lease bottom oysters.
- Increasing the current fine schedule for oyster related offenses, with a specific emphasis on undersized and unculled oysters and harvesting in prohibited, protected and leased areas to include modifying the current policy of "graduated violations" for harvesting within a sanctuary (distance from boundary) to one standard violation.
- Authorizing NRP to seize the vessel and/or equipment upon arrest and/or ticket issuance, if harvester(s) onboard are taking oysters/clams without a commercial license, operating with a suspended license, or committing theft in prohibited, protected, and leased areas.
- Enabling TFL license suspension by a court conviction as well as through an administrative hearing upon receiving a citation.

In addition, the Aquaculture Coordinating Council drafted a list of potential recommendations that the Maryland OAC concurrently supported including:

- Assigning one/two prosecutors to handle all natural resource cases statewide.
  or train one prosecutor in each county to handle these specialized cases. MDNR/NRP would provide training to these prosecutors regarding natural resource law.
- Establishing a dedicated day each month in each county to hear natural resource cases.
- Coordinating with the state's Attorney General's office to develop a system for complex conservation cases.
- As stated in the legal review report, giving judges the discretion to assess restitution on the defendant for egregious crimes.
- Recognizing that additional NRP staff funding is limited, consideration should be given to deploying:
  - Vessel-monitoring system devices on all commercial watermen vessels and require the system to be in operation any time the vessel leaves the dock.
  - Remote vessel-monitoring systems that would integrate into NRP's video surveillance network.

2) Virginia - In Virginia, recent actions by VMRC have demonstrated an increased effort to enforce fishery regulations including revoking licenses, confiscating harvesting gear, and hiring more enforcement officers (Travelstead, J., pers. comm.).

The Virginia Blue Ribbon Oyster Panel report additionally recognized the need for strong enforcement of fishery regulations. Their recommendations are provided in the box below.

The Virginia Blue Ribbon Oyster Panel made the following recommendations with respect to illegal harvesting:

Strong enforcement of fishery regulations and substantial patrolling of Virginia's sanctuaries and harvest areas are critical elements necessary for successful oyster restoration. Average fines levied for violations of most harvest rules provide little deterrent to those intent on violating the rules. Further deterrence, in the form of license revocation, is necessary. Accordingly, the Panel recommends the Commission make liberal use of its authority to revoke fishing licenses for up to two years (Section 28.2-232, Code of Virginia).

The Panel further proposes that the Commission revoke the license of any person convicted of any one of the following violations:

- Harvest of oysters from closed areas or sanctuaries
- Harvest of oysters from public grounds out of season
- Harvest of broodstock oysters, exceeding a maximum size limit.
- Tampering with aquaculture or experimental equipment
- Larceny from aquaculture equipment or private shellfish grounds.
- Violation of consumer health protection regulations

The length of the license revocation should increase significantly with multiple violations. While the manpower and equipment necessary for the proper enforcement of conservation and human health protection regulations are believed to be adequate at this time, the Panel expresses its concern that these resources be expanded, as necessary, to ensure an optimum level of enforcement.

4.6.3 FRESHETS

Freshets are huge influxes of freshwater during storm events that can kill very young oysters. The risk of freshets to oysters increases with proximity to the headwaters and typically is a greater concern for oysters in low salinity waters. Oysters become inactive at salinities less than 4 ppt (Haven et al. 1977). The length of time that oysters can survive at these reduced salinities depends most on water temperature, but also genetics and conditioning (Haven et al. 1977). Oysters can survive reduced salinities for 2 to 3 months in cooler months (less than 5.5°C), but as temperatures rise (21 to 27 C), Haven et al. (1977) document that 3 weeks is about the longest oysters can survive (Andrews et al. 1959). It is important to note that freshets are much more likely to occur during months where oysters are not metabolically active, and that adults are capable of tolerating freshets during the colder months of the year far more aptly than juveniles. Regardless, juveniles have much higher survival rates during a colder month freshet than a warmer month event. Freshets kill oyster larvae, but oyster larvae are typically in the water column only during the summer months when the chance for a freshet is small.

Tropical Storm Agnes, during the summer of 1972, was one of the largest documented freshwater influx events in recent history. Nearly all oysters north of the Chesapeake Bay Bridge died due to the prolonged reduction in salinity (CRC 1977) along with the reduction in DO and an influx of sediment and pollutants following the landfall of Agnes (NOAA 2003). The impact of Tropical storm Agnes on oysters has been documented in the tributaries of the upper west Bay as well as Virginia (Cory and Redding 1977, Haven et al. 1977). The Rhode, West, and South River oyster populations had mortality rates of 25 percent and were considered to not be as heavily impacted by Agnes's freshwater in comparison to other tributaries nearby due to reverse circulation patterns in these tributaries that kept bottom waters brackish (Cory and Redding 1977). Haven et al. (1977) estimated mortality on public and leased grounds in the major Virginia tributaries. They documented increased mortalities by mid to late July after salinities had been depressed for over three weeks. Mortalities on leased grounds were documented as follows: James River, 10 percent; York River, 2 percent; Rappahannock River, 50 percent; Corrotoman River, 20 to 22 percent; and the Potomac River tributaries, 70 percent. On public grounds, mortalities were estimated to be: James River, 5 percent; York River, negligible; Rappahannock River, less than 2 percent; Corrotoman River, less than 20 percent; and Potomac River (north of Cobb Island), nearly 100 percent. The upper portions of the Potomac were impacted more extensively than the lower portions. Haven et al. (1977) identified a line from Cobb Island in Maryland across the Potomac to Popes Creek in Virginia as the demarcation between the area upriver where nearly all oysters died and the area in the lower river where mortalities were not as significant. The smaller tributaries of the Potomac River were also investigated. Haven et al. (1977) estimated that about 70 percent of the oysters in these tributaries were killed by Agnes. The oyster populations in Eastern shore tributaries, the Piankatank and Great Wicomico Rivers, the Mobjack Bay Region and Lynnhaven Inlet were not seriously affected by Agnes as these systems received minimal freshwater input from Agnes (Haven et al. 1977).

Increased storm activity is predicted to be one result of climate change. More frequent storms would increase the risk of freshets to already susceptible low salinity populations.

4.6.4 HARMFUL ALGAL BLOOMS

Toxic dinoflagellate blooms ("mahogany" or "red" tides) or harmful algal blooms (HAB) can occur if nutrient levels are too high. Increased organic loadings, particularly dissolved carbon and phosphorus, may be increasing the frequency and diversity of HAB (Glibert et al. 2001). Shallow, poorly flushed systems are particularly at risk for HAB. HAB have the potential to kill oysters by reducing oxygen to concentrations that allow that hypoxia or anoxia to occur or by releasing toxins into the water column. Two common Chesapeake Bay HAB dinoflagellates, *Karlodinium veneficum*, and *Prorocentrum minimum*, pose a potential threat to oysters (Brownlee et al. 2005, Glibert et al. 2007). The timing of the blooms with respect to the oyster life cycle largely determines the impact on oysters. *P. minimum* blooms typically occur in spring and early summer while the frequency of *K. veneficum* blooms is greatest from June to September. Oyster embryos followed by larvae are far more vulnerable to dinoflagellate blooms than are adults (Glibert et al. 2007). The prevalence of *K. veneficum* in summer oyster spawning months, particularly July, and particularly in the northern Bay, could potentially limit oyster recruitment by impairing early life history stages (Glibert et al. 2007). Alternatively, *P. minimum* blooms typically occur prior to major spawning events, impacting the adult oysters exposed to short-term HAB-driven low oxygen events. Brownlee et al. (2005) showed that consumption of *P. minimum* by oysters increased growth rates. Others have found toxic effects on oysters from ingestion (Wikfors and Smolowitc 1995; Luckenbach et al. 1993). Toxicity of dinoflagellates varies with life stage. The conflicting results of these studies suggest that some life stages of the dinoflagellate may be a beneficial food source for oyster growth while others are toxic (Wikfors 2005).

4.7 CULTURAL AND SOCIOECONOMIC CONDITIONS

The cultural and socioeconomic environment of the Chesapeake Bay region is complex and diverse. Tables 4-2a and b, presented previously, summarize various characteristics of the communities in each tributary in Maryland and Virginia, respectively. Oysters play a variety of significant roles in this environment. The eastern oyster is highly valued as a source of food, a symbol of heritage, an economic resource supporting families and businesses, and a contributor to the health of the Chesapeake Bay ecosystem. Harvesting, selling, and eating oysters has historically been a central component and driver of social and economic development in the region. From the colonial period to the 20th century, oyster harvests supported a vibrant regional industry, which in turn supported secondary industries, fishing communities, and a culinary culture centered on the bivalve. Subsequently, society found various ways to 'dispose' of oyster shell. Native American populations created shell middens along shorelines. Post-European settlers used extensive amounts of oyster shell as fill material, including roads and driveways. This practice extended well into the 20th Century.

A culture can be defined as a body of knowledge and shared values that are learned through membership and participation in a specific group or community. The cultural value of oysters in the Chesapeake can be perceived in two different but related ways. Oysters are an economic resource that supports unique communities and an industry that is an important component of the region's heritage and identity. Within these communities, oysters are a source of income for families of watermen and those employed in the processing of oysters (e.g., shuckers); they support multigenerational businesses and contribute to a regional economy.

Oysters also give people the opportunity to interact with the marine environment in the most salient way possible – through work. These communities have helped to shape the character of the Chesapeake Bay region. Oysters are also a natural resource that carries cultural meaning as one symbol of a productive, healthy, beautiful Chesapeake Bay. These natural values are more implicit than stated, but they play a critical role in determining how different groups interact with each other and the environment. Economic and natural values combine to define what Chesapeake Bay means to people. To incorporate cultural meaning into policy, all groups' knowledge and values (implicit and explicit) must be recognized and evaluated based on an understanding of (1) how each group understands and uses oysters, and (2) how each group's perception of oysters affects its understanding of, support for, or resistance to policies and programs designed to manage and sustain the Bay's natural resources. A wide range of behaviors can be affected by changes in cultural meaning, including political support for oyster restoration plans, consumption of oysters, and participation in oyster recovery programs, commercial fishing, or the operation of oyster-dependent businesses (Paolisso et al. 2006).

Although the cultural influence of changes in oyster populations in the Bay extends to all residents, people with familial or historical ties to the region, taxpayers, restoration agencies, non-governmental organizations and various other users, the socioeconomic dimensions of such changes are most relevant for direct users. Direct users include watermen, and oyster growers, processors, packagers, shippers, and retailers. The oyster industries in Maryland and Virginia are quite distinct due to differences in oyster populations, regulatory frameworks, and structure. Processing, wholesale, and retail operations continue to operate in the region but depend increasingly on oysters imported from elsewhere.

The seafood industry contributes approximately $400 million each year (State of MD 2006) to Maryland's total gross domestic product of $257.8 billion (U.S Department of Commerce 2010). Virginia's seafood industry is the third largest producer of marine products in the nation, with an annual economic impact of more than $500 million (VA Seafood 2011) to Virginia's total gross domestic product of $383.0 billion. In 2009, commercial fisheries landings (i.e., the weight, number or value of a species of seafood caught and delivered to a port) alone earned $76,057,117 in Maryland and $152,729,813 in Virginia (NOAA 2007).

More than 6,600 watermen work Chesapeake Bay. They provide seafood to 74 seafood processing plants in Maryland and 109 plants in Virginia. MD processing plants employ more than 1,300 people (MD Seafood 2005) and the seafood industry provides approximately 11,000 part-time and full-time jobs in Virginia (VA Seafood 2011). These jobs represent an assortment of positions including day laborers, sales representatives, managers, maintenance workers, delivery personnel, and others. The sector relies on immigrant workers, particularly in oyster and crab processing facilities (Kirkley et al. 2005).

Oyster processing is a part of the larger seafood processing industry discussed above. The processing sector in Maryland, which consisted of 11 processing plants employing 249 people in 1997, is smaller than in Virginia, where 21 plants employed 389 employees that same year (NRC 2004; Muth et al. 2000). In Maryland, most oysters are harvested from public grounds during the winter (depending on the kind of equipment used, a designated time frame is set between October and March). In Virginia, a significant portion of landings comes from privately held leases, which often are harvested during the summer, whereas public beds are harvested during the winter (NRC 2004). During the 1990s, more than 96 percent of the oyster harvest in Maryland came from public beds, while less than 40 percent of Virginia's harvest came from public beds, and the rest came from leased beds. Although oystering earns watermen much less money than they earn from crabbing during the spring and summer, dredging or tonging for oysters during fall and winter enables them to continue to earn a small income, providing a financial safety valve for watermen and their families (NRC 2004).

Watermen in both Maryland and Virginia must purchase a special license to harvest oysters. In Virginia watermen must first purchase a Commercial Registration License followed by purchasing a license by gear type. In Maryland, anyone seeking to harvest oysters must first obtain an oyster harvesting license (OHL) or a tidal fish license (TFL), which allows the holder to harvest a range of commercially valuable, marine species in the Bay. To qualify to harvest oysters in any particular year, holders of an OHL or TFL must pay an annual oyster surcharge, which currently costs $300. The number of surcharges represents the number of people fishing for oysters. In any given year, many TFL holders elect not to fish for oysters; consequently, the number of oyster surcharges purchased by OHL and TFL holders is the best indicator of the number of Maryland harvesters active in the fishery during a year. Table 4-7 summarizes the total oyster surcharges and licenses obtained since 1999 in Maryland and Virginia.

In 2001, more than 1,000 watermen in Maryland paid the oyster surcharge, and 320 in Virginia held gear-specific oyster licenses. That same year, these harvesters earned an estimated $5,300 per license (either OHL or TFL) in Maryland and $1,800 per license in Virginia (NRC 2004). In 2010, only 698 watermen in Maryland paid the oyster surcharge, while 630 watermen in Virginia held oyster licenses (VMRC 2005). Over the period captured in Table 4-7, the decline in the number of watermen paying the oyster surcharge was more pronounced in Maryland compared to changes in oyster licensing in Virginia, where the trend included some increase.

Table 4-7. Oyster Surcharges and Licenses per Year for Maryland and Virginia

Year	Maryland-Number of Oyster Surcharges	Virginia-Licenses Sold for Various Types of Harvesting Gear
1999	1135	406
2000	1031	255
2001	1004	320
2002	725	546
2003	461	312
2004	284	420
2005	463	648
2006	637	557
2007	476	483
2008	570	515
2009	587	559
2010	701	630
2011	698	NA

Source: Data from Maryland Department of Natural Resources and Virginia Marine Resource Commission

For some watermen, oysters are an integral and essential component of their livelihood. For others, oysters represent a way to earn some extra money during the winter. For most watermen, oysters are a significant component that enables harvesters to continue working the water during winter, which is central to their cultural identity as watermen.

5.0 PLAN FORMULATION

Comprehensive oyster restoration faces a magnitude of challenges and the path forward will not be easy. The master plan discusses the challenges for oysters and defines strategies for addressing these stressors. Table 5-1 summarizes the overriding constraints to restoring oysters to the Chesapeake Bay and identifies actions recommended by the master plan to address those constraints. These recommended actions are developed in this section as well as the following Section 6.

5.1 EVALUATION STRATEGY

The evaluation strategy presented in the master plan examines numerous key tributaries and areas throughout the Bay that historically had oyster populations. In evaluating these tributaries for their restoration potential, a screening or layering approach was employed to identify the highest priority areas for restoration. Tier 1 tributaries are the highest priority tributaries that demonstrate the historical, physical, and biological attributes necessary to develop self-sustaining populations of oysters. Through the screening process, Tier 2 tributaries are identified as those tributaries that have identified physical or biological constraints that either restrict the scale of the project required, or affect its predicted long-term sustainability.

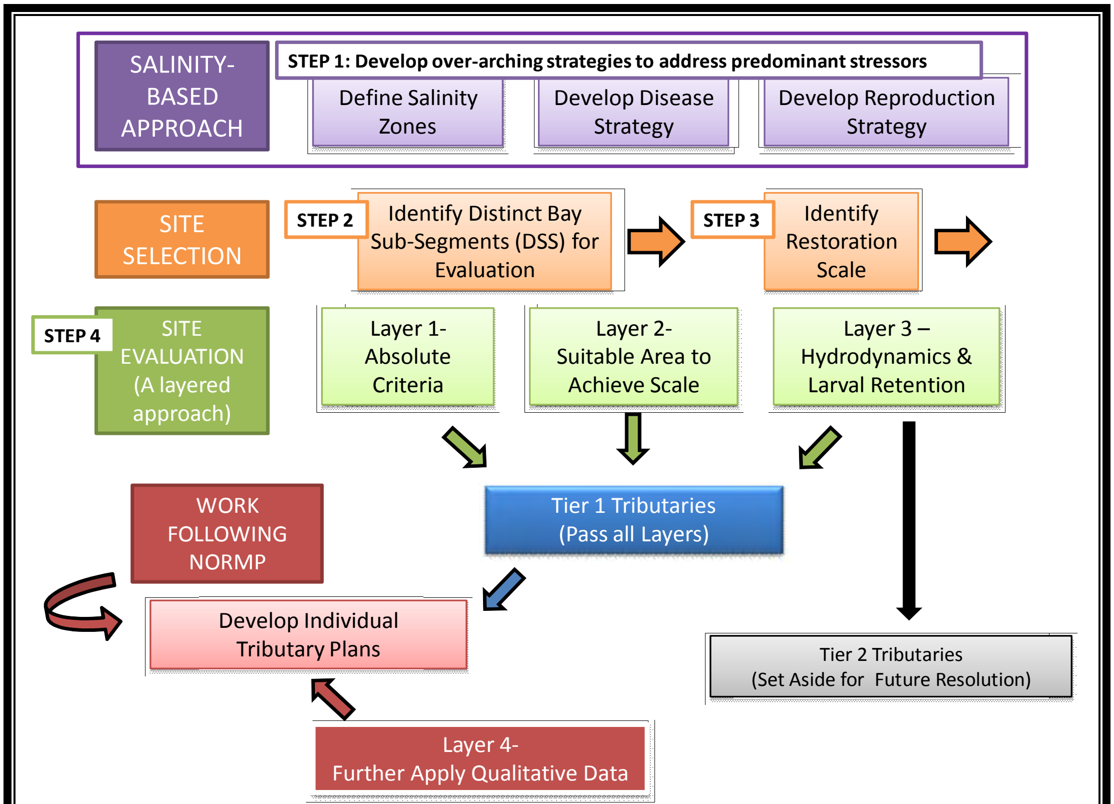
The evaluation strategy applied in the master plan is shown in Figure 5-1. The initial step was to define over-arching strategies that would serve as a foundation upon which to build the restoration plans. Salinity, more than any other individual property of the Chesapeake Bay, plays a role in all aspects of an oyster's life cycle. As such, the master plan adopts a salinity zone strategy in devising restoration plans. Similarly, disease and reproduction, which are largely salinity driven, are critical issues that must be addressed to return sustainability to the Chesapeake Bay oyster population. Therefore, the master plan also outlines a disease and reproduction strategy. Salinity and its implications for the effects of disease and reproduction influence the information presented throughout the master plan from site selection through restoration techniques at individual restoration sites.

The next step was to identify the tributaries and regions of the Bay that would be evaluated for oyster restoration which serve as the alternatives for the master plan. The master plan then addressed various issues of scale. As applied in the master plan, scale is specific to the size of Bay segments that should be evaluated and number of acres that need to be restored to reach the project goals (Step 3). With these issues defined, the site evaluation was a sequential application of various layers of information with an end goal of identifying tributaries and regions within the Bay that are most likely to develop sustainable populations of oysters with the implementation of bar construction, seeding, and other oyster restoration activities (Step 4). As each layer of information was applied there was a gradual focusing to the recommended areas or tributaries within the Bay. After the areas were identified estimated implementation costs were developed considering various construction alternatives. Specific design alternatives for construction will be developed in the follow-on tributary plans.

Table 5-1. Problems, Objectives, Constraints, Considerations, and Recommended Actions

Problem		
Degraded oyster populations in Chesapeake Bay due to loss of habitat, disease, water quality, and overharvesting.		
Objectives		
Long-range	Restore self-sustaining oyster sanctuary populations.	
Near-term- Habitat for oysters	Restore oyster abundances. Focus on restoring and maintaining habitat and in low salinity regions, broodstock.	
Near-term- Habitat for reef community	Restore bar/reef characteristics similar to undegraded oyster habitat.	
Near-term- Ecological services	Restore native oyster populations that provide ecological services typical of undegraded oyster habitat.	
Fisheries Management	Restore oyster spawning/habitat sanctuaries in multiple tributaries that export larvae outside the sanctuary boundaries and provide a larval source to harvest grounds.	
Constraint	**Master Plan Considerations**	**Restoration Action**
Salinity- Water Quality	freshets, salinity	site selection (in tributary plans)*
Dissolved Oxygen- Water Quality	DO, water depth	site selection- DO, limit water depth, construct reefs with elevation off bottom
Disease	salinity	sanctuaries, selection of strains for seeding, construct in trap estuaries, site selection- salinity
Reproduction	historic and recent spatsets; salinity; connectivity and available information about larval transport; existing oyster populations in region	trap estuaries, broodstock and seed planting, sanctuaries, site selection- salinity
Harvest	harvest records	sanctuaries
Substrate/Habitat	bottom condition, water quality, predation pressure, existing oyster populations	construct hard base, reseed or add substrate, site location- bottom that can support oysters
Scale	historic oyster habitat, past restoration efforts	target tributaries for large, system-wide restoration
Sedimentation- Water Quality	bottom condition	construct reefs with elevation off bottom; consider orientation to flow and currents in tributary plans; site selection- local sedimentation levels
Predation	salinity	site selection- salinity, seed with spat-on-shell, predator exclusion devices if cost-effective
General Water Quality	watershed land use	site selection- consider land use and proximity of site to potential sources of toxicity, harmful algal blooms
Funding	cost estimates based on region	accomplish restoration by leveraging resources of all organizations involved, adaptive management, start in small tributaries

* "site selection" under "Restoration Action" refers to reef selection within follow-on tributary plans



Layer 1 → *Absolute Criteria* → Determine the number of suitable acres available

- salinity > 5 ppt (growing season mean)
- DO $\geq$ 5 mg/L (summer mean)
- Water depth < 20 feet at MLLW
- Historic upstream limit of oyster bars

Layer 2 → *Scale* → Determine if there is enough suitable acreage available to meet the targeted scale for restoration.

Layer 3 →*Qualitative Hydrodynamic Rating* → Indicates whether a tributary has high, medium or low indicators of hydrodynamic properties that are preferred for restoration

Layer 4→*Additional Qualitative Data* →Important data to consider for restoration, but most not available quantitatively on Bay-wide scale. Further apply these data sets and/or collect additional data when developing tributary plans.

Figure 5-1. Master Plan Evaluation Strategy

5.1.1 Site Selection: Methodology to Select Tier 1 and Tier 2 Tributaries

As depicted in Figure 5-1, the master plan site selection screening process used three primary layers or filters to identify Tier 1 and Tier 2 tributaries. All tributaries or geographically distinct sub-segments (DSS) of larger tributaries with sufficient suitable acreage (Layer 1) to meet the required scale (Layer 2) and assigned a “High” qualitative hydrodynamic rating (Layer 3) were designated as Tier 1 (pass all layers). The tributaries or DSS that did not meet the screening requirements of each layer were identified as Tier 2.

5.2 DISEASE, REPRODUCTION, AND SALINITY ZONE STRATEGY

Two overarching factors influence all oyster restoration in the Chesapeake Bay: disease and oyster reproduction/recruitment. Both factors are influenced by salinity and require any large-scale Chesapeake Bay oyster restoration plan to include a salinity-based strategy. Two oyster diseases (MSX - *Haplosporidium nelsoni* and Dermo -*Perkinsus marinus*) have combined with other factors (direct harvest, loss of suitable habitat, and pollution) over the last 50 to 60 years to devastate oyster populations throughout the Chesapeake Bay. Site selection must explicitly address disease, its relationship to salinity, and promote the development of disease resistance in the wild population to ensure the sustainability of restoration. The following three sections of the master plan lay out USACE's salinity-based strategy for formulating oyster restoration and for addressing disease and reproduction with respect to restoration.

> The master plan adopted a salinity zone strategy in devising restoration plans in recognition that salinity, more than any other individual property of the Chesapeake Bay, plays a role in all aspects of an oyster's life cycle.

These strategies were formulated by developing white papers that discussed the significance of the paper's topic to oyster restoration and USACE's Master Plan, summarized the current state of knowledge, and described the application to the master plan. The white papers were provided to the two state sponsors and the collaborating agencies for review and comment. Comments were addressed by USACE. Ultimately, the formulation white papers were used to obtain consensus on USACE's proposed strategies among USACE, the sponsors, and the collaborating agencies. The formulation white papers are available in Appendix C-1. Significant comments and responses are described in the following sections.

5.2.1 SALINITY

Salinity affects all aspects of an oyster's life and with dissolved oxygen and temperature constitute the main physical environmental factors affecting survival, growth, and reproduction of oysters (Shumway 1996; Thompson et al. 1996; NRC 2004). In the 2004 Oyster Management Plan (OMP), the Chesapeake Bay resource agencies acknowledged the importance of salinity in oyster restoration and came to a consensus that oyster restoration in the Bay should follow a strategy based on salinity zones. In particular, three salinity zones [(low (1), moderate (2), and high (3)] were identified; the characteristics of these zones are described in Table 5-2.

During the course of the master plan effort, the project team decided to combine the OMP's Zones 2 and 3. The reason for this decision was that the scale of analysis and the variability of salinity over various timescales would not allow meaningful planning based on three salinity zones. Consequently, the master plan analyses utilized two zones (Table 5-2).

Zone 1 waters (5 to 12 ppt salinity) represent the lower limit that the native oyster can survive and grow in over the long-term. Disease pressure from Dermo and MSX is typically low in Zone

Table 5-2. Salinity Zone Strategy

OMP Salinity Zones (CBP 2004a)			
	Low (1)	Moderate (2)	High (3)
Salinity (ppt)	5 to 12	12 to 14	>14
Disease Pressure	Low	Moderate	High
Survival	Good	Moderate	Poor
Recruitment	Poor	Moderate	Good
Master Plan Salinity Zones			
	Zone 1	Zone 2	
Salinity (ppt)	5 to 12	>12	

1, which significantly increases the chances of oyster survival over time. Unfortunately, natural oyster reproduction and recruitment are typically very low in these areas, particularly under current conditions where broodstock are depleted. Subsequently, it is very important that restoration address recruitment in Zone 1.

Zone 2 waters are on average greater than 12 ppt during the summer. Disease pressure and mortality of adult oysters is much higher than in Zone 1, as both Dermo and MSX increase in virulence with increasing salinity. Natural recruitment is higher, however, and the result is a larger population of smaller oysters on bars in these areas. Where salinity is greater than 14 ppt during the summer, there is near constant pressure from the oyster diseases Dermo and MSX, and the mortality of wild stocks of juvenile and adult oysters can be very high. Larger oysters in this zone are demonstrating some natural disease resistance.

NORMP's approach to address salinity and develop population resilience is to develop a network of reefs in each targeted sub-estuary that are distributed throughout the high and low salinity zones. This is consistent with the recommendations of Mann and Powell (2007) and the 2008 Maryland Oyster Advisory Commission report that recommended the creation of a linked system of oyster habitat at a scale that is resilient in the face of climatic variability (e.g., exposure to freshets and droughts) and climate change.

One alternative that was discussed amongst the master plan partners was setting the minimum salinity of Zone 1 to 8 ppt rather than 5 ppt. Although, 5 ppt is the minimum salinity for long-term survival of adult oysters, it is recognized that other life stages have different optimal ranges (Shumway 1996). Mann et al. (1991) identified 8 ppt as the minimum salinity for larval development and survival. The justification for setting the 8 ppt minimum was the need to restore reproductive capability to low salinity waters in order to achieve sustainability. Further analyses of the salinity data determine that under average rainfall conditions, the 5-8 ppt region is limited to the upper portions of tributaries at the limit of oyster habitat, but also in large parts or all of the Patapsco and Magothy Rivers. At its maximum extent during wet rainfall conditions, the Magothy, Severn, South, Rhode, West, and Chester Rivers are likely to fall completely within 5 to 8 ppt. It was concluded that the extent of the 5-8 ppt zone does not appear to be limiting to the master plan restoration goals or of an expanse that would warrant its own zone, given the area of bottom available to achieve restoration goals that is not affected by

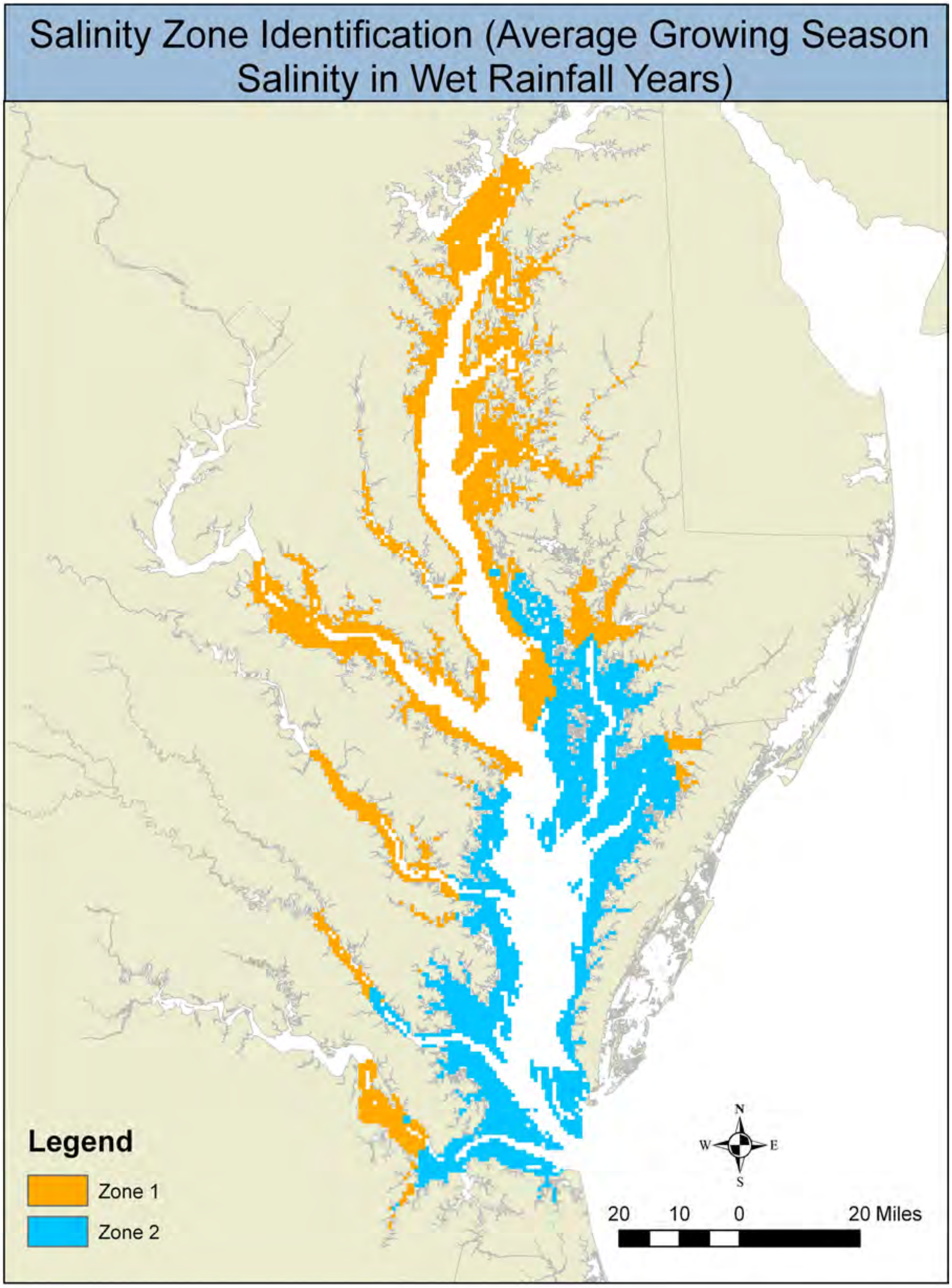


Figure 5-2. Salinity Zone Identification – Average Growing Season Salinity in Wet Rainfall Years

the shifting 5-8 ppt zone. The partners decided to give further evaluation to the location and size of the 5 to 8 ppt region determining specific tributary plans and to target areas with greater than 8 ppt salinity for the restoration of bars to jumpstart reproduction. (Further discussion and maps depicting the 5 to 8 ppt region under various rainfall conditions are in the 'Physical Characteristics- Physiochemistry' white paper in Appendix C-1.)

Salinity directly impacts the implementation and cost of restoration projects as it drives the frequency and intensity of stocking and whether large broodstock are used. Further, the probability of exposure of the stocking sites to freshets and drought is influenced by salinity.

5.2.2 DISEASE

The presence of disease complicates all other factors that must be addressed to achieve oyster restoration. The life cycles of the parasites that cause these diseases and the susceptibility of oysters to these diseases are linked to salinity concentrations, which vary as a result of changes in climatic conditions. MSX disease is most active when water salinities ≥14 ppt co-occur with water temperatures of 5-20 °C (Ewart and Ford 1993). MSX is not tolerant of low salinities waters (less than10 ppt) (Andrews 1983; Ford 1985). Dermo develops the heaviest infections and kills most readily at salinities >10 ppt, but it survives at much lower salinities (3 ppt) where infections are not typically fatal (Chu and La Peyre 1993; Chu et al. 1993; Ragone-Calvo and Burreson 1994). As a result, oysters in low salinity waters can live for long periods of time without experiencing the effects of disease.

As discussed in Section 4.4.1.1, oysters have the ability to develop resistance to disease. Constant disease pressure in high salinity waters kills many oysters just after they reach sexual maturity. Many of the oysters that survive exhibit some resistance to disease and represent the key to long-term development of disease-resistant native oysters (Carnegie and Burreson 2011). Reproduction of these resistant oysters promotes development of disease resistance in the population. It has not been shown yet whether the infrequent disease exposure in low salinity waters will permit disease resistance to develop or at what time scale it may take to achieve resistance in these oyster populations.

Further, oyster populations in low salinity waters are more threatened by disease during periodic droughts. During drought periods, salinity increases with the reduction in freshwater inflow. The diseases can kill large numbers of oysters that have not had the opportunity to develop disease resistance.

A full discussion of the current state of knowledge pertinent to disease as it relates to developing oyster restoration projects is available in Appendix C-1 in the Disease White Paper. Some of the more significant points are briefly discussed here.

5.2.2.1 Disease Strategy

All oysters in the Chesapeake Bay are exposed to disease – exposure is persistent in high salinity areas and intermittent in low salinity areas – and the only way for resistance to develop is for oysters to be exposed to disease. Oyster restoration conducted under the master plan will apply a genetic rehabilitation strategy that involves stocking and protecting oyster sanctuaries of sufficient size over a broad range of environmental conditions to encourage disease resistance to develop in the wild population.

a. Sanctuaries:

A network of permanent sanctuaries spanning salinity zones will be utilized to develop population level disease resistance. Sanctuaries and substantial reef height were identified as two key features of restoration by a group of regional oyster experts in 1999 (Chesapeake Research Consortium 1999 as cited by Carnegie and Burreson 2011). It was recognized at that time that sanctuaries protect large oysters, and provide for their long-term growth as well as enhanced fecundity, and the potential for the development of disease resistance. The sanctuary approach is consistent with the Maryland Oyster Advisory Commission Report (OAC 2009), which indicated that, "Focusing ecological restoration efforts in a large-scale, interconnected fashion (river system wide) is the strategy most likely to allow large populations of oysters to persist in the face of disease and other stressors." Also consistent with that report and reflecting the variability of salinity conditions in the Bay, the network of sanctuaries should be designed to be resilient in the face of climate change. That is, oyster bars should be established in various salinity zones (areas with salinity in the 5 to 12 ppt range and areas with salinity greater than 12 ppt) within the Bay and its tributaries to achieve a diversity of locations that will provide resiliency to the oyster population in the face of changing salinity, water depths, and temperature. Based on the findings of Carnegie and Burreson (2011) initial efforts should be focused in mesohaline-polyhaline salinities with particular attention given to mid-river reefs.

A 2007 Genetic Considerations Workshop recommended that broodstock should represent adult survivors from the selective agent (fresh water, disease) most likely to act on the reef where seed will be planted.

Sanctuaries have also been proposed as a potential mechanism to slow rates of shell loss that degrade oyster reefs and bars (Carnegie and Burreson 2011).

b. Trap Estuaries:

Hydrodynamics of the local waters in which restoration is attempted is an additional factor that can further enhance the long-term success of oyster restoration projects and development of disease resistance. Tidal action can retain oyster larvae, or flush them downstream, possibly even out of the local area entirely. Trap estuaries are tidally-influenced areas of rivers in which the tidal movements act to retain the oyster larvae produced by local spawning stock and limit downstream flushing. To further enhance recruitment and maximize the benefits of broodstock seeding, oyster restoration projects should first be constructed in retentive systems or "trap estuaries." Areas considered for restoration were assessed for hydrodynamics. (See Section 5.5.3 and Appendix C-1 for Hydrodynamics white paper.) As a combination of seeded and unseeded bar bases may be built, good recruitment of larvae spawned by disease-resistant strains of native oysters approaching or exceeding historical levels will be necessary for project success.

c. Appropriate Broodstock:

The genes of disease-resistant wild broodstock should be incorporated into restoration sites in targeted tributaries through a stocking program. Such a program would need to be coordinated with the state sponsors, hatchery operators, and watermen for implementation. In past restoration efforts, domesticated, disease-resistant, hatchery-bred strains have been used as broodstock to produce spat for planting as a means of increasing the population rather than wild stock. DEBY and Crossbred are two disease-resistant strains of Eastern oyster presently available from hatcheries in the Bay area. “Domesticated” lines like DEBY and Crossbred have been bred for fast growth and greater resistance to MSX than “wild” oysters in Chesapeake Bay.

The consensus among participants at a workshop entitled “Revisiting Genetic Considerations for Hatchery-Based Restoration of Oyster Reefs” held in 2007 was that the absence of documented evidence that planting domesticated oysters has yielded improved survival or higher subsequent recruitment is a compelling argument against the use of domesticated oysters in ecological oyster restoration. The participants recommended a precautionary approach to any use of artificially selected strains of oysters for restoration. They also concluded that the development of alternative strains of the Eastern oyster for use in restoration should not be pursued because selection is, by definition, a bottlenecking process; therefore, artificial selection for disease resistance would create strains with limited flexibility for coping with environmental change. They argued that the long-term goals of sanctuaries ‘are in conflict with the negative consequences expected from using artificially-selected broodstock to produce seed oysters.’ The workshop recommended that in high salinity areas broodstock for hatchery production of seed should come from disease-prevalent areas of the Bay and in low salinity waters where Dermo is rare or low in intensity that seed should be produced with broodstock from low salinity habitats. The workshop recognized that salinity gradients and freshets can be just as selective as disease.

A CBP Oyster Management Plan Meeting Relating to Oyster Disease Issues in 2007 made similar recommendations. This group based their recommendations on the fact that 1) the use of domesticated strains have not been shown to improve survival or enhance recruitment, 2) natural strains in the field have shown similar disease resistance, and 3) the costs associated with hatchery seed. This meeting recommended that creating sanctuaries where oysters could be left alone, along with a harvest moratorium, was a more cost-effective strategy for development of disease resistance (CBP 2007a).

d. Seeding and stocking:

The previous discussion leads to the following recommendations concerning stocking and seeding to restore oyster bars. Seeding is typically carried out by the local sponsor. Seed restoration sites with sufficient numbers of:

1) large adult, wild oyster broodstock that have survived disease,
2) hatchery-bred spat-on-shell derived from wild disease-resistant broodstock, and/or
3) spat collected from areas (within same salinity regime) where a proportion of the parent broodstock on sanctuaries has survived disease and other stressors.

Adult wild broodstock and spat collected from wild areas will not be planted in areas with a lower salinity regime than that of its origin. To decrease the potential effects of genetic bottlenecking among hatchery-produced, disease-resistant oysters, an approach called rotating (or revolving) broodstock is recommended. This approach entails obtaining new broodstock each year from wild stocks that are displaying evidence of disease resistance for hatchery production of spat-on-shell. Although, the feasibility and effectiveness of this approach has not been evaluated, the approach appears to merit further investigation because it might contribute to increasing the rate of propagation of disease resistance within a local oyster stock. Additionally, this approach was supported by many stakeholders that commented on the PEIS (USACE 2009). The recruitment that occurs when the broodstock oysters spawn or the spat-on-shell develop to sexual maturity will enhance base oyster populations that have higher levels of disease resistance.

e. Spat-on-Shell Production:

In addition to the bars planted with spat-on-shell and broodstock for initial restoration, trap estuaries will also be targeted for the production of spat-on-shell to be used as a secondary stocking program. In trap estuaries, a thin layer of shell could be applied to certain areas prior to spawning and if needed, fresh shell could be applied to some areas that have been previously shelled by VMRC, MDNR, or private leaseholders. In many areas within the Virginia sub-estuaries and high salinity waters of Maryland where aquaculture may develop, it is hoped that there will be an economic incentive for private leaseholders to perform thin shelling of some of their leaseholds to recruit large numbers of spat to sell for restoration efforts. Once these spat grow large enough to survive handling, the thin-shelled areas could be harvested using traditional methods by local watermen and moved to areas outside the trap estuary, but within the same or higher salinity regime, in order to plant them on other bar bases.

For this purpose, trap estuaries are referred to as “incubator systems,” and could potentially become the seed source used to enhance populations of native oysters throughout the Chesapeake Bay. Provided that there is sufficient broodstock to provide recruitment, clean bar structure in these locations would serve to provide setting substrate for larval oysters and begin to integrate the disease-resistant genes throughout the Chesapeake Bay population of *Crassostrea virginica*. This will be essential for the long-term recovery of the native oyster. Overall, it is expected to greatly magnify the initial disease-resistant oyster biomass seeded on the incubator bars. Spat-on-shell produced on incubator bars would then be used as part of a larger secondary stocking program. The expectation with this action is to increase survival in the face of disease and accelerate the spread of the disease-resistant trait.

f. Demonstrated Success:

The genetic rehabilitation strategy, begun in the Great Wicomico River (GWR) has shown promising signs of success for projects throughout the high and medium salinity zone waters of the Chesapeake Bay.

There is evidence that USACE’s Great Wicomico restoration project population is continuing to grow in the face of disease (Schulte et al. 2009a). Great Wicomico bars have been populated by significant numbers of large adult broodstock oysters, which have persisted for over 5 years. Over 100 million adult oysters in these sanctuaries are making significant contributions to recruitment in the system. During 2007 and 2008, over 42,000 bushels of spat-on-shell (20,000 bushels in 2007 and 22,000 in 2008) were purchased from lease-holders in the Great Wicomico by Virginia to augment populations in other river systems (Coan, Yeocomico, Rappahannock, and Nomini). During this time, the GWR was the only viable source of spat-on-shell in Virginia waters. No other regions of the lower Bay except the Great Wicomico had sufficient recruitment to make moving the spat-on-shell economically viable. It is estimated that approximately 25 percent of the public ground harvest in 2008 and 2009 were the result of the subsequent harvest of this spat-on-shell, which had been planted on public grounds in the lower Rappahannock

River as well as several Potomac River tributaries. While there is no specific monitoring data, it is suspected that the increased oyster survival to market size is tied to the genetic make-up of these progeny as well as favorable climatic conditions.

g. Development of the Strategy:

The foundation for the disease strategy is the genetic rehabilitation strategy implemented by USACE-Norfolk in high salinity regions and the recent findings by Carnegie and Burreson (2011). Carnegie and Burreson (2011) confirmed the development of resistance to MSX in oyster populations in mesohaline to polyhaline waters of the lower Chesapeake Bay in Virginia. Disease resistance was most developed in the Lynnhaven River because salinities are high enough that MSX is a constant presence. Resistance was also documented in the lower Rappahannock River, at Wreck Shoal in James River, and Aberdeen Rock in the York River.

Discussions with master plan partners were critical in development of the master plan disease strategy. Partners discussed three main issues: 1) the transportation of wild diseased stock to lower salinity waters, 2) whether disease resistance can be developed and maintained in low salinity waters, and 3) genetic bottlenecking.

The argument for transporting wild stock, particularly from high to low salinity, is to enable the use in low salinity waters of large, reproductive oysters that have survived high salinity disease challenge. The intent is to introduce disease resistant genes into the reproductive pool of low salinity waters. However, there is the risk that transplanting the oysters from high salinity waters into low salinity waters will also transport disease into these waters. This could potentially introduce more virulent disease strains to which the low salinity oyster populations have never been exposed. There is also the question of whether disease resistant genes would be maintained in low salinity waters that are not frequently disease challenged. In developing this disease strategy, the partners acknowledged the recommendations of the 2007 Chesapeake Bay Oyster Management Plan's Disease Workshop that put restrictions on the transplantation of diseased stock (2007a). As a result, the master plan recommends that potentially diseased stock be moved only to regions of similar or higher salinity. Additionally, broodstock from high salinity regions can be used by the hatcheries to produce spat-on-shell to place on restoration sites in these areas, effectively introducing the disease-resistant traits.

The second issue of whether disease resistance can be developed and maintained in low salinity waters was debated, but could not be conclusively resolved. This strategy has never been attempted in low salinity waters. Selective pressure from disease is lighter in low salinity waters. Some question whether disease resistant genes can be maintained in low salinity waters where oysters are not frequently challenged by disease. Further, it needs to be considered whether the artificial introduction of disease resistant traits into low salinity waters would occur at the expense of other desirable traits such as low salinity tolerance. If this were to occur, it could reduce the diversity of the Bay oyster population and make it more susceptible to stressors such as climate change. In order to promote and maintain desirable traits in the low salinity populations, but not introduce traits not endemic of low salinity waters, master plan partners agreed to stock bars in the lower salinity areas with spat-on-shell derived from mature, parent stock from similar or lower salinity waters. The spat-on-shell could be produced in a hatchery or be taken from the wild population. These mature, parent stock could have some resistance to disease that would be promoted by this strategy, without introducing artificial traits to the low salinity populations.

Genetic bottlenecking is an issue that could affect hatchery production if stocks are not managed properly. The large-scale restoration that USACE is recommending is going to require a large increase in hatchery production of spat-on-shell. Hatchery stock used to produce the spat-on-shell will need to be managed so that genetic diversity is maintained in the restored populations. The partners agreed to investigate further the concept of rotating broodstocks that was discussed in Section 5.2.2.1(d) above to minimize the potential for a bottleneck.

Summary of Disease Strategy

1. Establish a network of permanent sanctuaries spanning salinity zones to develop population level disease resistance;
2. Focus initial efforts in retentive systems (trap estuaries where possible) to concentrate and magnify larval production;
3. Do not use domesticated oyster strains such as DEBY and CROSSBred for stock enhancement;
4. Use a rotating brood stock approach for hatchery production;
5. In low salinity zones, and where appropriate in high salinity, plant sites with spat from disease-resistant parent stock either from hatcheries or obtained from wild populations growing in similar conditions to the restoration site;
6. Seed restoration sites with sufficient numbers of large adult wild oyster broodstock that have survived disease;
7. Restrict the movement of wild broodstock and spat-on-shell to areas with a similar or higher salinity regime;
8. Use 'incubator reefs' to provide a seed source for restoration work;
    - Transplant spat-on-shell produced on incubator reefs to restoration sites within the same or greater salinity zone

5.2.3 REPRODUCTION

Oyster biology and reproduction are critical factors to consider in recommending and developing potential restoration projects. Reproduction within oyster populations and strategies to jump-start reproduction both play important roles in sustainable oyster restoration. Physical factors such as salinity, temperature, and dissolved oxygen, have strong influences on both reproduction and survival of larvae, spat, and adult oysters (as discussed in Section 4.4). As documented by Rose et al. (2006), the prolific fecundity of this species might allow for a rapid regeneration of historic numbers if not for the low density of remaining breeders in a severely degraded environment with intense disease pressure (Boesch et al. 2001; Burreson and Ragone-Calvo 1996; Jackson 2001). Because parent broodstock is severely limited in the Bay, reproduction must be supplemented.

Topics addressed relevant to reproduction:

- Physical and biological influences on reproduction
- Fecundity and recruitment
- Larval distribution
- Strategies to jump-start population reproduction

A broader discussion of topics such as salinity is provided in companion white papers in Appendix C. Oyster reproduction is discussed in more detail in Section 4.4.2 and the Reproduction White Paper.

A closely-related problem that inhibits an oyster bar from becoming biogenic is low recruitment of juvenile oysters to the system. Larval mortality rates are estimated to be close to 99 percent. (NRC 2004) and Bay-wide recruitment levels are a fraction of what they were historically. It is important that larvae locate and settle on a suitable substrate within the 2 to 3 week larval period, and before they are flushed out of an area where suitable habitat is available. Further understanding of larval transport processes are needed to wisely site restoration projects and provide connectivity.

5.2.3.1 Reproduction Strategy

The master plan recommends various methods focused on jump-starting reproduction, tailored to site salinity and disease prevalence. The master plan incorporates all of the following in the strategy to jump-start reproduction:

- Stocking with spat-on-shell,
- Broodstock enhancement with adult oysters, and
- The use of wild stocks that appear to be displaying some degree of disease resistance.

a. Stocking with spat-on-shell:

Stocking rates on restored bars can vary widely and are largely determined by remnant broodstock populations and their larval production and retention within any given system as well as physical parameters such as salinity. When broodstocks are low, higher stocking rates are required to augment, and thus jump-start, population growth on restored bars before the substrate becomes fouled and unsuitable for oyster setting.

There is very little if any scientific data to guide the appropriate level of stocking on restored oyster bars. Ultimately, the goal is to achieve a density of oysters with an appropriate age (young to mature) structure and sex ratio (male to female) to maintain fecundity and provide the necessary water filtration and vertical relief to prevent the bar from being smothered with sediment. Winslow (1882) provided guidance from his extensive surveys of Tangier and Pocomoke Sounds on age structure. He recommended that for every 1,000 mature oysters there should be 1,500 young oysters to provide the necessary broodstock to maintain the fecundity of the bar; a ratio of 2 mature oysters to 3 young.

Restoration efforts in Maryland have seeded restored sanctuary bars with 2 million spat/ac and harvest bars with 1 million spat/ac. However, recent monitoring has shown a high level, approximately 50 percent, of initial mortality. A large portion of this high mortality occurs during planting when the shells holding the hatchery-set spat settle upside-down, are smothered, and die. Preparation or selection of good substrate for planting also plays a significant role in the success of the planting. In response to this, the Oyster Recovery Partnership and the University of Maryland are advising that the number of spat planted per acre on a sanctuary be increased to 4 to 5 million and that plantings only be performed on optimal bottom substrates.

High salinity regions that experience good regular spatsets despite the current depleted populations, may not need to be seeded or may only require one initial planting to jump-start restoration. However, in lower and middle salinity waters that have experienced a nearly complete collapse of reproductive success, initial planting of spat should be followed by plantings in subsequent years to develop a multi-age population. At least two plantings, several years apart, will be required to ensure presence of males and females.

An oyster restoration project constructed in Virginia's Lynnhaven River (high salinity) in 2008 was seeded with one bushel of spat-on-shell/m^2 of bar constructed. The concentration of spat per bushel was approximately 1,000 to 2,000 (D. Schulte, pers. comm.), providing an initial stocking rate of approximately 4 to 8 million spat/ac. On high-relief bars (~8 to 15 inches in height) constructed in the Great Wicomico River in 2004, the initial spatset derived from wild broodstock was found at a concentration of approximately 2,000 spat/m^2 of restored bar. This initial spatset resulted in densities in 2007 and 2009 of 200 oysters/m^2 when a bar was 10 percent high-relief to over 1,000 oysters/$m^2$when a bar was 90 percent high-relief (Schulte et al. 2009a).

b. Broodstock Enhancement with adult oysters:

Broodstock enhancement may involve adding adult oysters to some restored bars to enhance recruitment to the bar and to the surrounding area as discussed in Section 5.2.2. Large natural oysters can be harvested and aggregated on bars to enhance fertilization success. Stocking adult oysters on a restoration site is a more costly alternative than spat-on-shell, but may be warranted in areas with low natural recruitment. Adult oysters have much higher fecundity than young oysters and have the ability to immediately contribute to reproduction. Recognizing that the additional costs associated with broodstock enhancement are high, this approach will require in-depth analyses to determine its value and feasibility.

c. Use of Wild vs. Genetically Manipulated Stocks

The master plan recommends using wild rather than genetically manipulated stocks as discussed in the earlier disease section, Section 5.2.2.

d. Development of the strategy

Discussions with the master plan partners were critical in development of the master plan reproduction strategy. The partners identified various areas where the master plan needed to provide better information, such as the age at which oysters switch from male to female, how many eggs are produced by females, factors affecting larval survival and settlement, clarification of the salinity zones, and the optimal salinity for reproduction. All of these are documented in the Reproduction White Paper in Appendix C-1. Of note, reproduction is most efficient in areas with greater than 12 ppt and negligible below 8 ppt. The partners agreed that restoration sites for jumpstarting reproduction should be focused in those areas. The differences between the proposed strategies at high and low salinities were clearly identified. Importance was also placed on the role of monitoring and adaptive management. Adaptive management should be used to decide whether a site needs to be reseeded. It was stressed that natural recruitment, not stocking, should be the prime mechanism by which multi-age populations are developed. It was proposed that restoring additional acreage within the tributary would be a better use of resources than continually restocking an individual site. The role of monitoring was discussed. All agreed that monitoring should be used to determine not only whether recruitment is occurring, but if not, the reasons why. Additionally, monitoring will be important to measure mortality and identify the cause of any documented mortality. USACE will work with local universities, researchers, and environmental consultants to monitor restoration projects. The approaches to developing self-sustaining, reproducing oyster populations may be modified depending on the salinity

Summary of Reproduction Strategy

Low to moderate salinity zones (<12 ppt) – low and intermittent recruitment events, often separated by many years

1. Provide substrate as needed.
2. Substrate should be stocked immediately following planting to avoid degradation.
3. Use adult wild stock from endemic disease areas to produce the spat-on-shell in hatcheries, to take advantage of any naturally developed disease resistance, that could be passed on to progeny.
4. Monitor (pre- and post-construction) to assess natural recruitment, population, mortality, and condition, to determine the need for additional stocking.
5. Monitor and, as needed, restock at initial stocking rate, 2 to 3 years following initial planting to provide a multi-age population.

High salinity zones (> 12 ppt) - higher, more consistent spatsets

1. Provide substrate as needed.
2. Plant substrate immediately prior to spawning season. Where natural recruitment is sufficient, may not need seeding. Where reefs were not planted and either natural recruitment is not occurring and/or substrate degradation is occurring, consider adding new material and/or restocking.
3. Use either adult wild spat-on-shell from areas where broodstock is showing signs of disease resistance or use stock from endemic disease areas to produce the spat-on-shell in hatcheries.
4. Stock and aggregate large natural oysters harvested from areas with demonstrated disease resistance to enhance fertilization success.
5. Monitor (pre- and post-construction) to assess natural recruitment, population, mortality, and condition, to determine the need for additional stocking.
6. Reseed if sufficient natural spatset is not occurring as predicted based on spatfall survey data.

regime in which the restoration work is taking place. One of the fundamental differences in the salinity approaches as outlined is that recruitment may initially need to be augmented more consistently in the lower salinity waters where annual recruitment is generally lower because broodstocks are particularly depleted and disconnected in these areas. This augmentation would take place via spat-on-shell stocking.

5.3 IDENTIFICATION OF TRIBUTARIES AND SUB-REGIONS

The next step in the evaluation was to identify appropriate tributaries and sub-regions of the Chesapeake Bay for evaluation based on geographic position and similarity of physical characteristics. The team developed the list of the major tributaries by identifying distinct tributaries and DSS within the historic extent of oyster habitat.

The final list of tributaries and DSS was expanded by segmenting the larger tributaries into sub-segments or sub-basins. Researchers at the University of Maryland Center for Environmental Studies assisted with defining the sub-basins based on groupings of simulated oyster bars (North and Wazniak 2009; North et al. 2006, 2008). Sub-basin classifications were made based on channel morphology and bar spacing to create natural groupings of oyster habitat polygons. Oyster habitat polygons in large tributaries (Potomac and Rappahannock Rivers) were divided into three groups. Polygons were divided into two groups in the seven medium sized tributaries (e.g., Choptank and York Rivers). Small systems like the Little Choptank River were not sub-divided because they would be too small for meaningful analysis at the master plan scale. The defining of sub-basins for larger tributaries resulted in a final set of 63 tributaries and sub-regions for evaluation (34 in Maryland and 29 in Virginia) (Fig 5-3). When classifying oyster bars in the mainstem, lines were simply drawn from point to point across tributary mouths and those bars outside the tributaries were designated as being in the mainstem.

During the evaluation process, the team determined that hydrologic linkages between the sub-basins of the larger tributaries do not support definite subdivisions. That is, not all the data compiled could be interpreted appropriately at the sub-segment level. Therefore, information is presented for the large tributaries at both the sub-segment level and the full tributary level. Final recommendations are provided for tributaries or DSS of larger tributaries.

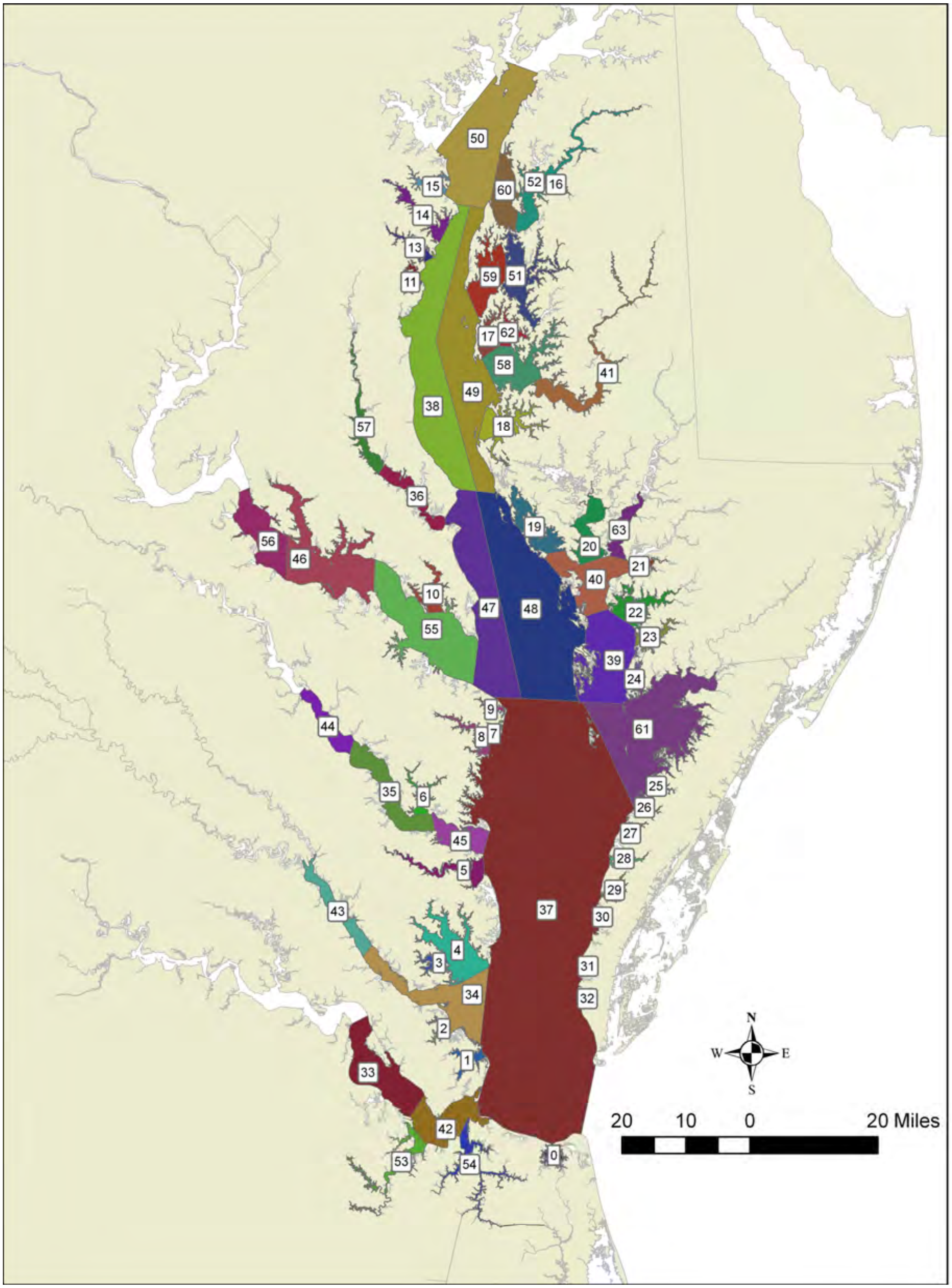


Figure 5-3. Tributaries and Sub-Regions Considered for Restoration in the Master Plan

The legend is located on the following page.

Figure 5-3 (continued). Legend- Tributaries and Sub-Regions Considered for Restoration in the Master Plan

5.4 RESTORATION SCALE

Scale for the master plan is defined as the approximate number of acres of habitat in a given tributary or sub-region required to develop a self-sustaining oyster population. This requirement is based on the understanding that a critical mass of oysters and habitat are necessary for a network of bars to provide sufficient habitat and larval recruitment to sustain itself over time. It is assumed that fully functional biogenic oyster bars will provide significant ecosystem services, and that this goal can be achieved throughout the system by scaling and locating projects appropriately. Restoration projects presented in the master plan must be designed to address important scale issues related to both bar size/structure (physical component) and oysters populating these bars (biogenic component). Some past restoration failures have been a result of insufficient project size given the size of the tributary or sub-region size. While the specific placement and distribution of bars within each tributary or sub-region is also important, that identification requires a more complete understanding of local hydrodynamics, which will be addressed in the site-specific tributary implementation documents that will follow the master plan.

The master plan attempts to answer the question:

> "At what scale must oyster reefs be developed (i.e., how many acres of habitat) in various areas/tributaries of the Bay to support the long-term master plan goal of achieving self-sustaining oyster populations?"

5.4.1 SPATIAL DISTRIBUTION, CONNECTIVITY, AND METAPOPULATIONS

The plan presented in the master plan targets the recovery of a keystone species (oysters), but also involves an ecosystem restoration objective. The goal is to achieve recovery of oyster bar and its function. With nearly 99 percent gamete mortality (Rumrill 1990; Morgan 1995), a large number of oysters are needed to jumpstart the population. Historically, oyster bars were distributed throughout the bay tributaries where they provided ecosystem services, and scaling projects should ultimately consider a similar distribution in order to achieve full ecosystem recovery. Another reason for considering the distribution of oysters throughout the Bay is connectivity. The Eastern oyster population is composed of numerous metapopulations. The connectivity within and among metapopulations within the Bay and in the tributaries adds spatial complexity to the resource and is just beginning to be understood. A significant amount of area is necessary to restore connectivity and spatial complexity. The wide distribution of the historic population within tributaries and throughout the Bay gave redundancy to the population and provided a resilient network that enabled the oyster to thrive and survive in the face of various natural challenges and harvest pressures. The appropriate restoration scale (area relative to tributary size) is influenced by the distribution and density of the oysters populating these bars (biogenic component).

Modeling capabilities are now shedding light on metapopulation and network dynamics. Lipcius et al. (2008) described the importance of position in the estuary and hydrodynamic characteristics of the reef setting to establishing a network of reefs. For example, five reef types were identified from an evaluation of 45 reefs in the Lynnhaven river system (Lipcius et al. 2008). Of the five reef types, source reefs, which self-replenish with larvae, and putative reefs (those that do not consistently self-replenish or provide larvae to other reefs, but become sources when environmental conditions change) must be part of the restored reef network in a tributary. These reefs must be of sufficient size, distribution, and number to restore self-sustaining populations.

In order to successfully influence the stock/recruit relationship, restoration efforts will need to be much larger and more numerous than have been built in the past. In general, larger estuary systems will require proportionally larger spatial scale of bar structure in them for the bars to become sustainable living features within the system. When oysters spawn, the larvae must find attachment substrate or they will die. Larger systems have more open water that the larvae must navigate to find suitable habitat, and will require restoration of large amounts of attachment substrate. The small scale restoration efforts that have taken place in the past in these large river systems have simply not been large enough to influence oyster dynamics and be sustained over time.

A metapopulation is a "population of populations" (Levins 1969, 1970); in which distinct subpopulations (local populations) occupy spatially separated patches of habitat. The habitat patches exist within a matrix of unsuitable space, but organism movement among patches does occur, and interaction among subpopulations maintains the metapopulation (Rohrbach 2010).

5.4.2 ESTIMATES OF HABITAT DEGRADATION

A once extensive network of subtidal oyster bars and reefs existed in the Chesapeake Bay, but only a very small remnant of that structure and viable population currently exists. Wilberg et al. (2011) estimates that oyster abundance has declined by 99.7 percent since the early 1880s and 92 percent since 1980, and that habitat has been reduced by 70 percent between 1980 and 2009. Between 1999 and 2001, Smith et al. (2005) surveyed 39 km^2 of bottom in the lower Choptank River and adjacent western Bayshore that was classified as supporting productive oyster populations in 1911. Their investigations estimated that over 90 percent of that area has been degraded to mud, sand, or heavily sedimented oyster shell. Haven and Whitcomb (1986) showed that only 21.8 percent of Virginia oyster bars from the beginning of the century still survived. Whitcomb and Haven (1987) found only 19.5 percent of original public oyster grounds remained in Pocomoke Sound using a sonar and verification by sampling with hydraulic patent-tongs. The oyster population was recognized as degraded at the time of these investigations in the late 1980s with projected habitat losses ranging from 52 to 86 percent. Oyster resources are undoubtedly further degraded today than at the time of the Whitcomb and Haven survey. The existing oyster habitat is in such poor condition that recruitment is limited due to lack of attachment sites for planktonic oyster larvae. Only very low population densities relative to the historic population are likely to persist on the remnant oyster habitat throughout the Chesapeake Bay, and little recovery of the habitat is expected to occur naturally. The master plan seeks to define the appropriate scale

Less than 10% of historic oyster habitat is likely to still be viable (Smith et al. 2005).

of restoration for each tributary or sub-region to ensure that the restored habitat and any existing habitats in the segment will be sustainable and contribute larvae and other benefits to surrounding portions of the Bay in the short-term and self-sustaining in the long-term.

5.4.3 CURRENT STATE OF KNOWLEDGE FOR DETERMINING SCALE

There is no generally accepted method or approach to estimate the proper scale of oyster restoration projects to achieve self-sustaining populations or any other ecosystem factors or services. (The Restoration Scale white paper in Appendix C-1 contains the full discussion of the state of knowledge pertaining to developing the proper scale of oyster restoration projects.) Based on the current status of the oyster population in the Chesapeake Bay USACE supports the conclusion that past restoration efforts were not implemented at a scale needed to address the problems facing the oyster and affect a system-wide change in oyster resources. The *PEIS* recognized that sanctuary programs have established some successful reefs, but have contributed a relatively small number of oysters to the total population of the Bay (USACE 2009). Past restoration efforts were implemented in a piecemeal fashion (ORET 2009) and were not planned with the intent of affecting a system-wide change. Typically, restoration occurred on a few acres within an entire tributary. The *PEIS* identified that the level of future restoration efforts will be substantially greater than past efforts (USACE 2009). Both the Maryland OAC and Virginia Blue Ribbon Panel have recommended concentrating restoration efforts by establishing large, permanent sanctuaries for oyster restoration (OAC 2009, Virginia Blue Ribbon Oyster Panel 2007). The Oyster Metrics Workgroup (OMW) further concluded that in setting a tributary goal, the Executive Order acknowledged the need to "undertake restoration at a sufficiently large scale to dramatically increase oyster populations and realize enhanced ecosystem services at a tributary-wide scale" (OMW 2011).

5.4.4 APPROACH TO DETERMINE APPROPRIATE SCALE

The following section describes the approach developed for the master plan to estimate the appropriate scale necessary to achieve the long-term goal of self-sustaining oyster reefs in the tributaries of the Chesapeake Bay.

5.4.4.1 Identify Extent of Historic Bar and Reef Habitat

Restoration involves achieving some level of ecological recovery compared to what existed in the historical past. Therefore, the first step in arriving at scale is to determine the approximate historical number of acres of oyster habitats that were present in the past in the Chesapeake Bay and tributaries.

Two historic surveys set the baseline of oyster bar resources in the Bay. They are generally referred to by the names of the leaders of the surveys: 1) the Yates Survey (Yates 1913) mapped the Maryland bars from 1906 to 1911, identifying what are call the Yates Bars; and 2) Baylor (Baylor 1895) mapped oyster bar leases in Virginia in 1894, leading to the Baylor Grounds. Based on historical accounts, both these surveys occurred after significant loss of oyster bars had occurred. The Yates Survey of 1906-1911 is the most comprehensive account of historic oyster resources in Maryland. Neither the Yates nor Baylor surveys were truly accurate in delineating the original extent of oyster bars. MDNR (1997) describes the methods used in the Yates survey:

"...a "local assistant" (watermen from the area, appointed by the county) would point out the approximate position of all known oyster bars in the area. The launch "Canvasback" would then run a zigzag or parallel series of lines across the bar to ascertain its exact limits. During these passes, the "local assistant", operating a chain-wire apparatus from which he could feel the vibrations indicating the condition of the bottom, reported the oyster density on the bottom as either barren, very scattering, scattering, medium or dense. Bottom types were plotted on charts, and all areas except those classified as barren were considered Natural Oyster Bars. These areas were enclosed in straight-sided boundaries (polygons) on charts, and became what we now know as the "Yates Bars". Names assigned by the Yates survey were those provided by local sources."

Even though it is recognized that the population was already showing signs of degradation at that time, the Yates Survey identified 779 named bars on 214,772 acres. In 1894, the Baylor Survey mapped 232,016 ac of oyster habitat in Virginia. As these surveys were subject to political factors, the project delivery team developed and applied a method to more accurately estimate the area of historic bars based on the Yates and Baylor surveys. There are few good quality historic era maps that provide detailed information on the extent of viable oyster beds that could be compared to the Baylor or Yates surveys. In Virginia, there is one dated 1909 for the James River produced by Dr. H.F. Moore, U. S. Bureau of Fisheries. Similarly, F. Winslow surveyed oyster beds in Tangier Sound in Maryland in 1878 (Winslow 1882; McCormick-Ray 1998, 2005). These two surveys were completed on a much smaller area than the Yates and Baylor surveys, but provide a means to filter the broadly delineated oyster habitat from the State-wide Yates and Baylor Surveys with more precise habitat maps.

The master plan uses the Moore survey map to assess the actual extent of viable reefs in the James River compared to the Baylor polygons and then applies this correction to all Virginia Baylor polygons. In Maryland, the Winslow Tangier Survey is used to assess the actual extent of viable bars in Tangier Sound compared to the Yates bars and is then applied to all Yates bars.

This comparison was completed by overlaying the habitat boundaries from the broader Baylor with the more scientifically mapped Moore boundaries in GIS (Figure 5-4). The Winslow survey was not available digitized. Therefore, the acreages of ‘oyster rock’ determined by Winslow (McCormick-Ray 1998) were compared with the acreage of Yates Bars in Tangier Sound that were included in Winslow’s survey (Figure 5-5). Corrections were made for differences between the two surveys’ boundaries. The percentage of the Yates and Baylor polygons that contained documented oyster bars from the Winslow and Moore surveys, respectively, was calculated.

This evaluation determined that within the Baylor polygons, approximately 47 percent contained viable oyster reefs based on the Moore maps. A similar analysis for Tangier Sound using the Yates surveys revealed that the Winslow surveyed hard bars made up approximately 43 percent of the Yates Bars in Tangier Sound. In the absence of comparable historical maps, the master plan uses these percentages as a surrogate to apply to all other Baylor and Yates polygons throughout the Virginia and Maryland portions of the bay respectively to arrive at approximate historical acreage.

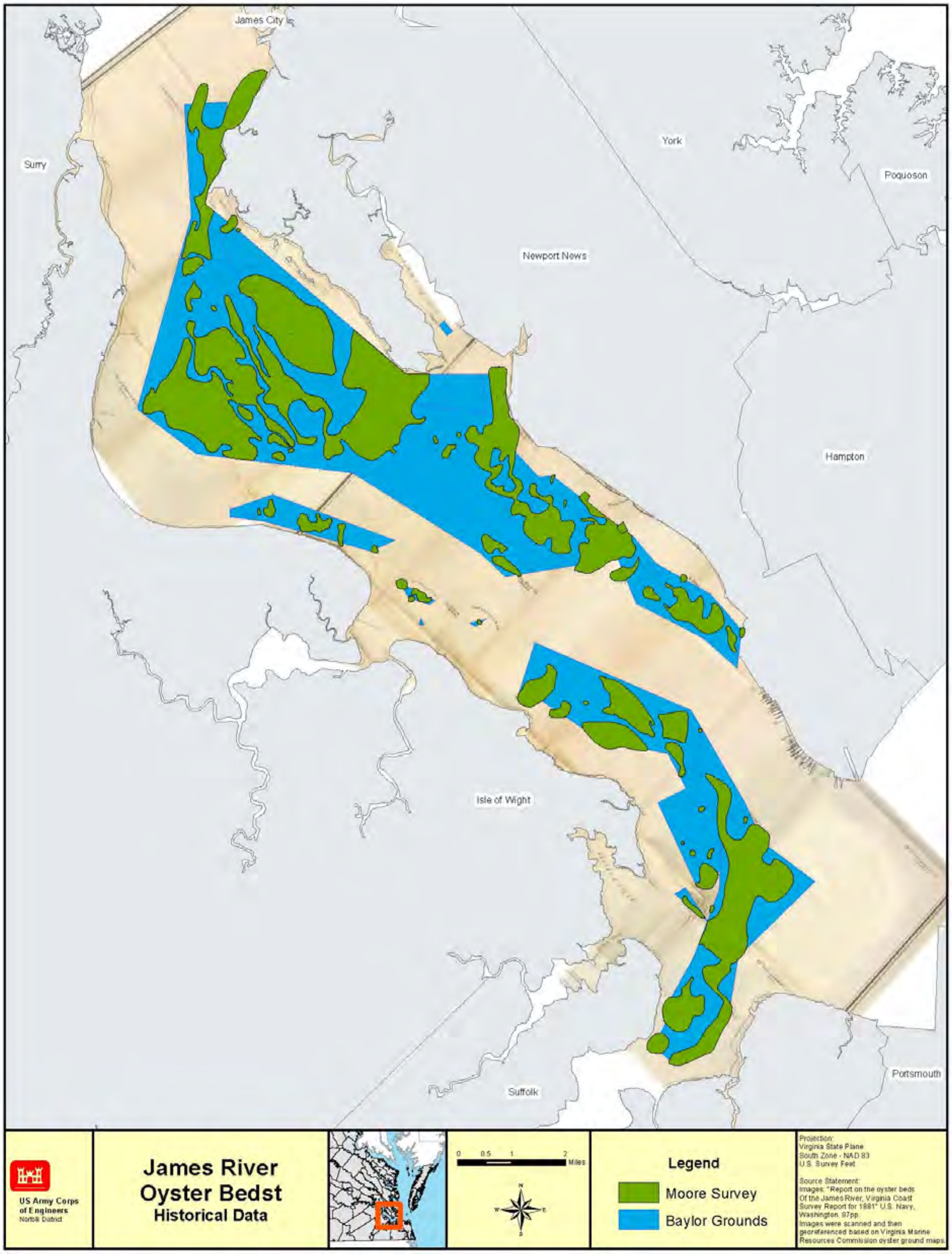


Figure 5-4. Baylor Grounds Compared to Moore Survey in James River.
This figure depicts the actual oyster reefs surveyed by Moore within the Baylor polygons.

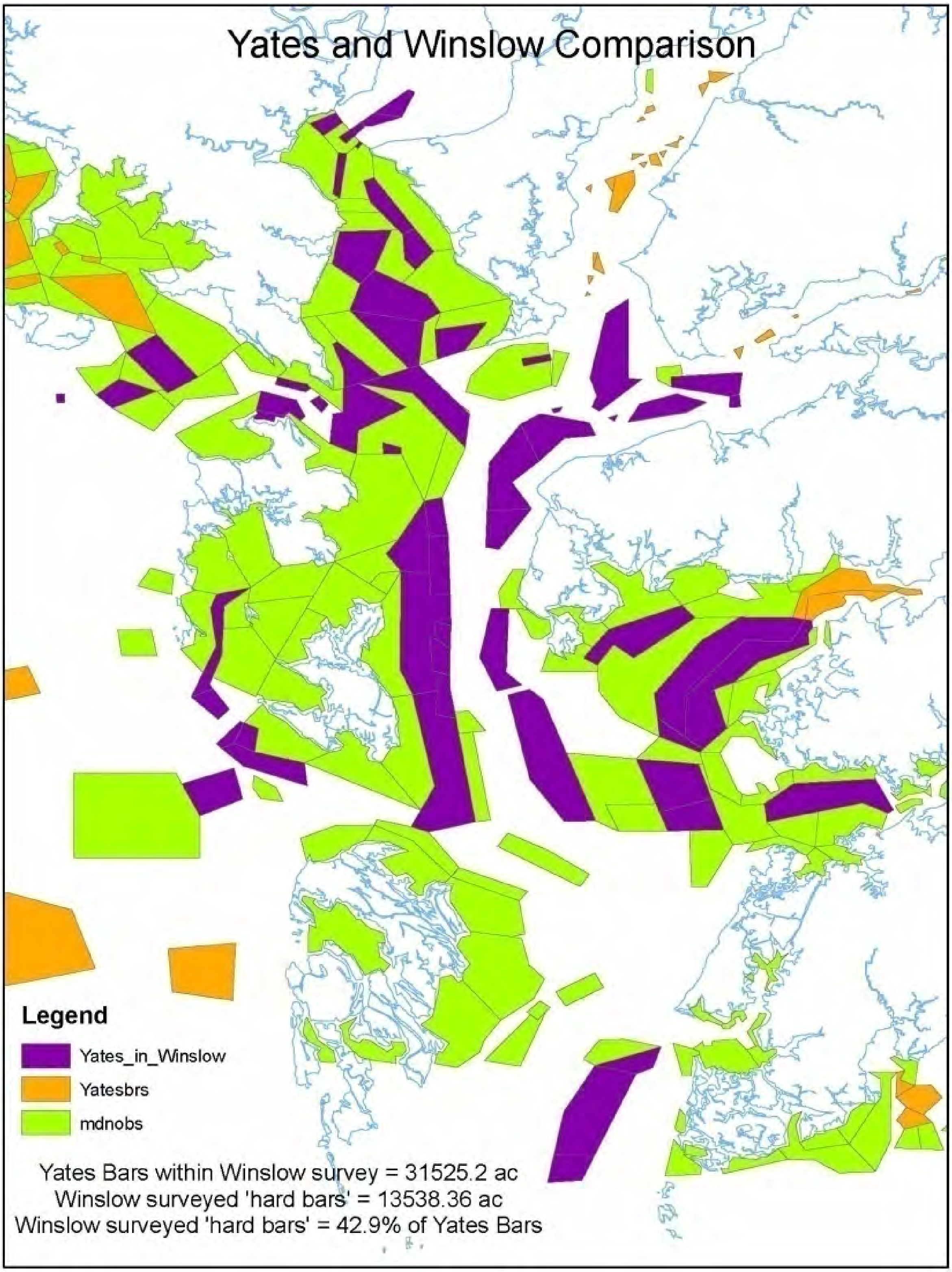


Figure 5-5. Yates Bars Compared to Winslow Survey in Tangier Sound.
This figure depicts the oyster habitat surveyed by Winslow within the Yates Bars.

5.4.4.2 Using Marine Protected Area Target Percentages to Arrive at Scale

The next step in determining scale is to decide what percentage of historic habitat would have to be restored in order for oysters within a given area or tributary to become self-sustaining over the long-term. Marine Protected Areas (MPAs) are often designated to assist in the recovery of target species and communities. The MPA range of protected habitat typically applied (20-70 percent) can be considered as a range of habitat for oyster recovery (NRC 2001). It should be noted however that no MPAs for oysters currently exist in Chesapeake Bay and none are being recommended here. MPA is used here because it is generally recognized and the methodology for determining the size of MPAs seems to be applicable to the oyster scaling approach. Typically, sessile reef building invertebrates such as the oyster would be expected to need a protected range on the lower end of the MPA percent spectrum, compared to finfish for example. Migratory species and large, motile predatory fish that produce fewer but larger young per adult, such as sharks, and usually require larger areas of protection.

Halpern (2003) discussed issues related to the sizing of marine reserve in his review of the scientific literature concerning the topic. He indicated that the goals of fishery managers in establishing reserves often include targets for total catch outside the reserve and ensuring that all species are present and abundant enough to be self-sustaining. These goals are consistent with the master plan goal of restoring an abundant, self-sustaining oyster population throughout the Chesapeake Bay that performs important ecological functions (e.g. reef community, nutrient cycling, spatial connectivity, water filtration) and contributes to an oyster fishery. Halpern (2003) indicated that small reserves may be insufficient because they may not provide significant export functions and that "for reserves to serve as larval sources they must be large enough to sustain themselves as well as supply…target areas." Similarly, past efforts in oyster restoration in the Chesapeake Bay that established small, widespread bars have generally not been as successful as expected and have not lead to system-wide restoration. To be consistent with the master plan goal, the recommended sanctuary size should be large enough to be self-sustaining and export larvae.

5.4.4.3 Lessons Learned from Past Restoration to Determine Percentage Historical Acreage to Restore

The historic quantifications of oyster bar habitat can be used to consider the relative scale of previous, more recent restoration efforts. The most comprehensive analysis of past restoration efforts was coordinated by Maryland Sea Grant and is summarized in *Native Oyster (Crassostrea virginica) Restoration in Maryland and Virginia: An Evaluation of Lessons Learned 1990-2007* (ORET 2009). ORET (2009) identified past restoration efforts on 10,398 ac in Maryland, which amounts to restoring 4.8 percent of the Yates surveyed grounds. It can be assumed that the wild seed transplant efforts included as restoration, targeted fishery improvements rather than ecological restoration. If those acres are removed from the total area of previous restoration efforts, that reduces the attempted restoration to just 2 percent of historic acreage on a Bay-wide scale. ORET's (2009) report of 2,214 ac of restoration performed in Virginia amounts to approximately 1 percent of historic acreage. Taking into consideration the reduction of Yates and Baylor surveyed acreages (Section 5.4.4.1), restoration efforts have only addressed 2 percent and 11 percent of historic acreage in Virginia and Maryland, respectively.

None of this past restoration was concentrated within one area, but was spread across the Bay in small isolated patches. Past efforts attempting to restore Chesapeake Bay oyster populations did not reach an appropriate scale necessary to restore either a critical biomass or a critical area of spatial complexity (Mann and Powell 2007). Both are necessary to successfully restore a sustainable oyster population. Many past efforts were also vulnerable to harvests, whether legal or illegal. The only restoration effort thus far to achieve a sustainable population of oysters over an extended period of time (approximately 6 years) is the Great Wicomico River restoration effort implemented by USACE and VMRC. That project restored approximately 40 percent of the original bar extent within a hydrodynamically restricted portion of the river (Schulte et al. 2009a). If considered within the entire Great Wicomico from its mouth where the river connects to the Chesapeake Bay, approximately 10 percent of the corrected historic acreage of the tributary was restored in a concentrated area.

5.4.5 *Scale Recommendation and Justification*

Scale for the master plan is defined as the approximate number of acres of functioning habitat in a given tributary or sub-region required to develop a self-sustaining oyster population.

The recommended scale in NORMP is appropriate as a general guideline throughout the Bay and appropriate for planning and programming purposes. Restoration of oysters in the Chesapeake Bay is not a 'one size fits all' situation. There is no documented evaluation that identifies the correct percent of historic oyster habitat to restore to achieve success, likely because the conditions in each tributary system are unique. Considering that sessile bivalves would be expected to fall on the lower end of the MPA range, but also recognizing the reasons presented above that support the need for significant and expansive oyster habitat to achieve sustainability, the master plan is proposing a restoration target ranging from 20 to 40 percent of historic (corrected) acreage within a tributary. This equates to 8 to 16 percent of the Yates and Baylor Grounds (if uncorrected). Figure 5-6 depicts the process of developing this scale recommendation. In recognition that one number will not fit perfectly in every circumstance, the master plan is recommending a range that should be revised to a more precise number by the follow-on specific tributary investigations. In systems that are more open hydrodynamically or have lower salinity, it may be necessary to restore a greater percentage of the original bar area. The recommended 20 to 40 percent will be a target that should be refined and adapted once a system is studied in detail prior to restoration, through phased implementation, or as lessons are learned through monitoring of completed projects.

The master plan recommends restoring 20 to 40% of historic (corrected) habitat within sanctuaries in a tributary in order to achieve sustainability. This target should be refined during detailed tributary plan development.

When individual projects are developed in detail in the follow-on documents to the master plan, information critical to determining and designing the final scale will include: assessment of existing populations, hydrodynamic modeling/evaluations, and bottom condition surveys. It is highly likely that unsuitable bottom condition (lack of hard bottom or substrates that can support hard substrate) will limit restoration in some tributaries. Sections 5.5.4 and 6 discusses further

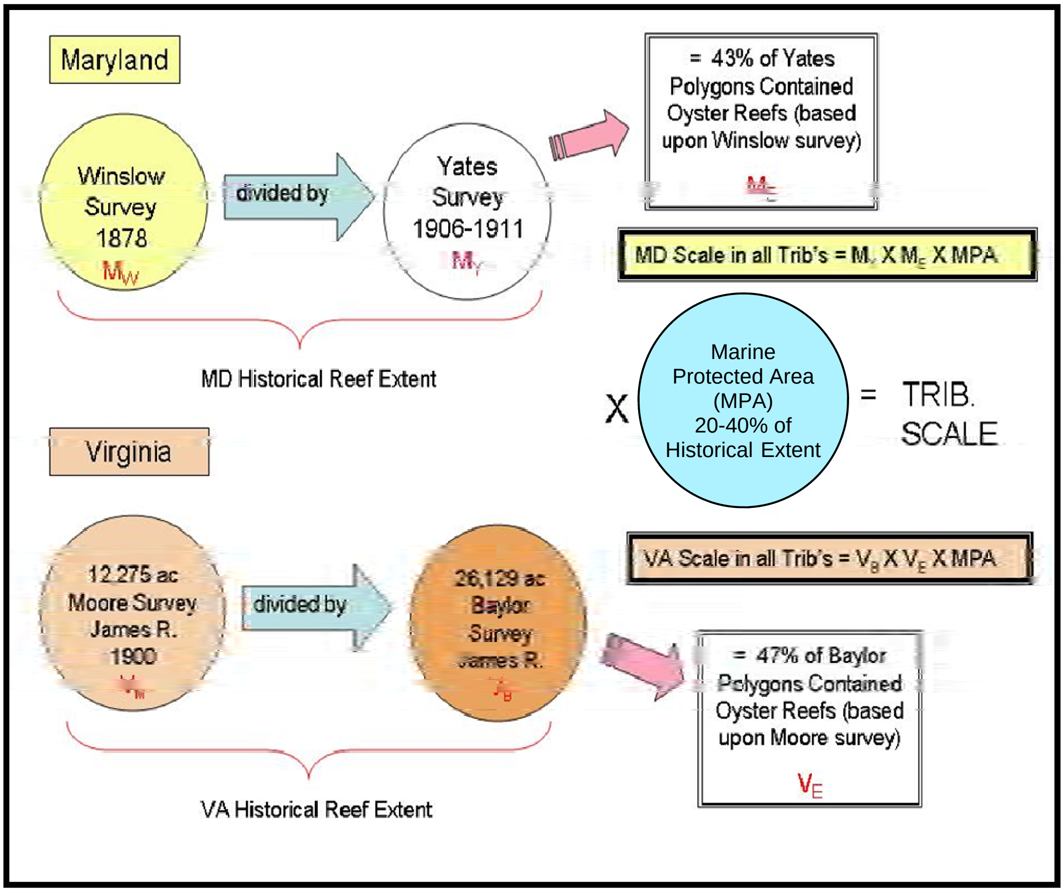


Figure 5-6. Approach for Determining Scale

the factors that need to be covered by tributary specific evaluations. It is expected that the restored areas will be concentrated within regions determined to be hydrodynamically connected. Halpern (2003) recognized the susceptibility of small reserves to catastrophic events as another potential drawback of small reserves and Mann and Powell (2007) indicated that the best approach to restoring oysters would be to ensure that reproductively capable populations are distributed throughout the Chesapeake Bay. So, not only must individual restoration sites be large enough to be self-sustaining as individual sites, support an estuarine community, and export larvae, but they must be distributed sufficiently throughout the Bay and within a particular tributary to respond to anthropogenic and climatic events (including freshets and droughts). These factors dictate that a relatively large area of sanctuaries must be established in any distinct sub-segment of the Bay to establish a self-sustaining population.

Recognizing the resources (shell or other substrate and spat) needed to construct expansive bars, available funding, and uncertainty surrounding the scale needed to achieve sustainability; the master plan is recommending that tributary restoration occur in phases, a proportion of the habitat at a time. During the implementation phase, if projects are built in phases within a tributary or sub-region, monitoring and adaptive management will allow projects to be scaled up or scaled back in a tributary or sub-region depending on biogenic bar structure development, larval recruitment, and adult broodstock survival and performance. The 20 to 40 percent range provides a good preliminary estimate of the scale of restoration that is likely to be successful in a tributary. The individual bars must be large enough to be self-sustaining, export larvae to other bars (both other sanctuaries and harvest areas), contain densities of oysters to maintain necessary shell structure, provide ecosystem services, and be distributed throughout the estuary to be resilient. These goals are not likely to be achieved if a substantial amount of habitat is not restored.

Restoration targets are provided for each tributary or sub-region by estimating the 'corrected' historical extent from all the mapped Baylor or Yates grounds in each tributary or sub-region, and then applying the targeted restoration range (20-40 percent) to that acreage. Any existing habitat identified by bottom surveys would count towards achieving the restoration goal. Similarly, there may be acreage identified that only requires some rehabilitation or enhancement. Work done on that acreage would also count toward achieving the restoration target. The targets are the proposed number of functioning habitat acres needed to produce a sustainable population in a tributary; they are not meant to be interpreted strictly as the number of new acres to construct. In such, cost projections needed to include restoration of all acres. In doing so, estimates are conservative because it is anticipated that not all restoration will be the construction of new acreage. The accounting of the presence and condition of existing habitat is recommended as an initial step when developing specific tributary plans. Once that information is obtained, restoration actions will be tailored to the habitat conditions and costs revised.

Restoration targets are the proposed number of functioning habitat acres needed to produce a sustainable population in a tributary; targets are not meant to be interpreted strictly as the number of new acres to construct. The targets include existing functioning oyster habitat.

The following tables provide the results of applying this calculation to each tributary or sub-region. Table 5-3 is a key to Table 5-4 a and b. Table 5-4a and b contains summary information about each tributary and region, as well as information that will be developed in following sections of this report.

Table 5-3. Key to Table 5-4 a and b

Column	Content	Report Section
A	Tributary/DSS name, generally arranged from north to south	5.3
B and C	Tributary/DSS salinity regime	5.5.1.2
D to F	Scale calculation- analysis of the appropriate self-sustaining restoration scale	5.4
G	Recommended restoration target range (acres)	5.4.5
H to J	Acres of current sanctuaries and previous restoration efforts	
K to N	Suitability Analysis- GIS screening outputs	5.5.2
O	Qualitative Hydrodynamic Rating	5.5.3
P	Tier assignment	5.5.5

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Table 5-4a. Master Plan Summary of Formulation Data – Maryland

A	B	C	D	E	F				G	H	I	J	K	L	M	N	O	P
	Salinity Type		Scale							Sanctuaries			Suitability Analysis- Absolute Criteria and Yates/Baylor				Hydrodynamics	Tier
Distinct Sub-Segment (DSS)	Salinity	Salinity > or < 12 ppt	Yates or Baylor Grounds (Historic Oyster habitat) (acres)	Oyster Habitat within Yates/Baylor Grounds (43% Yates; 47% Baylor)	Raw Restoration Target-minimum (20%)	Raw Restoration Target-maximum (40%)	Rounded Restoration Target(min) (acres)	Rounded Restoration Target (max) (acres)	Rounded Restoration Target Range (acres)	Existing Designated Oyster Sanctuaries (acres)	Existing Restored Habitat	Revised Target	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Is suitable Habitat Greater Than Restoration Target?	Qualitative Trap Estuary Retention Rating	Restoration Teir (1, 2)
MARYLAND				(43%)	(20%)	(40%)												
Magothy River	Low Mesohaline	<	228	98	20	39	20	40	20-40	5,360			193	0	0	yes	M	2
Severn River	High Mesohaline	<	1,980	851	170	341	200	300	200-300	7,205	10	190-290	1,411	147	220	yes	H	1
South River	High Mesohaline	<	1,057	455	91	182	90	200	90-200	2,032			872	48	61	yes	H	1
Rhode River	High Mesohaline	<	84	36	7	14	10	10	10-10	-			26	17	0	yes	L	2
West River	High Mesohaline	<	136	58	12	23	10	20	10-20	-			33	23	0	yes	L	2
Chester River	Low and High Mesohaline	<	12,747	5,481	1,096	2,192	1,100	2,200	1100-2200	30,749			10,577	809	4	yes	H	
lower Chester		<	6,344	2,728	546	1,091	500	1,100	500-1100	20,854			5,179	562	4	yes	H	1
upper Chester		<	6,404	2,754	551	1,101	600	1,100	600-1100	9,895			5,398	247	0	yes	M	2
Corsica River	Low Mesohaline	<	190	82	16	33	20	30	20-30	1,257			67	114	0	yes	L	2
Eastern Bay	High Mesohaline	<	17,358	7,464	1,493	2,986	1,500	3,000	1500-3000	13,753			14,472	919	0	yes	H	
lower Eastern Bay		<	8,288	3,564	713	1,426	700	1,400	700-1400	6,327			7,145	213	0	yes	H	1
upper Eastern Bay		<	9,070	3,900	780	1,560	800	1,600	800-1600	7,426			7,328	705	0	yes	H	1
Choptank River	Oligohaline, Low and High Mesohaline	~	20,995	9,028	1,806	3,611	1,800	3,600	1800-3600	25,081			17,232	1,372	21	yes	H	
lower Choptank		>	16,057	6,905	1,381	2,762	1,400	2,800	1400-2800	8,924			14,047	498	21	yes	H	1
upper Choptank		~	4,938	2,123	425	849	400	800	400-800	16,156			3,185	874	0	yes	H	1
Harris Creek	High Mesohaline	~	3,479	1,496	299	598	300	600	300-600	4,302			3,245	0	1	yes	H	1
Broad Creek	High Mesohaline	~	2,569	1,105	221	442	200	400	200-400	-			2,353	0	0	yes	H	1
Little Choptank	High Mesohaline	>	4,092	1,760	352	704	400	700	400-700	8,837			1,851	910	841	yes	H	1
Honga River	High Mesohaline	>	5,163	2,220	444	888	400	900	400-900	694			4,798	0	12	yes	M	2
Potomac River	Tidal Fresh, Oligohaline, Low and High Mesohaline	~	10,808	4,647	929	1,859	900	1,900	900-1900	3,491			253	7,207	1,595	no	M	
lower Potomac		>	991	426	85	170	90	200	90-200	-			0	483	258	no	M	2
middle Potomac		~	9,817	4,221	844	1,689	800	1,700	800-1700	3,491			253	6,724	1,337	no	L	2
upper Potomac		<	0	0	-	-	-	-	-	-			-	-	-	no	L	2
St. Mary's River	High Mesohaline	>	2,461	1,058	212	423	200	400	200-400	1,228			341	1,092	610	yes	H	
Tangier Sound	Polyhaline, High Mesohaline	~	20,192	8,683	1,737	3,473	1,700	3,500	1700-3500	6,237			17,384	0	13	yes	H	1
lower Tangier		>	9,963	4,284	857	1,714	900	1,700	800-1700	356			8,351	0	2	yes	H	1
upper Tangier		~	10,229	4,398	880	1,759	900	1,800	900-1800	5,881			9,033	0	11	yes	H	1
Fishing Bay	Low Mesohaline	~	4,434	1,906	381	763	400	800	400-800	-			4,404	0	0	yes	M	2
Nanticoke River	Low Mesohaline	<	857	369	74	147	70	100	70-100	9,702			779	69	10	yes	M	2
Monie Bay	Low Mesohaline	<	392	169	34	67	30	70	30-70	492			392	0	0	yes	L	2
Manokin R.	High Mesohaline	>	4,869	2,094	419	837	400	800	400-800	15,057			4,599	0	0	yes	H	1
Big Annemessex R.	High Mesohaline	>	1,220	525	105	210	100	200	100-200	648			1,220	0	0	yes	M	2
Little Annemessex R.	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	no	L	2
Patuxent River	Oligohaline, Low and High Mesohaline	~	5,662	2,435	487	974	500	1,000	500-1000	9,855			153	986	2,817	no	M	2
lower Patuxent		>	4,188	1,801	360	720	400	700	400-700	619			153	924	1,630	no	M	2
upper Patuxent		<	1,474	634	127	254	100	300	100-300	9,236			0	63	1,188	no	L	2
Upper MD Mainstem		<	21,461	9,228	1,846	3,691	1,800	3,700	1800-3700	8,043			4,623	15,833	354	yes	L	2
Middle West Mainstem		~	25,178	10,827	2,165	4,331	2,200	4,300	2200-4300	24,712			15,100	3,733	1,156	yes	M	2
Middle East Mainstem		~	21,385	9,196	1,839	3,678	1,800	3,700	1800-3700	2,455			13,299	5,856	596	yes	M	2
Lower West Mainstem		>	16,841	7,242	1,448	2,897	1,400	2,900	1400-2900	3,792			4,008	2,652	2,092	yes	M	2
Lower East Mainstem		>	8,664	3,726	745	1,490	700	1,500	700-1500	38,294			7,848	0	0	yes	M	2

Table 5-4b. Master Plan Summary of Formulation Data – Virginia

A	B	C	D	E	F				G	H	I	J	K	L	M	N	O	P
	Salinity Type		Scale							Sanctuaries			Suitability Analysis- Absolute Criteria and Yates/Baylor				Hydrodynamics	Tier
Distinct Sub-Segment (DSS)	Salinity	Salinity > or < 12 ppt	Yates or Baylor Grounds (Historic Oyster habitat) (acres)	Oyster Habitat within Yates/Baylor Grounds (43% Yates; 47% Baylor)	Raw Restoration Target-minimum (20%)	Raw Restoration Target-maximum (40%)	Rounded Restoration Target(min) (acres)	Rounded Restoration Target (max) (acres)	Rounded Restoration Target Range (acres)	Existing Designated Oyster Sanctuaries (acres)	Existing Restored Habitat	Revised Target	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Is suitable Habitat Greater Than Restoration Target?	Qualitative Trap Estuary Retention Rating	Restoration Teir (1, 2)
VIRGINIA				(47%)	(20%)	(40%)												
Virginia Mainstem		>	36,136	16,984	3,397	6,794	3,400	6,800	3400-6800	-			29,108	0	0	yes	L	2
Little Wicomico R.	Polyhaline	>	206	97	19	39	20	40	20-40	-			198	0	0	yes	L	2
Cockrell Creek	High Mesohaline	>	23	11	2	4	2	4	2-4	-			11	0	0	yes	L	2
Great Wicomico R.	High Mesohaline	>	2,479	1,165	233	466	200	500	200-500	80	100	100-400	2,086	0	0	yes	H	1
Rappahannock River	Tidal Fresh, Oligohaline, Low and High Mesohaline	>	40,127	18,860	3,772	7,544	3,800	7,500	3800-7500	-			7,443	3,225	16,874	yes	H	
lower Rappahannock		>	13,703	6,440	1,288	2,576	1,300	2,600	1300-2600	48			7,443	669	369	yes	H	1
middle Rappahannock		>	23,904	11,235	2,247	4,494	2,200	4,500	2200-4500	-			0	579	15,962	no	H	2
upper Rappahannock		~	2,520	1,184	237	474	200	500	200-500	-			0	1,977	543	no	H	2
Corrotoman River	High Mesohaline	>	2,757	1,296	259	518	300	500	300-500	2			0	0	2,171	no	H	2
Piankatank River	Polyhaline	>	7,097	3,336	667	1,334	700	1,300	700-1300	7			6,210	0	0	yes	H	1
Mobjack Bay	Polyhaline	>	8,866	4,167	833	1,667	800	1,700	800-1700	-			8,589	0	0	yes	H	1
Severn River	Polyhaline	>	193	91	18	36	20	40	20-40	-			165	0	0	yes	L	2
York River	Tidal Fresh, Oligohaline, Polyhaline, High	~	11,986	5,633	1,127	2,253	1,100	2,300	1100-2300	60			8,750	1,619	117	yes	H	
lower York		>	11,226	5,276	1,055	2,110	1,100	2,100	1100-2100	60			8,750	1,112	115	yes	H	1
upper York		~	760	357	71	143	70	100	70-100	-			0	508	3	no	H	2
Poquoson River	Polyhaline	>	180	85	17	34	20	30	20-30	-			180	0	0	yes	L	2
Back River	Polyhaline	>	182	86	17	34	20	30	20-30	-			182	0	0	yes	L	2
Pocomoke/Tangier Sound	Polyhaline, High	>	31,576	14,841	2,968	5,936	3,000	5,900	3000-5900	8			29,879	0	2	yes	H	1
Onancock Creek	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	no	L	2
Pungoteague Creek	Polyhaline	>	91	43	9	40	10	40	10	-			88	0	0	yes	L	2
Nandua Creek	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	yes	L	2
Occohannock Creek	High Mesohaline	>	130	61	12	60	10	60	10	-			130	0	0	yes	L	2
Nassawaddox Creek	Polyhaline	>	166	78	16	80	20	80	20	-			100	0	0	yes	L	2
Hungars Creek	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	no	L	2
Cherrystone Inlet	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	no	L	2
Old Plantation Creek	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	no	L	2
James River	Tidal Fresh, Oligohaline, Polyhaline, Low	~	30,393	14,285	2,857	5,714	2,900	5,700	2900-5700	-			25,902	2,988	3	yes	H	
lower James		>	9,578	4,502	900	1,801	900	1,800	900-1800	-			9,381	0	0	yes	H	1
upper James		~	20,815	9,783	1,957	3,913	2,000	3,900	2000-3900	-			16,521	2,988	3	yes	H	1
Elizabeth River	Polyhaline	>	2,860	1,344	269	538	300	500	300-500	14 sites			2,176	0	42	yes	H	1
Nansemond River	Polyhaline	>	1,173	551	110	221	100	200	100-200	-			1,151	0	0	yes	L	2
Lynnhaven Bay	Polyhaline	>	990	465	93	186	90	200	90-200	52	50	40-150	251	0	0	yes	H	1

5.5 SITE EVALUATION

Site evaluation is one of the most critical aspects to consider in developing oyster restoration projects and is critical to project success. The success of the project will depend on selecting sites with the proper attributes to allow oysters to survive and become self-sustaining.

The team assembled a list of criteria or critical factors affecting the capacity of a location to support oyster bars. These initial screening criteria are listed in Table 5.5 and further explained in Table 5.6. The criteria are discussed in further detail in Section 5.5.4 and the white papers (Appendix C-1). Initially, all criteria that could affect oyster bars were considered:

Table 5-5. Initial Screening Criteria Considered

Initial Criteria Considered	
Physiochemical	Salinity, dissolved oxygen, water quality, temperature, freshets
Physical	Water depth, hydrodynamics and retentiveness; substrate; water flow; sedimentation
Biological	Historic habitat/upstream extent, recruitment history; food availability; harmful algal blooms; proximity and quantity of existing broodstock populations
Regulatory	Harvesting closure areas; sanctuary locations
Miscellaneous Considerations	Scale; previous results, successes, failures; watershed suitability; position relative to other estuarine habitats

Table 5-6. Description of Initial Screening Criteria Considered

Parameter	*Description*	*Evaluation Criteria*	*Location of Detailed Information*
Salinity	The higher the salinity the greater reproductive potential and growth rates. High salinity also increases disease intensity. Adult oysters can survive salinities between 0 and 36+ ppt, but various life stages have narrower salinity ranges (Kennedy 1991) and optimal ranges exist for all stages.	Average growing season bottom and surface salinity- 5 ppt is minimum for growth and survival; 8 ppt is minimum for reproduction.	Physiochemical White Paper

Parameter	Description	Evaluation Criteria	Location of Detailed Information
Dissolved oxygen	Determine whether the overlying waters are well oxygenated. Small, poorly flushed coves may become hypoxic or anoxic, particularly in the summer when the water is warmest. Hypoxia can affect shellfish directly (e.g., reduce recruitment and survival (Breitburg 1992)) and indirectly (e.g., fish and crabs escaping areas of low oxygen may converge on bars or nearby shellfish populations and alter community structure through predation or competition (Lenihan and Peterson 1998)).	Average summer DO > 5 mg/L to support oysters and reef community	Physiochemical White Paper
Water Depth	Historically, oyster beds were located in shallows and deep waters; today, deep waters are avoided due to issues with hypoxia and anoxia.	<20 feet (7.6 m) [20 feet to 30 feet is less desirable, but possible; > 30 ft is not acceptable (CBP 2004a)]	Physical Characteristics of Oyster Reefs White Paper
Historic upstream extent of oyster habitat	Oysters occurred through the mainstem of Chesapeake Bay and into the tributaries. Typically, the upstream extent of oyster habitat was controlled by salinity.	No comprehensive historic survey of oyster habitat exists for the entire Bay prior to significant harvesting efforts. Baylor (1895) and Yates (1913) surveys are most comprehensive for VA and MD, respectively. Also, the U.S. Public Health Service oyster habitat map (Cumming 1916) fills in some of the gaps for which no Baylor or Yates surveys exist.	Scale Discussion in Plan Formulation Section
Recruitment and History of Wild Spatsets	Historic spatset data provides information on the larval production of a tributary or region prior to recent oyster population degradation. Optimal locations will have sufficient spat settlement to facilitate the development of a self-sustaining population. Even low to moderate occasional spat settlements may build up an area over time, but areas with no history of spat settlement are not suitable since a population put there would probably not be self-sustaining (CBP 2004a).	Average annual spatset	Hydrodynamics Discussion in Plan Formulation Section, Data is in Appendix C-1

Parameter	*Description*	*Evaluation Criteria*	*Location of Detailed Information*
Hydrodynamics and Retentiveness	Each tributary has its own unique hydrodynamics and currents that are driven by tides, tributary shape and size, freshwater input, benthic structures, and winds. Hydrodynamics influences oyster larval transport and retention within and between tributaries, local flows over an individual bar, sedimentation, and ultimately, survival, growth, and recruitment. Determine whether area is a "sink" for larvae being transported in from "source" areas. Populations have a higher chance of recovering most rapidly in areas that are "sinks" for larvae (Crowder et al 2000). Initially locate restoration projects within "trap estuaries" (Pritchard 1953) which have a high degree of retention to promote recruitment of shellfish larvae and other colonizing species.	No specific numeric criteria established. Investigate scientific literature to identify any existing investigations into hydrodynamics of the selected tributary. Evaluate any existing larval transport modeling results and historic spatset data. Consult with regional oceanographers familiar with currents of selected tributary.	Hydrodynamics White Paper and discussion in Plan Formulation Section
Disease prevalence and intensity	MSX and Dermo are more prevalent in higher salinity waters. There is evidence that disease resistance is developing in high salinity areas of VA.	None specifically applied. Little or no disease mortality @ <10ppt. Increasing disease mortality @ 10-14 ppt. High mortality @ > 15 ppt.	Disease White Paper and Plan Formulation Section that lays out Disease Strategy
Water Quality	WQ threats other than low DO include sources of sedimentation (e.g., erosive banks, poorly buffered shorelines), excessive nutrients, stormwater, and other point sources of pollution.	Water quality criteria for some parameters are established by USEPA (USEPA 2003). Local water quality impairments should be investigated further when specific tributary plans are being developed.	Section 4.2
Temperature	Temperature can affect reproduction, feeding rates of oysters, available food sources (phytoplankton), growth and survival, and disease pressure as well as the dissolved oxygen concentration of the water column which in turn affects numerous aspects of oyster growth and survival.	-2 to 36 C. Not a limiting factor to Chesapeake Bay oysters.	Physiochemical White Paper
Scale	Ability to construct a project large enough in a tributary to have a significant chance to become self-sustaining within a specified time period.	Identified by the master plan as 20-40% of historic habitat.	Scale discussion in Plan Formulation Section

Parameter	Description	Evaluation Criteria	Location of Detailed Information
Restoration Results	Results of previous restoration projects in the waterbody to date. Favorable results are desired.	Acres of restored bar that are currently providing functional benefits can be applied to reduce the number of acres needed to reach the targeted restoration goals of a tributary or sub-region.-region.	Hydrodynamics discussion of Plan Formulation Section
Bottom type that can support oysters	Hard bottom, preferably with at least some shell (CBP 2004a). Typically bottom classified as shell, hard bottom, or sand are suitable. Muds are not suitable. However, firm sandy muds and muddy sands may be good; it is even better if they contain 10% shell and/or rocky material. Soft mud (>80% silt and/or clay) or shifting sand (>80% sand) are typically not suitable (CBP 2004a).	Shell, hard bottom, and sand are typically suitable. Will be investigated for specific sites by collecting current bottom surveys when developing tributary specific plans.	Maryland Bay Bottom Survey (1983), Virginia bottom probe surveys conducted by Haven in the 1970s and Wesson in the 1990s.1990s. NOAA and MGS are conducting current bottom profiling.
Water Flow	Water flow is critical to bringing food and oxygen to the oysters and removing silt, feces and pseudofeces that can smother the oysters (CBP 2004a).	11 to 600 cm/sec (Stanley and Sellers 1986). It was identified that there exist scouring currents along the scarps that maintained sediment free oysters and likely brought increased food to the bed (Smith et al. 2003). Seliger and Boggs (1988) suggests oyster habitat is sustainable where the bottom gradient, $dz/dr \times 10^3 \geq 20$	Growth and Physical Characteristics of Oyster Reefs White Papers
Sedimentation Rate	An area is unsuitable if the rate of sedimentation outpaces oyster growth. Excess sediment degrades habitat and compromises substrate for oyster larval settlement (CBP 2004a). Sediment impairs oyster gill function and metabolic efficiency by increasing pseudofeces production. Oysters exposed to sediments exhibit decreased growth and reproductive efficiency, plus increased mortality and susceptibility to disease (Héral et al. (1983) as cited by Rothschild et al. (1994)).	Will vary by location or region. Growth rate > local sedimentation rate. It takes only 3-4 mm of fine sediment to accumulate on a shell bar to make it unsuitable as an attachment site for oyster larvae.	Growth White Paper and Plan Form Section

Parameter	*Description*	*Evaluation Criteria*	*Location of Detailed Information*
Watershed suitability	Reflects the amount of urbanization and/or agricultural activity, imperviousness, and effectiveness of wastewater treatment facilities and stormwater controls. The greater the development of a watershed (imperviousness), the greater the overland runoff and nutrient and pollutant inputs to the water body.	Watersheds become impacted at 10% impervious cover (Center for Watershed Protection).	Affected Environment Section
Harmful Algal Blooms (HAB)	Toxic dinoflagellate blooms or HAB pose a threat to oyster populations because of their capability to suppress oxygen levels to hypoxic or anoxic levels and by their release of toxins. Impact is dependent on oyster life stage. Timing of blooms affects impacts to specific life stages. Some life stages may benefit from consumption of these dinoflagellates. Greatest risk is in shallow, poorly drained systems. Investigate further during development of specific tributary plans.	Consider frequency and composition of HAB.	Plan Formulation Section
Freshets	Huge influxes of freshwater during storms can kill oysters by suppressing salinity for long durations. The length of time that oysters can survive at these reduced salinities depends most on water temperature, but also genetics and conditioning (Haven et al. 1977). Risk of freshets is greatest in winter and early spring. Life stage affects impacts. Generally, western shore tributaries receive larger freshwater inputs than eastern shore tributaries are more likely to experience freshets.	Consider frequency and duration of freshets.	Plan Formulation Section

Parameter	Description	Evaluation Criteria	Location of Detailed Information
Shellfish harvesting closures	Bacterial contamination stemming from sewage and septic systems and wild animals poses a threat to human consumption of oysters. In areas where contamination is a problem, typically in urbanized watersheds, areas are closed to shellfish harvesting. These areas may be good choices for restoration because they act as sanctuaries. Closed areas are designated by Maryland and Virginia. Specific harvest closure sites will need to be further coordinated with Maryland and Virginia prior to any final selection for restoration.	Location of closure, adjacent land uses, and nature and degree of contamination should be considered to determine if an area closed for harvest is suitable for oyster restoration.	Plan Formulation Section
Phytoplankton resources (food availability)	Typically food is not limiting to oysters in the Chesapeake Bay as phytoplankton is overly abundant. However, the size of available phytoplankton resources can affect oyster food availability. Oysters filter particles >4 microns at near 100% efficiency (Landgon and Newell 1996) and provide near zero filtration of particles <2 microns (picoplankton). Suspect that there have been shifts in diet as quality and dynamics of Bay food web have been altered with eutrophication. Greatest potential for oysters to impact phytoplankton is in tributaries (Fulford et al. 2007).	Investigate any available phytoplankton monitoring data. Consider size distribution of assemblage in local area.	Growth White Paper and Plan Formulation Section
Position relative to other estuarine habitats	Oyster habitats are one component of the Bay ecosystem. Positioning restoration sites near other important habitats will increase the overall ecosystem value of restored oyster habitats and promote connectivity.	Consider position of proposed restoration site within Bayscape.	Affected Environment Section, SAV maps in Plan Formulation Section
Existing Broodstock Populations	Local oysters may contain some residual genetic material from the original local oysters, and because they already live in the target restoration area they may have developed natural resistance to factors that inhibit survival. Quantity of existing resources will reduce investment needed to reach restoration goals. Promotes connectivity within and between tributary or sub-region.-region.	Location and distance from proposed restoration site.	Comprehensive maps of current habitat and populations do not exist. NOAA and MGS bottom mapping will be used to map current resources for specific tributary plans.

In order to evaluate the many identified criteria that play a role in determining the restoration potential of a given area with respect to oysters, the master plan makes a sequential application of various layers of information with an end goal of identifying tributaries and regions within the bay that are most likely to develop sustainable populations of oysters with the implementation of bar construction, seeding, and other oyster restoration activities. The steps of the layered formulation evaluation are discussed in the following sections.

5.5.1 LAYER 1- APPLY ABSOLUTE CRITERIA TO IDENTIFY SUITABLE ACREAGE

The initial criteria were categorized as either absolute or secondary criteria. The absolute criteria, are physical and biological criteria that, once applied spatially on maps, define areas within which restoration can take place. Absolute criteria must be met for a location to support oysters. Secondary criteria do not have to be satisfied for an area to support oysters and are typically criteria that affect the quality of the oyster habitat.

Salinity, DO, water depth and the historic upstream limits of oyster bars in the bay meet the requirements for absolute criteria. Salinity, bottom DO, water depth, and historic upstream extent of oyster habitat was identified as absolute criteria. The remaining criteria were secondary. The absolute criteria are set as:

- Mean salinity greater than or equal to 5 ppt during the oyster growing season during wet, dry and normal years,
- Mean DO greater than or equal to 5 mg/L during the summer during wet, dry and normal years,
- Water depth less than 20 feet at mean lower low water (MLLW), and
- The historic upstream limit of oyster bars as defined in 1916 and the Baylor and Yates surveys.

5.5.1.1 Data Collection and Organization

The team applied GIS to organize the data and identify the suitable oyster restoration areas in the Chesapeake Bay. Versar, Inc., under contract to USACE, generated 24 GIS map images (rasters) to depict salinity and DO at both the surface and bottom of the water column under various freshwater flow conditions. The data was compiled over the most important time of year to assess conditions for supporting oysters. For DO, they generated rasters to depict the mean for the summer season (June-August) during two recent wet (2003-2004), dry (2001-2002), and average rainfall years (2005-2006). For salinity, they generated rasters to depict the mean for the growing season (April-October) during each of 2 recent wet (2003-2004), dry (2001-2002), and average rainfall years (2005-2006). This data is summarized in Appendix C-2. Point data were gathered from MDNR, the Maryland Department of the Environment, Alliance for Chesapeake Bay, Virginia Department of Health/Division of Shellfish Sanitation, and the CBP (CBP 2011). Maps showing salinity and DO for individual hydrologic regimes are presented in Appendix C-4. The distribution of sampling stations is shown in Figure C-4T of Appendix C-4. Interpolations were performed to

> Absolute criteria, are physical and biological criteria that, once applied spatially on maps, define areas within which restoration can take place.

convert the point data into a GIS coverage using Inverse-Distance Weighting (IDW), which accounts for the distance of a data point from a location in its weight in its contribution to the actual value for an area. The team reviewed the GIS information and selected appropriate layers to use in the analysis as described below.

5.5.1.2 Salinity Layer

The master plan identified areas with average annual oyster growing season salinity (both surface and bottom) greater than or equal to 5 ppt as areas with suitable salinity for oysters. This analysis identified areas with the Chesapeake Bay that had both average annual growing season surface and bottom salinity greater than or equal to 5 ppt. This is the minimum concentration for sustained feeding by adult oysters (Kennedy 1991). The analysis applies surface and bottom salinity concentrations because the success of oyster larvae that occupy the water column is affected by minimum salinity concentrations as well. Figure 5-7 defines suitability of Chesapeake Bay waters for salinity greater than or equal to 5 ppt concentration using data from 2001-2006 that covers dry, wet, and average freshwater flow years. Therefore, areas identified as suitable (shown in green on Figure 5-7) will not exceed the criterion under any of the flow conditions considered in the data set. Figure 5-7 also shows areas that are not suitable under any hydrologic rainfall year (shown in blue) as well as those that fluctuate between being suitable or unsuitable depending on hydrologic rainfall year (shown in yellow). Figures C-4A through F in Appendix C-4 provide individual maps of surface salinity and bottom salinity for each hydrologic regime. Suitability analyses for dry, wet, and average freshwater flow years, respectively are available in Appendix C-4, Figures C-4G to I. The method used to develop the linked bottom and surface salinity layer is described in Appendix C-3. A full discussion of the identification of 5 ppt as the suitable criterion for salinity is available in Appendix C-1 in the Physical Characteristics-Physiochemistry White Paper.

5.5.1.3 Bottom Dissolved Oxygen Layer

Oysters are capable of withstanding anoxic conditions over a period of time (varying from hours to weeks, depending on life stage and other conditions such as temperature). Comprehensive data that considers duration and concentration over such a short time interval is not available. DO concentrations are lowest in the bottom of the water column and during the summer when water temperature and biological activity are high. Therefore, the GIS layer used to define oyster restoration potential for DO was selected as the mean concentration of bottom DO during the summer (June-August, rather than the growing season (April-October) that is used for salinity). The master plan focuses on areas for restoration with average annual summer DO greater than or equal to 5 mg/L. Figure 5-8 depicts the areas that have DO concentrations greater than or equal to 5 mg/L based on data from 2001-2006 that covers dry, wet, and average freshwater flow years. Figure 5-8 also shows areas that are not suitable under any hydrologic rainfall year as well as those that fluctuate between being suitable or unsuitable depending on hydrologic rainfall year. Figures C-4J through O in Appendix C-4 provide individual maps of bottom and surface DO for each hydrologic regime. Suitability analyses of bottom DO for dry, wet, and average freshwater flow years, respectively, are available in Appendix C-4, Figures C-4P to R. Although the 5 mg/L concentration does not represent a specific tolerance level for oysters over a specific time period, it defines areas where DO concentration is limiting to habitat value. Areas with an average concentration less than 5 mg/L do not have as great a potential to provide quality habitat as areas with a DO concentration above 5 mg/L.

Recognizing that areas with an average summer DO concentration greater than 5 mg/L experience periods of low DO, investigations into the monitoring data identified that only 33 of the 1280 suitable sites (2.6%) had a minimum DO measurement below 2 mg/L. This suggests that the sites identified as suitable by the criteria accurately represent areas that are relatively free of hypoxia. Additionally, the team considered setting the DO criteria to 2 mg/L. This suitability map is available in Appendix C-4 (Figure C-4S). The 2 mg/L definition could not discriminate areas with poor DO conditions. As discussed above, oxygen concentrations of less than 5 mg/L affect the behavior and survival of fish and reflect overall conditions of lower habitat quality because of hypoxia. The Physical Characteristics-Physiochemistry White Paper in Appendix C-1 provides further discussion of DO.

Further, it has been identified that percent oxygen saturation or partial pressure may be more appropriate than concentration to evaluate DO because these measurements are tied biologically to the delivery of oxygen to an oyster (Newell, personal communication). Bivalve mollusks are not stressed until oxygen is below ~25% of full saturation (Bayne 1971 a,b; Widdows et al. 1989), but this equates to different oxygen concentrations (mg/L) depending on salinity and temperature. Oxygen concentration was used for the master plan, given the wide acceptance of mg/L for setting DO criteria and the master plan's broad scale. However, the alternate expressions for dissolved oxygen should be given further consideration when the more detailed tributary plans are being developed.

Dockside harvest collection. Photograph courtesy of MDNR.

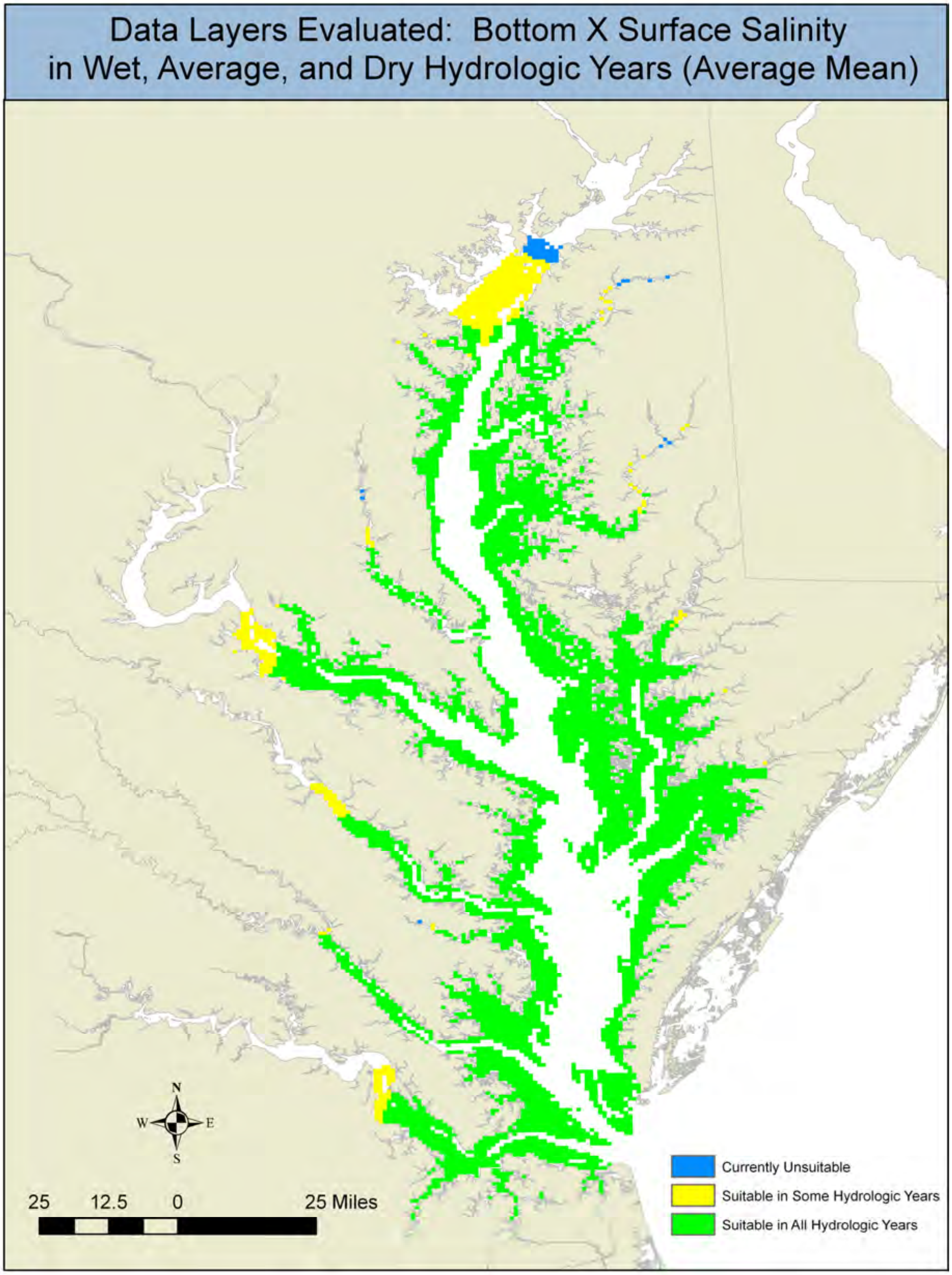

Figure 5-7. Suitability Analysis of Salinity (Bottom x Surface)

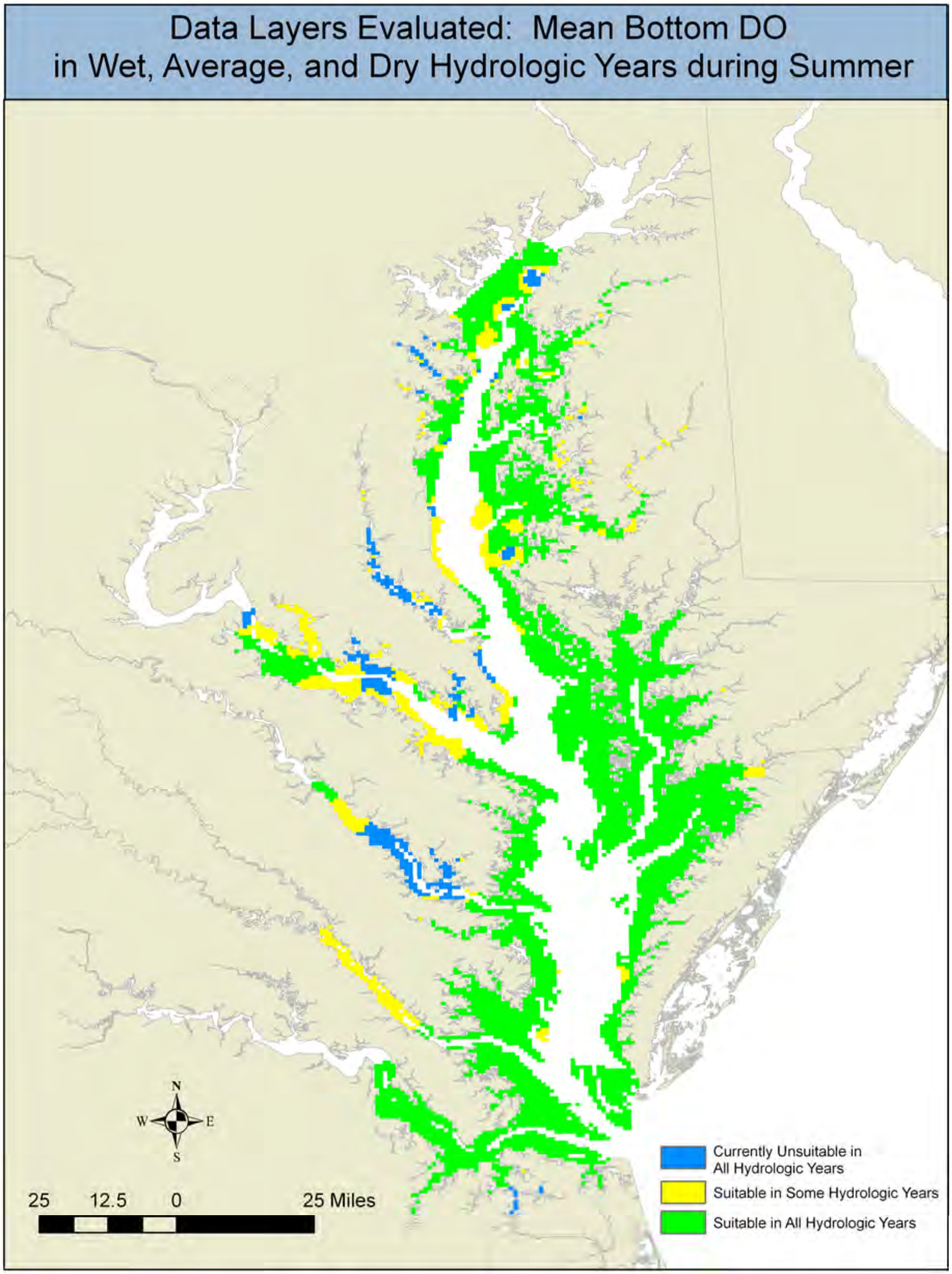

Figure 5-8. Suitability Analysis of Bottom Dissolved Oxygen

5.5.1.4 Water Depth Layer

The master plan established a criterion for suitable water depth based on the CBP OMP (CBP 2004). The CBP OMP identified 20 ft as the maximum water depth at which oyster restoration should occur based on water quality. Deeper waters typically experience poor DO. Figure 5-9 shows Bay waters that are suitable for restoration based on a water depth criterion of less than 20 ft MLLW. Further discussion of water depth is available in the Physical Characteristics-Physiochemistry White Paper in Appendix C-1.

5.5.1.5 Historic Extent of Habitat

The master plan limits the evaluation of oyster restoration to the upper limit of tributaries that supported oysters in 1916 based on the Yates and Baylor survey maps (Figure 1-2) and Cumming (1916) (Figure 4-4).

Generally, the Yates and Baylor surveys are where historic oyster habitat was located. Although it is recognized that these surveys are overestimates (Section 5.4.4.1), the Yates and Baylor surveys provide the most complete view of historic oyster habitat across the Chesapeake Bay. In theory, the boundaries of the Yates Bars and Baylor Grounds should represent the best locations for oyster habitat. No regulations state that restoration is restricted to only these historic areas, but in Maryland, all previous restoration efforts have been located within the boundaries of the Yates Bars. Further, these are public grounds owned by the States of Maryland and Virginia, respectively.

Restoration will be largely driven by the area of hard bottom ('restorable bottom') within a tributary that can support shells or other substrates placed for restoration of reef habitat. Ideally, the amount of hard bottom in a tributary would be included as an absolute criterion. However, this information is not available on a Bay-wide scale. The most recent comprehensive survey of the condition of the Maryland Bay Bottom was conducted between 1974 and 1983. A comparable dataset in Virginia is the geo-referenced bottom probe surveys conducted by Dexter Haven of VIMS in the 1970s. The bottom substrates are much different today making these surveys an unreliable basis for making current restoration decisions. Therefore, the master plan decided to make its Bay-wide evaluation on the historic oyster boundaries with the recommendation to perform bottom surveys prior to tributary plan development rather than basing decisions on substrate maps that are not current. The coverage of recent NOAA and MGS bottom surveys is discussed further in Section 5.5.4.3. The need to acquire current bottom and bathymetric surveys at the beginning of developing tributary plans is discussed in Sections 6.2.1 and 6.2.4.

> Although it is recognized that oyster habitat had been widely impacted from harvests by the time they were completed, the Yates and Baylor surveys provide the most complete view of historic oyster habitat across the Chesapeake Bay.

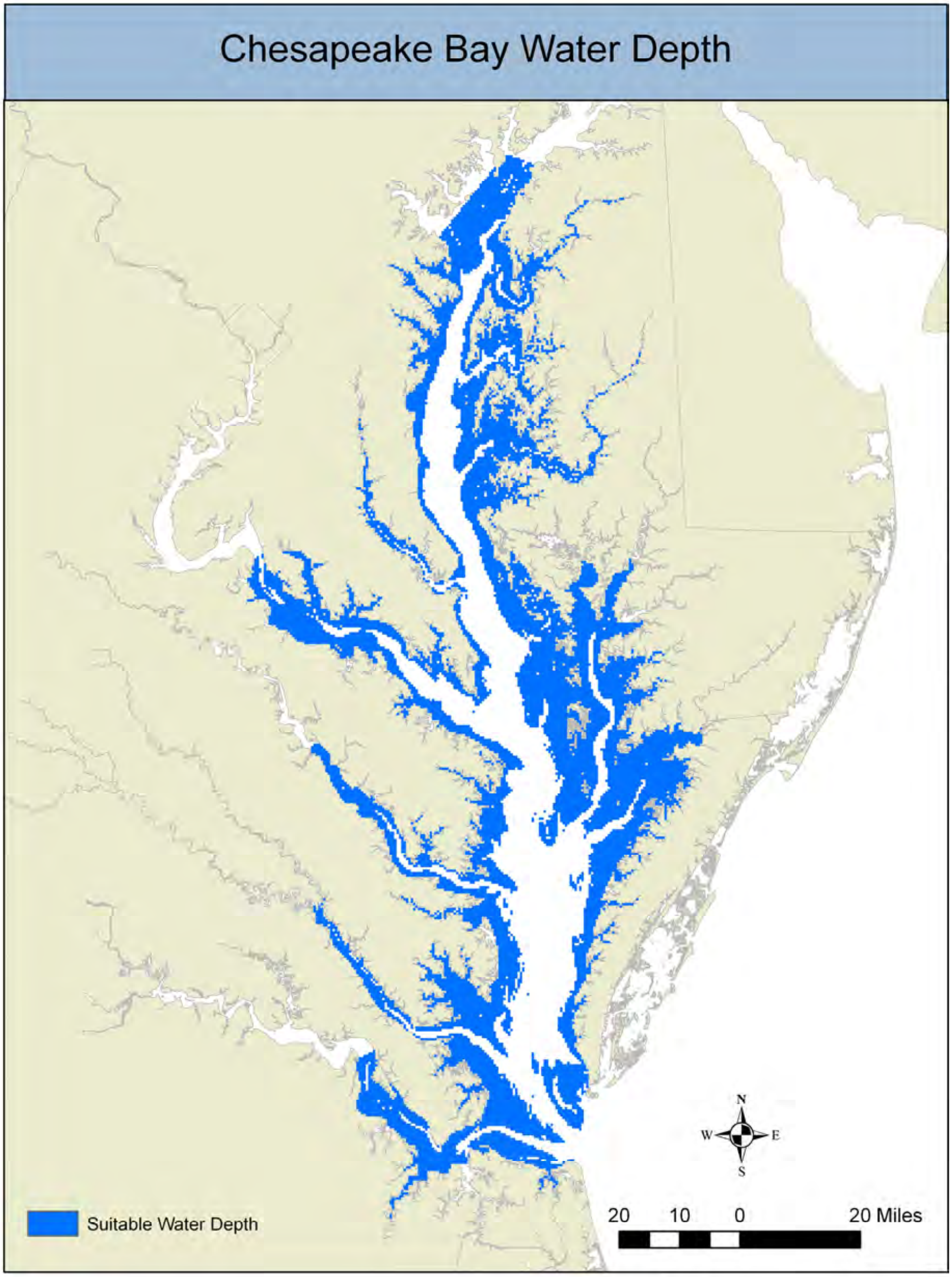

Figure 5-9. Suitable Water Depths for Oyster Restoration in the Chesapeake Bay

5.5.1.2 Suitability Analysis Results

Once compiled, the four absolute criteria were overlaid using ArcGIS to produce a suitability map showing areas in the Bay with conditions satisfying all the absolute criteria (Figure 5-10). Figure 5-11 portrays suitability within Yates and Baylor grounds. Figure 5-12 presents suitability within sanctuaries. Figure 5-13 further constrains the results to areas within designated sanctuaries and Yates Bars in Maryland (Geospatial data was not available for sanctuaries in Virginia to perform similar analyses for Virginia). Appendix C-3 provides a detailed discussion of the GIS methodology performed to evaluate the absolute criteria. Table 5-4a and b provide the tabulation of the 'currently unsuitable', 'suitable in some hydrologic years', and 'suitable in all hydrologic years' acreage in each tributary or sub-region within the Yates and Baylor Grounds. Table 5-7a and b contain the full results of the suitability analysis once it was expanded to account for current sanctuary boundaries. The acreages shown are conservative totals due to the data coverage from the existing network of sampling stations. There are not enough sampling stations to provide a continuous data layer over all areas of the Bay. This resulted in areas with no data that are not represented in the acreage totals of Table 5-7a and b. Additionally, spatial data was not available for the Virginia sanctuaries to provide a determination of the number of suitable acres within sanctuary boundaries (Column L-Q on Table 5-7b and Figures 5-12 and 5-13). Entries shown in red colored text in Table 5-7 a and b represent acreages that are below the target restoration size for that tributary.

5.5.2 LAYER 2- SCALE

The purpose of Layer 2 is to determine if a tributary or sub-region has enough suitable area (as defined by Layer 1) to achieve restoration at the targeted scale (i.e. 20 to 40 percent of the historic habitat). An estimated restoration target was calculated for each tributary or sub-region based on the corrected initial historic oyster habitat acreage (Yates for Maryland or Baylor for Virginia Grounds) (as calculated in the 'Scale' determination discussed previously) and the 20 to 40 percent restoration target. The full calculations are shown in Columns D-G of Table 5-4a and b. For each tributary or sub-region, the estimated restoration target was compared to the number of suitable acres identified in the Layer 1 Absolute Criteria analysis within Yates and Baylor Grounds. If the number of suitable acres is less than the estimated restoration target, the tributary or sub-region was designated as Tier 2 and was not considered suitable for restoration until changes are made in the waterbody to improve its condition relative to the absolute criteria. These tributaries typically either have low DO problems or low salinity. Tributaries or sub-regions with suitable acres in excess of the estimated restoration target were carried further through plan formulation. An evaluation was also performed to check whether a tributary or sub-region had enough suitable acreage within designated sanctuaries to meet the estimated restoration target (Table 5-7a and b).

- 'Currently unsuitable' denotes areas that do not meet the absolute criteria under current conditions under any hydrologic regime (wet, dry, average rainfall).
- 'Suitable in some hydrologic years' is defined as areas that meet the absolute criteria in some, but not all hydrologic regimes.
- 'Suitable in all hydrologic years' is defined as areas that meet the absolute criteria regardless of hydrologic regime.

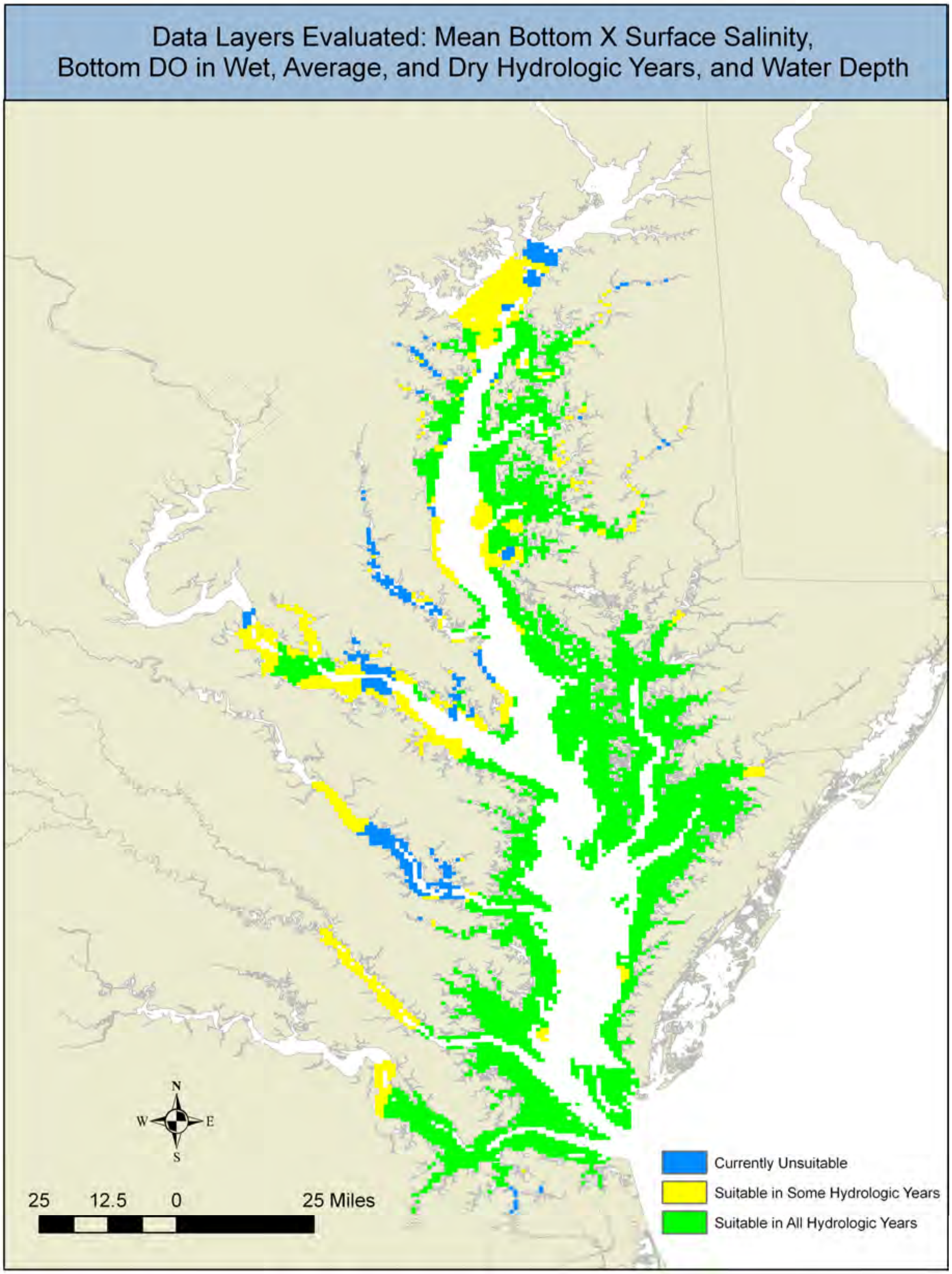

Figure 5-10. Suitability Analysis of Absolute Criteria: Evaluation of Bottom and Surface Salinity, Bottom Dissolved Oxygen, and Water Depth in All Hydrologic Flow Regimes

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Table 5-7a. Summary of Complete Suitability Analysis – Maryland

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Tributary/DSS	DSS acres	Yates/Baylor acres within DSS	Total Sanctuary Acres within DSS	Yates/Baylor acres within Sactuary within DSS	Suitable acres (applying only Absolute Criteria)			Suitable acres within Yates and Baylor			Suitable acres within designated sanctuary			Suitable acres within Yates or Baylor and within designated sanctuary			Restoration Target Range
					Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	
Magothy River	5,666	228	5,360	228	3,023	434	418	193	0	0	2,981	394	292	193	0	0	20-40
Severn River	10,019	1,980	7,205	1,305	2,894	1,292	2,290	1,411	147	220	1,806	617	2,257	869	56	220	190-290
South River	4,938	1,057	2,032	139	2,473	572	341	872	48	61	402	367	337	64	0	61	90-200
Rhode River	1,095	84	0	0	137	268	0	26	17	0	-	-	-	-	-	-	10-10
West River	1,943	136	0	0	635	456	0	33	23	0	-	-	-	-	-	-	10-20
Chester River	46,097	12,747	30,749	8,276	29,677	3,764	731	10,577	809	4	19,992	2,860	391	6,807	563	4	1,100-2,200
lower Chester River	23,001	6,344	20,854	6,001	16,493	1,364	4	5,179	562	4	15,240	1,352	4	4,935	554	4	500-1,100
upper Chester River	23,096	6,404	9,895	2,274	13,185	2,400	726	5,398	247	0	4,753	1,508	387	1,872	9	0	600-1,100
Corsica River	1,320	190	1,257	190	270	612	-	67	114	0	263	592	0	67	114	0	20-30
Eastern Bay	54,681	17,358	13,753	4,542	32,473	3,048	219	14,472	919	0	6,660	1,964	176	2,955	603	0	1,500-3,000
lower Eastern Bay	25,602	8,288	6,327	1,668	16,434	319	0	7,145	213	0	3,545	315	0	1,009	213	0	700-1,400
upper Eastern Bay	29,079	9,070	7,426	2,873	16,038	2,729	219	7,328	705	0	3,115	1,648	176	1,946	390	0	800-1,600
Choptank River	57,450	20,995	25,081	6,006	36,796	6,169	310	17,232	1,372	21	11,853	5,422	238	3,673	1,256	0	1,800-3,600
lower Choptank River	33,447	16,057	8,924	2,969	26,067	1,385	21	14,047	498	21	4,994	1,132	0	1,918	448	0	1,400-2,700
upper Choptank River	24,003	4,938	16,156	3,037	10,730	4,784	289	3,185	874	0	6,860	4,290	238	1,755	808	0	400-800
Harris Creek	7,045	3,479	4,302	1,993	5,612	0	1	3,245	0	1	3,182	0	0	1,776	0	0	300-600
Broad Creek	7,154	2,569	0	0	5,124	0	0	2,353	0	0	-	-	-	-	-	-	200-400
Little Choptank	18,580	4,092	8,837	1,697	8,434	3,005	2,086	1,851	910	841	5,440	27	0	1,215	0	0	400-700
Honga River	20,523	5,163	694	205	17,067	0	12	4,798	0	12	437	0	12	70	0	12	400-900
Potomac River	188,310	10,808	3,491	1,154	29,044	73,539	18,220	253	7,207	1,595	0	1,388	1,046	0	382	444	900-1,900
lower Potomac	82,981	991	0	0	9,527	23,982	2,528	0	483	258	-	-	-	-	-	-	90-200
middle Potomac	69,646	9,817	3,491	1,154	10,742	31,632	13,268	253	6,724	1,337	0	1,388	1,046	0	382	444	800-1,700
upper Potomac	35,684	0	0	0	8,775	17,925	2,425	-	-	-	-	-	-	-	-	-	-
St. Mary's River	9,024	2,461	1,228	52	1,362	2,280	3,402	341	1,092	610	0	172	717	0	0	46	200-400
Tangier Sound	101,237	20,192	6,237	1,242	77,628	93	305	17,384	0	13	6,234	1	1	1,065	0	11	1,800-3,600
lower Tangier	63,380	9,963	356	148	45,985	0	159	8,351	0	2	283	0	0	75	0	0	900-1,700
upper Tangier	37,857	10,229	5,881	1,094	31,642	93	147	9,033	0	11	5,951	1	1	990	0	11	1,000-1,900
Fishing Bay	19,508	4,434	0	0	17,825	0	0	4,404	0	0	-	-	-	-	-	-	400-800
Nanticoke River	11,757	857	9,702	525	8,824	1,275	0	779	69	10	6,937	918	142	447	69	10	70-100
Monie Bay	4,112	392	492	0	3,326	0	0	392	0	0	400	0	0	-	-	-	30-70
Manokin River	16,535	4,869	15,057	4,869	12,384	34	111	4,599	0	0	12,253	0	101	4,599	0	0	400-800
Big Annemessex River	6,907	1,220	648	0	5,495	0	0	1,220	0	0	419	0	0	-	-	-	100-200
Little Annemessex River	2,893	0	0	0	1,979	0	0	-	-	-	-	-	-	-	-	-	-
Patuxent River	26,931	5,662	9,855	1,859	530	3,359	12,364	153	986	2,817	64	731	6,138	5	222	1,161	500-1,000
lower Patuxent River	14,737	4,188	619	433	530	2,859	5,003	153	924	1,630	64	235	7	5	159	7	400-700
upper Patuxent River	12,193	1,474	9,236	1,426	0	500	7,361	0	63	1,188	0	495	6,131	0	63	1,154	100-300
Upper MD Mainstem	104,832	21,461	8,043	3,622	10,894	59,264	14,666	4,623	15,833	354	2,275	4,745	4	1,170	2,353	4	1,800-3,700
Middle West Mainstem	135,841	25,178	24,712	11,433	27,885	10,979	1,919	15,100	3,733	1,156	12,763	4,242	883	6,199	2,384	514	2,200-4,300
Middle East Mainstem	113,085	21,385	2,455	1,343	48,999	18,037	1,147	13,299	5,856	596	2,324	0	0	1,343	0	0	1,800-3,700
Lower West Mainstem	100,984	16,841	3,792	2,198	12,874	6,416	2,794	4,008	2,652	2,092	474	241	754	272	20	146	1,400-2,900
Lower East Mainstem	181,031	8,664	38,294	4,655	108,967	1,236	2	7,848	0	0	32,698	0	0	3,971	0	0	700-1,500

Table 5-7b. Summary of Complete Suitability Analysis – Virginia

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Tributary/DSS	DSS acres	Yates/Baylor acres within DSS	Total Sanctuary Acres within DSS	Yates/Baylor acres within Sactuary within DSS	Suitable acres (applying only Absolute Criteria)			Suitable acres within Yates and Baylor			Suitable acres within designated sanctuary			Suitable acres within Yates or Baylor and within designated sanctuary			Restoration Target Range
					Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	
Virginia Mainstem	752,766	36,136	0	0	309,604	4,695	151	29,108	0	0	-	-	-	-	-	-	3400-6800
Little Wicomico River	1,721	206	0	0	877	0	0	198	0	0	-	-	-	-	-	-	20-40
Cockrell Creek	777	23	0	0	228	0	0	11	0	0	-	-	-	-	-	-	2-4
Great Wicomico River	6,643	2,479	80	0	3,879	0	0	2,086	0	0	-	-	-	-	-	-	100-400
Rappahannock River	66,453	40,127	48	0	11,206	14,365	23,239	7,443	3,225	16,874	-	-	-	-	-	-	3,800-7,500
lower Rappahannock River	18,959	13,703	35	0	11,206	797	432	7,443	669	369	-	-	-	-	-	-	1,300-2,600
middle Rappahannock River	32,417	23,904	10	0	0	977	21,608	0	579	15,962	-	-	-	-	-	-	2,200-4,500
upper Rappahannock River	15,077	2,520	3	0	0	12,590	1,199	0	1,977	543	-	-	-	-	-	-	200-500
Corrotoman River	6,186	2,757	2	0	0	79	3,717	0	0	2,171	-	-	-	-	-	-	300-500
Piankatank River	12,879	7,097	7	0	9,047	307	107	6,210	0	0	-	-	-	-	-	-	700-1,300
Mobjack Bay	33,560	8,866	3	0	28,276	0	141	8,589	0	0	-	-	-	-	-	-	800-1,700
Severn River	3,810	193	0	0	2,316	0	0	165	0	0	-	-	-	-	-	-	20-40
York River	71,964	11,986	42	0	32,450	19,903	1,254	8,750	1,619	117	-	-	-	-	-	-	1,100-2,300
lower York River	53,992	11,226	25	0	32,450	6,087	541	8,750	1,112	115	-	-	-	-	-	-	1,100-2,100
upper York River	17,972	760	17	0	0	13,815	713	0	508	3	-	-	-	-	-	-	70-100
Poquoson River	2,160	180	1	0	1,236	0	154	180	0	0	-	-	-	-	-	-	20-30
Back River	4,849	182	1	0	3,311	0	0	182	0	0	-	-	-	-	-	-	20-30
Pocomoke/Tangier Sound	129,172	31,576	8	96	104,632	3,096	445	29,879	0	2	658	0	0	68	0	0	3,000-5,900
Onancock Creek	1,826	0	0	0	1,072	0	0	-	-	-	-	-	-	-	-	-	-
Pungoteague Creek	1,640	91	1	0	794	0	0	88	0	0	-	-	-	-	-	-	10
Nandua Creek	2,329	0	0	0	1,895	0	0	-	-	-	-	-	-	-	-	-	-
Occohannock Creek	1,918	130	0	0	1,318	0	0	130	0	0	-	-	-	-	-	-	10
Nassawaddox Creek	2,398	166	0	0	967	0	0	100	0	0	-	-	-	-	-	-	20
Hungars Creek	1,213	0	0	0	542	0	109	-	-	-	-	-	-	-	-	-	-
Cherrystone Inlet	1,402	0	0	0	668	0	0	-	-	-	-	-	-	-	-	-	-
Old Plantation Creek	633	0	0	0	423	0	0	-	-	-	-	-	-	-	-	-	-
James River	80,285	30,393	2	0	56,767	11,637	527	25,902	2,988	3	-	-	-	-	-	-	2,900-5,700
lower James River	33,713	9,578	1	0	27,207	0	219	9,381	0	0	-	-	-	-	-	-	900-1,800
upper James River	46,572	20,815	1	0	29,560	11,637	307	16,521	2,988	3	-	-	-	-	-	-	2,000-3,900
Elizabeth River	12,861	2,620	14 sites	0	4,144	101	1,106	2,176	0	42	-	-	-	-	-	-	200-500
Nansemond River	11,916	1,173	0	0	6,068	0	612	1,151	0	0	-	-	-	-	-	-	100-200
Lynnhaven Bay	3,147	990	57	0	1,666	0	0	251	0	0	-	-	-	-	-	-	40-150

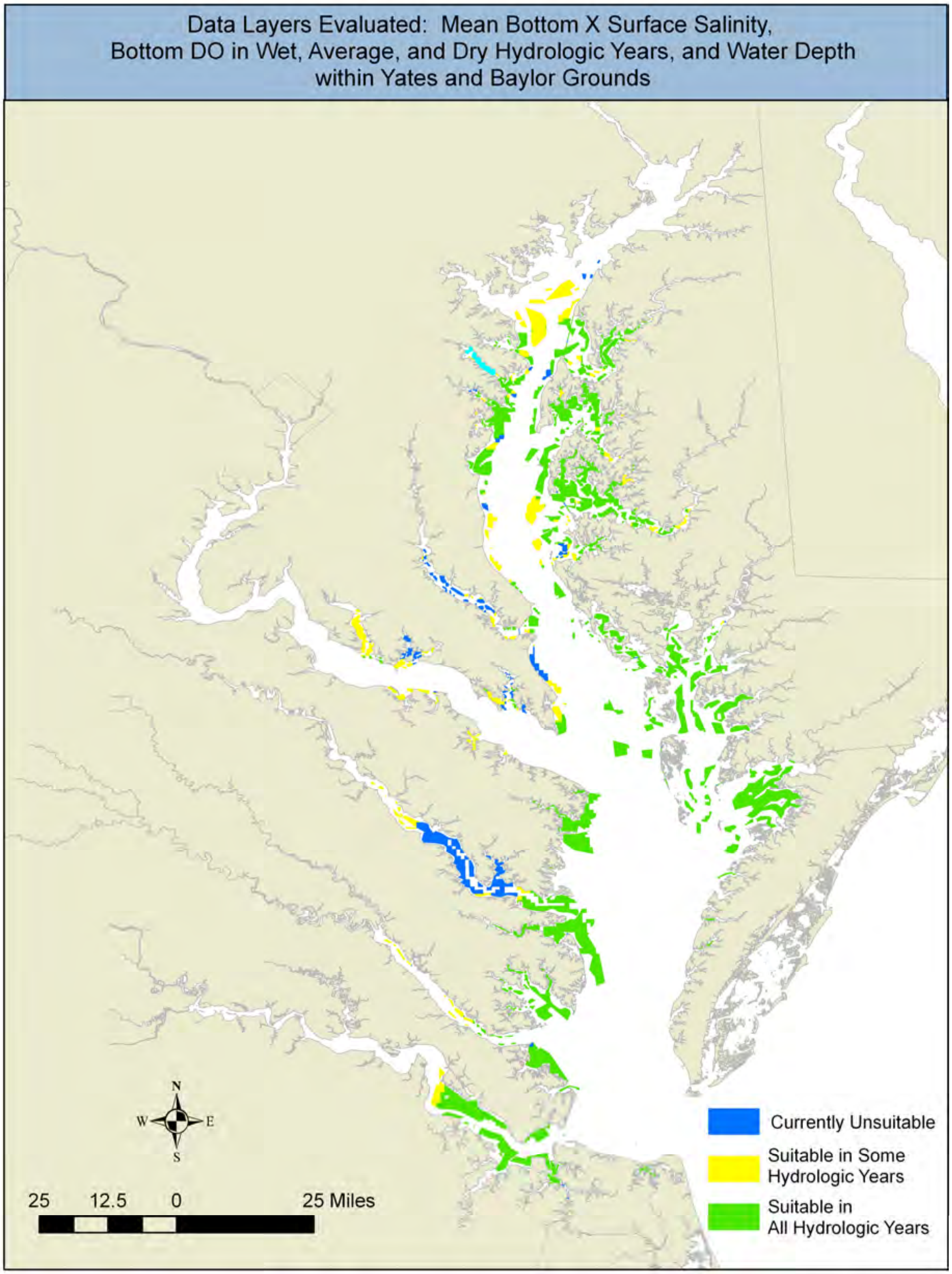


Figure 5-11. Suitability Analysis of Absolute Criteria within Yates Bars and Baylor Grounds.

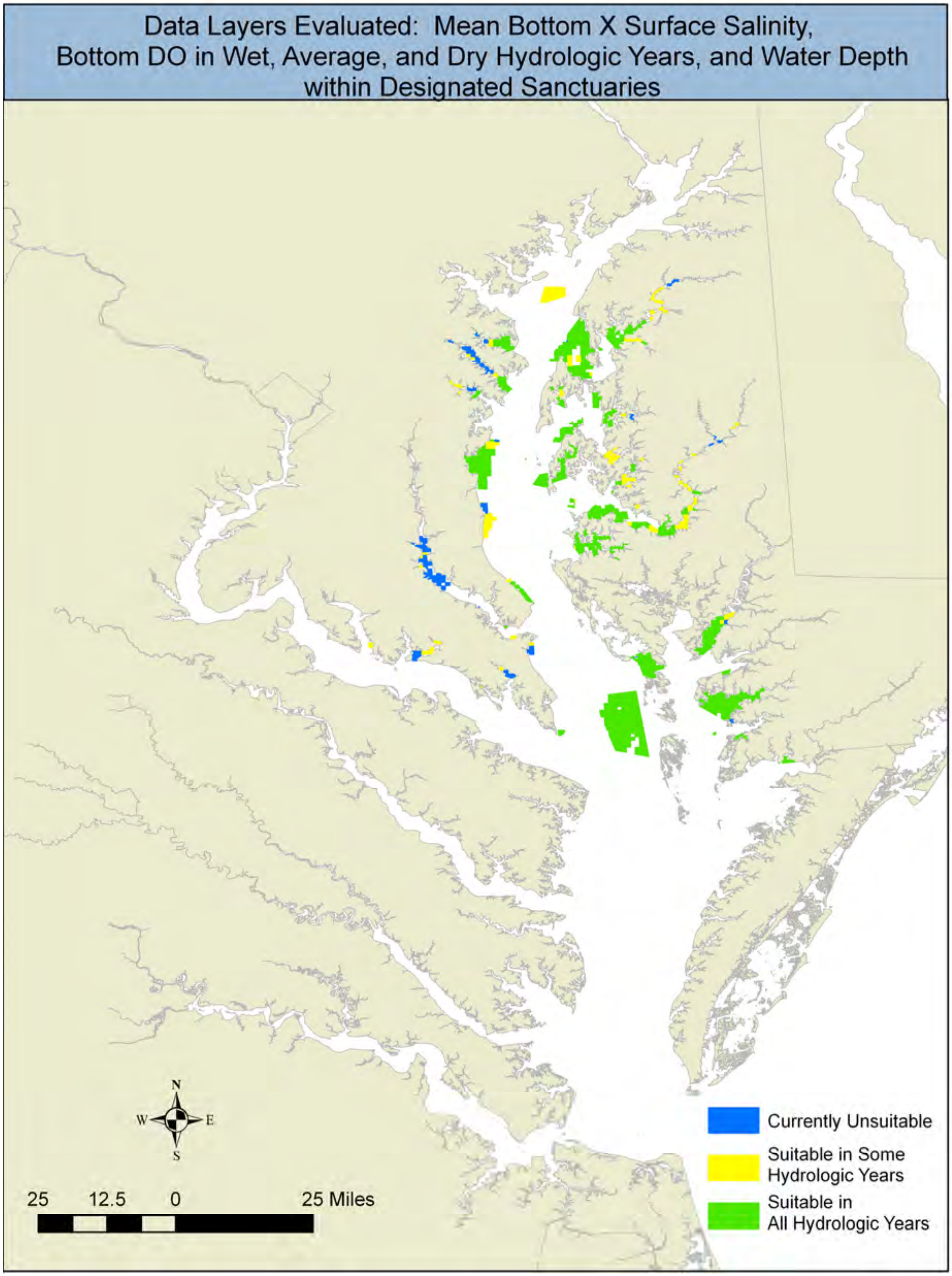


Figure 5-12. Suitability Analysis of Absolute Criteria within Designated Sanctuaries in Maryland

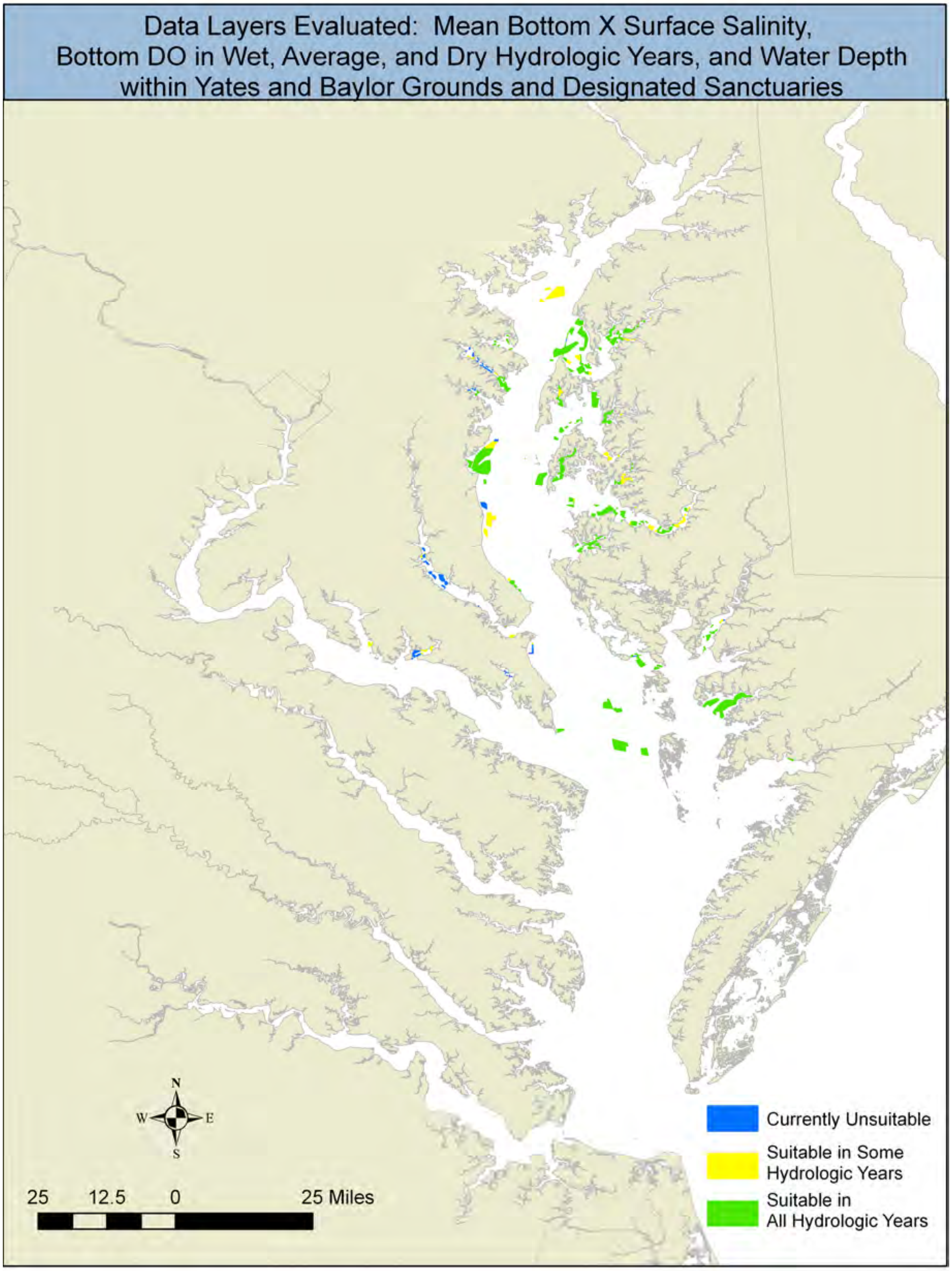


Figure 5-13. Suitability Analysis of Absolute Criteria within Yates Bars and Designated Sanctuaries in Maryland

5.5.3 LAYER 3- QUALITATIVE HYDRODYNAMICS RATING

Each tributary has its own unique hydrodynamics and currents that are driven by tides, tributary shape and size, freshwater input, benthic structures, and wind. For this evaluation, hydrodynamics is focused on retention of larvae and re-establishing habitat connectivity. However, hydrodynamics and retention also impact water quality and sedimentation in a tributary. These issues are discussed further in Section 5.5.4.

The hydrodynamic properties of the tributary or sub-region that have suitable acreage available to meet the estimated restoration target were evaluated. There are a number of small embayments and/or tributaries to the mainstem of the Chesapeake Bay that have low tidal exchange rates, and as a result, tend to retain planktonic oyster larvae at much higher rates than areas with higher tidal flushing rates. Such waters are called "trap estuaries" and, during the early implementation phases of the master plan, will allow restored oyster habitat areas within them a much higher chance to auto recruit and become sustainable than waters in more open systems.

Unfortunately, there is no comprehensive analysis of hydrodynamics for all tributaries of interest in the Chesapeake Bay. Therefore, the team compiled and considered all available information focused on tributary hydrodynamics and larval transport and recruitment. This enabled the tributaries to be rated based on the weight of evidence from different sources.

"With oysters now so depleted in most estuaries of the Atlantic coast of the U.S.A. (Kirby 2004), restoration strategies must be based on knowledge of hydrodynamics so as to concentrate reef restorations in areas of larval retention and seeded by sufficient spawning stock biomass to insure sustained recruitment (Mann 2000). For North Carolina's northern Pamlico Sound and the Maryland portion of Chesapeake Bay, spatial strategies of rebuilding of oyster stocks may be necessary, first establishing core retention areas of high spawning stock biomass and then subsequently extending oyster reef restorations further and further from the margins of these already restored areas." (Powers et al. 2009).

5.5.3.1 Compiled Hydrodynamics Data

Information in Layer 3 is derived from existing literature, reports, monitoring data, and historic information as well as modeling results. This information is used here to provide a hydrodynamic rating for each tributary or sub-region. Compilation of this data provides evidence to identify areas in the bay with the greatest potential to retain larvae and allow successful recruitment of oysters. The information and data are described in Table 5-8.

The master plan compiled and considered all available information focused on tributary hydrodynamics, larval transport, and recruitment to determine a qualitative hydrodynamic rating.

Table 5-8. Description of Information and Data Used to Determine Qualitative Hydrodynamic Rating

Existing Literature, Reports, Monitoring Data, and Historic Information

1. Scientific Literature (Column D and E in Table 5-9a and b).

A number of studies were referenced in the literature that focused on retention times in various Chesapeake Bay tributaries. Shen and Wang (2007) investigated the age of water of the Rappahannock, Potomac (106-214 d), York (32-136 d), and James (50-108 d) Rivers. Shen and Lin (2006) estimated mean residence time of the James River at 95 d. Shen and Haas (2004) likewise estimated the mean residence time of the York River at 100 d. Breitburg et al. (2003) looked at the hydrodynamics of the Patuxent River as it impacts dissolved oxygen patterns. Also for the Patuxent River, Hagy et al. (2000) estimated mean residence time at 68 d. The Patuxent was also the focus of Testa and Kemp (2008). This study looked at physical transport processes within the river. Manning and Whaley (1954) focused on the hydrodynamics and larval transport processes of the St. Mary's River. Their work identified three distinct regions of the river based on circulation, larval abundance, and spatfall. Larval retention and hydrodynamics of Broad Creek was studied in Boicort (1982) and Seliger et al. (1982). Zones of spawning, transport, and larval setting were identified. Lipcius et al. (2008) investigated the hydrodynamics and metapopulations of the Lynnhaven River and identified larval source and sink areas. None of these analyses used similar methods making it difficult to compare results.

From the few available sources of residence time estimates made for large tributaries and the estimates from Wazniak et al. (2009) for small tributaries it takes a much longer time for water to exit the larger systems compared to the smaller tributaries (Shen and Wang 2007, Shen and Haas 2004, Gay and O'Donnell 2009, and Shen and Lin 2006). It is evident that the large and small tributaries have retentive properties on different scales and this fact has been considered in the analysis of information.

2. Historical Spatsets (Column F in Table 5-9a and b)

Historical spatset data provides information on the larval production of a tributary or region prior to recent oyster population degradation. Krantz and Meritt (1977) compiled MD historical oyster spatset data for the period 1939 to 1975. This work provided an average spatset by region for 1939 -1965 and 1966-1975. The average spatset for 1939-1965 was selected as representative of historical oyster spatset. Although, harvesting was already impacting oyster populations at this time and older data may be available for some areas, this was the most comprehensive data available for Maryland. Kimmel et al. (under review) further analyzed MD's historical spatset record and identified prime bars that had consistently high spatset with low variability as well as regions of the Bay where the highest performing bars were located. This information is noted in Tables 5-9a and b. Historical spatset data for Virginia was compiled from the VIMS archives by VIMS, but was limited in spatial coverage. Average spatsets were calculated to be comparable to MD data. However, VA spatset data was only available starting in 1947. Compiled spatset records are in C-1, Attachments B and C. Table 5-9a and b provides the average spatset for each tributary or sub-region and the assigned rating. The data was rated as follows:

High: > 100 spat/bu	*Medium: 50-99 spat/bu*	*Low: < 50 spat/bu*

3. Current restoration activities

NAO has been actively restoring oyster resources in Lynnhaven and Great Wicomico Rivers. Research and monitoring in these two tributaries have identified the retentive properties of these two systems. The restoration achieved in these two tributaries was considered in determining the final ratings of the Lynnhaven and Great Wicomico (Lipcius et al. 2008; Schulte et al. 2009a).

In Maryland, restoration efforts between 1997 and 2001, have shown that oysters can grow and survive in the Chester, upper Choptank and upper Patuxent Rivers (Paynter 2008).

4. Best Bar Identification by Maryland Department of Natural Resources and Historical Spatset Data (Column G in Table 5-9a and b)

Jones and Rothschild (2009) evaluated 1985 to 2007 MDNR Fall Survey Data in various forms. This effort identified the most productive bars or 'Best Bars' as those with market oyster abundance in the top 10% (>70 market oysters/bu) of all bars surveyed in four or more years over the study period (1996-2007). Tributary production in terms of spatset was also considered in the evaluation.

The master plan takes into consideration whether tributaries contain a 'Best Bar', and if so, how many (Table 5-9a and b). Also, we valued the tributaries that had the highest spatsets over the period of record. (The tributaries that are identified in Table 5-9a and b as a 'Top 10 Tributary for Spat Set' fell in the top 10 for all metrics compiled in Jones and Rothschild (2009). Those that fell within the Top 10 for some metrics of Jones and Rothschild (2009), but not others were noted as 'ranked high for spat sets' in the matrix.)

Comparable recent bar ratings were not available for Virginia oyster bars.

Modeling Results

5. Small Tributary Flushing Times (Column H in Table 5-9a and b)

The residence time of small tributaries was evaluated by Wazniak et al. (2009) specifically for the master plan. This effort focused on small tributaries and used the flushing time as a measure of retention. The retention of oyster larvae in a system depends upon the flushing rate (or residence time) of the water in the system as well as the amount of suitable settlement habitat. For small tributaries an estimate of the flushing time was developed using the adjusted intertidal volume method. This method takes into account surface area, volume, and depth, as well as tidal forcing. The analysis was limited to small tributaries that do not have significant freshwater input or a well-defined gravitational circulation. The size of the large tributaries violated the assumptions made to perform the small tributary analyses and therefore prohibited an identical analysis. Significant freshwater flow into the large tributary induces density-driven (gravitational) circulation. The small tributary analysis assumes that tidally-driven circulation is the main component of tributary flow patterns (Wazniak et al. 2009).

A "tidal flushing index" (T_f in days) was determined for each of the 36 small tributaries considered. Flushing times for each tributary were scored using the following criteria:

High: T_f>5	Medium: T_f 3-5	Low: T_f<3

6. Geomorphology (shape) of Small Tributaries (Column I in Table 5-9a and b)

The Small Tributary Flushing Times methodology did not take into consideration the shape of the tributary and therefore, in cases of long and/or branched tributaries, the retentiveness was underestimated. For tributaries exposed to large fetches and therefore, wind-driven flushing, the method tends to overestimate flushing time.

Shape was qualitatively considered along with the flushing time scores in the master plan analysis. Tributaries with long and/or branched morphology were noted. It is expected that these tributaries would likely have flushing times greater than those calculated using the small tributary flushing times method. Tributaries with wide, open configurations would likely have reduced flushing times. See Table 5-9a and b for the evaluation of tributary shape.

Analyses of larval transport were made for the PEIS and can be used as a proxy for the influence of hydrodynamics on larval transport (North et al. 2006, 2008). The greater the retention of larvae in a tributary in which larvae were produced was used to signify potentially greater retentive hydrodynamic properties. This is not a perfect proxy for hydrodynamics because the amount of settlement in a system depends not only on hydrodynamics but also on biology and the amount of habitat within a system. The modeling used estimates of the existing quantity of oyster habitat within the system. Therefore, tributary or sub-region with a larger estimated area of habitat would be rated as more successful for larval recruitment and, in turn, larval retention, because it generated more larvae (in the model) and contained more habitat upon which the larvae could settle in the DS. Despite the uncertainties and the fact that the model is currently undergoing verification, the model provides the best and most consistent knowledge available of larval transport and hydrodynamics for all of the large tributaries in the Chesapeake Bay. Various metrics were applicable to this evaluation and are discussed in the following sections.

7. Larval Transport Modeling- Self-recruitment Metric of Large Tributaries (Column J of Table 5-9a and b)

The master plan uses the self-recruitment metric compiled by North et al. (2008) for the large tributaries (Chester, Eastern Bay, Mainstem- MD and VA, Choptank, Little Choptank, Patuxent, Potomac, Tangier, Rappahannock, Piankatank, York, Mobjack Bay, and James). This metric represents the percent of successfully settled particles that settled within the basin of origin and is based only on particles that successfully settled. The number of particles that did not successfully settle in the basin was not considered in determining the metric. Higher scores represent more retention of particles within the basin where they originated.

Tributaries were scored by this metric using the following criteria:

High: $\geq$80	Medium: 50-79	Low: <50

8. Larval Transport Modeling- self-recruitment of sub-basins (Column K of Table 5-9a and b)

Given that the initial larval transport modeling efforts did not evaluate all tributary or sub-region, North and Wazniak (2009) prepared a companion document for the master plan (Appendix C-1, Attachment 1-E) to provide additional information about larval transport on the sub-basin scale. They calculated a self-recruitment metric for each tributary or sub-region. The metric indicates the percentage of all released particles representing oyster larvae that successfully settled within the same basin in which they originated. The values calculated for this self-recruitment are lower than those determined by North et al. (2008) because the North and Wazniak (2009) metric was based on 'all released particles', including those that did not find suitable habitat upon which to settle, rather than 'all successfully settled particles.' Basing the metric on 'all released particles' effectively diluted the North and Wazniak (2009) percentages. This does not reduce the utility of this metric, but prevents a direct comparison with the results of North et al. (2008).

Tributaries were scored by this metric using the following criteria:

High: >60	Medium: 40-59	Low: <40

9. Larval Transport Modeling- Particle Accumulation Zones (Column L of Table 5-9a and b)

North and Wazniak (2009) and North et al. (2006) investigated the spatial accumulation of particles as modeled by the larval transport model and identified accumulation zones. The accumulation zones represent areas of the bottom where it would be expected that the greatest density of larvae would collect. They defined two zones representing the densest concentrations: 1) particle concentrations greater than the 75th percentile of all particle concentration values and 2) particle concentrations greater than the 90th percentile of all particle concentration values. For restoration purposes, these accumulation zones provide an estimate of locations where habitat structure should be placed to provide settlement structure for the larvae. These zones also suggest where hydrodynamic properties may be working to retain larvae. We focused on the 90th percentile accumulation zones as most likely estimates of where high densities of larvae may concentrate. The GIS coverage of 90th percentile accumulation zones was used to compute the area within a tributary or sub-region that was estimated to be a 90th percentile zone. This allowed the percent coverage of a tributary or sub-region that was estimated to be a 90th percentile zone to be calculated.

Tributaries were scored by this metric using the following criteria:

High: $\geq$20% of a tributary or sub-region's area was projected to be a 90thpercentile accumulation zone	Medium: $\geq$10-19	Low: <10

The data for the hydrodynamics analysis is summarized in Table 5-9a and b. Column A lists the segment evaluated. Column B and C contain salinity information. Columns D through L provide the hydrodynamic information compiled. All cells highlighted in 'green' denote a 'high' rating for that individual data set. Cells highlighted in 'yellow' represent 'medium' ratings and 'blue' represents low ratings. Column M provides the overall qualitative hydrodynamic rating for the segment or tributary. Selecting sites with good larval retention is a key component of bay oyster restoration. Small tributaries are rated in their entirety. Large tributaries were assigned a final rating in their entirety and as sub-segments because the information highlighted that hydrodynamics of large tributary sub-basins did not always reflect the hydrodynamics of the whole tributary due to interactions within sub-basins. Larval transport, circulation, and retention should be a particular focus for further investigation, specifically within sub-segments of larger tributaries, prior to development of restoration plans.

Table 5-9a. Master Plan Summary of Hydrodynamic Data – Maryland

A	B	C	D	F	G	H	I	J	K	L	M
Distinct Sub-Segment (DSS)	**Salinity > or < 12 ppt**	**Scientific Investigations**	**Residence time/Age of Water**	**Historic Spat Set**	**Number of MD Best Bar and Rankings**	**Small trib flushing time score***	**Geomorphology (shape- long and/or branched)+**	**Self-recruitment of large tributaries*****	**Self-recruitment of sub-basins****	**Percent of DSS estimated to be 90% Accumulation Zone**	**Qualitative Hydrodynamic Rating**
Magothy River	<			No Data		5.95	possibly			0%	M
Severn River	<			16.9	1	8.51	Y			7%	H
South River	<			19.9	1	5.98	Y			2%	H
Rhode River	<			19.9		3.8	possibly			0%	L
West River	<			19.9		3.2	possibly			0%	L
Chester River	<				2-'ranked 'Top 10 for production'			81			H
Chester-lower	<			12.4	(1)				50.9	27%	H
Chester-upper	<			13.4	(1)				54.5	19%	M
Corsica River	<			10-25		3.87	Y			0%	L
Eastern Bay	<	Location of prime bars and region of consistently high spatsets (Kimmel et al., in review).			4- 'ranked high for spat sets and Top 10 for production'			62.5			H
Eastern- lower	<			122.4	2				15.4	16%	H
Eastern- upper	<			113.6	2				48.1	21%	H
Choptank River	~	Seliger et al. (1982) supports retention. Lower- location of prime bars and consistently high spatsets (Kimmel et al., in review).			'ranked Top 10 for production'			77.2			H
Choptank-lower	>			71.1					42.8	29%	H
Choptank-upper	~			26.8					68.3	13%	H
Harris Creek	~	Within region of consistently high spatsets (Kimmel et al., in review)		203.6	1- 'Top 10 Tributary for Spat Set and Production'	4.26	possibly			19%	H
Broad Creek	~	Seliger et al. (1982) identified zones of spawning, transport, and setting. Prime bar (Kimmel et al., in review).		160.5	3- 'Top 10 Tributary for Spat Set and Production'	4.1	Y			20%	H
Little Choptank	>	Location of prime bars and region of consistently high spatsets (Kimmel et al., in review).		136.8	4- ranked 'Top 10 for production and high for spat set'	4.01	possibly	37.3	29.2	13%	H
Honga River	>	Location of a prime bar (Kimmel et al., in review).		166.9	ranked high for spat set	3.01	N		74.8 (as part of upper Tangier)	7%	M
Potomac River	~	Shen and Wang (2007) identified long residence time, likely due to size of Potomac. Prime bar located at mouth (Kimmel et al, in review)	106-214 d		ranked high for spat set			93.7			M
Potomac-lower	>			106.3					19.8	17%	M
Potomac-middle	~			36					40.1	16%	L
Potomac-upper	<			8.2					43.4	8%	L
St. Mary's River	>	Manning and Whaley (1954) identified zones of spawning, transport, and setting. Prime bars (Kimmel et al., in review)		150.7	Top 10 Tributary for Spat Set and Production'	6.17	Y			10%	H
Tangier Sound	~	Location of prime bars (Kimmel et al., in review).			ranked 'Top 10 for Spat Set'			96.7		16%	H
Tangier- lower	>			47.7				96.7 (as part of Tangier)	68.6		H
Tangier- upper	~			108.9				96.7 (as part of Tangier)	74.8		H
Fishing Bay	~			55.9		2.79	N	96.7 (as part of Tangier)	74.8 (as part of upper Tangier)	20%	M
Nanticoke River	<			33.3			Y	96.7 (as part of Tangier)	74.8 (as part of upper Tangier)	13%	M
Monie Bay	<			33.3		2.05	N	96.7 (as part of Tangier)		3%	L
Manokin R.	>	Location of prime bar (Kimmel et al., in review).		108.8	ranked high for spat set	1.88	N	96.7 (as part of Tangier)		13%	H
Big Annemessex R.	>			78.1		2.03	N	96.7 (as part of Tangier)		7%	M
Little Annemessex R.	>			46.8		1.71	N	96.7 (as part of Tangier)		14%	L
Patuxent River	~	Hagy et al. (2000)- full Patuxent has moderately high residence time	68 d					67.2			M
Patuxent- lower	>			18.65					22.1	28%	M
Patuxent-upper	<			18.2					19	0%	L
Mainstem-Upper	<			23.9				84.7	24.3	18%	L
Mainstem- Middle West	~			7.7				84.7	21.4	29%	M
Mainstem-Middle East	~			92.3	1			84.7	29.4	17%	M
Mainstem- Lower West	>			40.4	1- ranked high for spat sets			84.7	11.4	20%	M
Mainstem-Lower East	>			209.3	ranked high for spat sets			84.7	35.1	8%	M

Table 5-9b. Master Plan Summary of Hydrodynamic Data – Virginia

A	B	C	D	F	G	H	I	J	K	L	M
Distinct Sub-Segment (DSS)	Salinity > or < 12 ppt	Scientific Investigations	Residence time/Age of Water	Historic Spat Set	Number of MD Best Bar and Rankings	Small trib flushing time score*	Geomorphology (shape- long and/or branched)+	Self-recruitment of large tributaries***	Self-recruitment of sub-basins**	Percent of DSS estimated to be 90% Accumulation Zone	Qualitative Hydrodynamic Rating
Mainstem- Virginia	>			ND				72.7	5.4	6%	L
Little Wicomico R.	>			ND		2.87	Y			1%	L
Cockrell Creek	>			ND		4.05	Y			0%	L
Great Wicomico R.	>	VA Oyster Atlas (Mann et al. 2009) identifies as trap estuary		286.9		5.56	Y		12.1	10%	H
Rappahannock River	>	Shen and Wang (2007) identified longest residence time of 4 major VA tributaries	110-193 d	ND				92.1			H
Rappahannock- lower	>								34.3	35%	H
Rappahannock- middle	>								49.2	40%	H
Rappahannock- upper	~								68.7	32%	H
Corrotoman River	>			qualititative evidence for high^		5.3	Y			5%	H
Piankatank River	>	VA Oyster Atlas (Mann et al. 2009) identifies as trap estuary		57.8		5.62	Y	69.4	40.6	16%	H
Mobjack Bay	>			ND		3.73	possibly	92.3	45.4	14%	H
Severn River	>			ND		2.34	Y			9%	L
York River	~	Shen and Wang (2007) and Shen and Haas (2004) identify fairly long residence time	32-136 d, 100 d	49.2				93.7			H
York- lower	>						possibly		18	17%	H
York- upper	~						Y		81.3	38%	H
Poquoson River	>			ND		1.61	Y			3%	L
Back River	>			ND		1.23	Y			1%	L
Pocomoke/Tangier Sound	>	Location of a prime bar (Kimmel et al., in review)		ND					68.7	15%	H
Onancock Creek	>			ND		1.56	Y			0%	L
Puncoteague Creek	>			ND		1.33	Y			0%	L
Nandua Creek	>			ND		1.4	N			0%	L
Occohannock Creek	>			ND		1.44	Y			0%	L
Nassawaddox Creek	>			ND		1.07	Y			0%	L
Hungars Creek	>			ND		0.87	possibly			0%	L
Cherrystone Inlet	>			ND		1.03	N			0%	L
Old Plantation Creek	>			ND		0.57	possibly			0%	L
James River	~	Boon et al. (2001) documents retention between upper and lower James segments. Shen and Lin (2006) and Shen and Wang (2007) calculate residence times.	50-108 d, 95	50.4				98.4			H
James- lower	>								49.7	35%	H
James- upper	~								47.8	34%	H
Elizabeth River	>			ND		4.98	Y			2%	H
Nansemond River	>			ND		1.54	Y			14%	L
Lynnhaven Bay	>			ND		0.71	Y			0%	H

5.5.3.2 Assignment of Qualitative Hydrodynamics Rating to each Tributary or Sub-region

The 9 data sets were compiled for each tributary or sub-region (Table 5-9a and b) and an overall hydrodynamic qualitative rating assigned as high (H), medium (M), and low (L). In determining the qualitative ratings, any documentation of hydrodynamics or retention including historic and current spatset, MDNR Best Bar analysis, current restoration activities, and retention documented by scientific literature was given the greatest weight, followed by the modeling analyses. The flushing rate determination was given lowest priority because of recognized short-comings, but was still valuable for some tributaries that had no other available information. The quantity and quality of information was variable across the tributary or sub-region. Therefore, general rating guidelines were established to provide for a uniform evaluation:

- A tributary or sub-region was assigned a 'High' if it had data and modeling that confirmed high retention or multiple 'High' data sources that provided evidence to support 'Medium' modeling ratings. If there were no data or documentation available for a tributary or sub- sub-region some combination of high and medium modeling scores were assigned a 'High'.
- A tributary or sub-region was assigned a 'Medium' if there was at least one data set supporting retention in addition to low or medium modeling, or if the tributary or sub-region had 'High' modeling scores with 'Low' data or other 'Low' modeling scores.
- A tributary or sub-region was assigned a 'Low' for 'Low' data scores, or for 'Low' or 'Medium' modeling scores in conjunction with 'Low' or no data scores.

The assigned qualitative hydrodynamic rating for each segment or tributary is listed in Column M of Table 5-9a and b. Attachment 1-A in Appendix C-1 provides an explanation of the rating assigned to each tributary or sub-region.

5.5.4 LAYER 4- QUALITATIVE DATA

Layer 4 is the final layer to be considered in the formulation analysis. This layer includes factors that influence oyster recovery in a given water body, but are not adequately quantified to apply as a complete screening layer on the Bay-wide scale of the master plan. The factors outlined in Table 5-10 and discussed in this section were considered to the extent possible in the master plan, but should be considered further during the development of individual tributary plans. For some, data gaps can be cost-effectively addressed on the tributary level, but not at a Bay-wide scale.

The current knowledge of these factors is discussed below. Quantitative data for these factors applicable to oyster restoration is limited. Where available, the master plan presents the data in GIS generated maps. It is not cost-effective or appropriate for the master plan to attempt to compile this data at a Bay-wide scale. Therefore, it is recommended that each of these factors be considered and investigated in detail when individual tributary plans are being developed to support future decisions about where to focus and locate future restoration efforts. The maps presented in this section indentify "information gaps" based on the most current information to help target future data collection efforts.

Table 5-10. Qualitative Data Layers

Criteria To Be Further Considered During Development of Specific Tributary Plans	
Physiochemical	freshets, local water quality (DO, salinity, temperature)
Physical	bottom that can support oysters; water flow; sedimentation
Biological	phytoplankton resources; harmful algal blooms; location and quantity of existing broodstock
Regulatory	harvesting closure areas; sanctuary locations
Miscellaneous Considerations	watershed suitability; position relative to other estuarine habitats

5.5.4.1 Freshets

Another important aspect of site selection is to choose sites that are less prone to warm-season freshets. Upriver oyster resources are typically exposed to a greater risk from freshets. As evidenced by the investigations into the impacts of Agnes (Section 4.6.3), the vulnerability of a tributary to the development of freshets is closely tied to the amount of overland runoff a tributary receives. Generally speaking, western shore tributaries receive larger freshwater inputs than eastern shore tributaries and are therefore more likely to experience freshets. The potential for freshets to occur should be further considered when developing individual tributary plans. The master plan recommends avoiding areas that are most likely to be affected by freshets

5.5.4.2 Local Water Quality

Salinity, DO, and temperature have been discussed extensively in Sections 4.2 and 5.2.1 as well as the Physiochemistry White Paper in Appendix C-1, and applied in the master plan formulation in Section 5.5.1. However, it is still necessary to consider local water quality once a tributary is selected for restoration. The data used in the master plan was from a network of monitoring stations distributed across the Bay. Additional data, specific to the selected tributary, may be available on the smaller, tributary scale for use in the tributary plan development. Further, a data record that spans a longer timeframe is likely available for a local region and can be considered at that time.

5.5.4.3 Bottom that can support oysters

NOAA and Maryland Geological Survey (MGS) are working to map and characterize the current Bay bottom with respect to substrate. Table 5-11 summarizes all the areas that have recently undergone bottom surveys. The most recent complete investigation to characterize the substrate covering the Bay bottom in Maryland is the Maryland Bay Bottom Survey (MBBS) conducted from 1974 – 1983 by MDNR (MDNR 1983). Bottom type designations include cultch, mud, sand, mud with cultch, sand with cultch, hard bottom and leased bottom. A comparable dataset in Virginia is the geo-referenced bottom probe surveys conducted by Dexter Haven of VIMS in the 1970s and Jim Wesson of VMRC in the 1990s. These surveys provide data verifying bottom sediment type in Virginia and designate bottom as oyster rock, shell and mud, shell and sand,

Table 5-11. Bottom That Has Been Surveyed by NOAA and MGS Using Seabed Classification and/or Seismic Profiling

Region	Total surveyed acreage	Total Acreage with confirmed seabed classification and/or seismic profile	Surveyed bars
Chesapeake Mainstem	13909	10274	Hooper Island Reef, Talyor's Island Reef, Calvert Cliffs Reef, Sandy Point South, Memorial Stadium Reef, Man-O-War Shoal, Six Foot and Nine Foot Knolls, Sharps Point Montrose grounding, Summer Gooses Reef 1, Hills Point, Point Lookout Bar, Calver Cliffs powerplant, Sharps Island, West River (Three Sisters), James Island
Magothy	2888	0	Magothy River
Rhode-West	9487	0	Rhode West River
Anne Arundel shore	3857	0	Three Sisters, Hackett Point, Holland Point
Baltimore Harbor	3640	3640	Site170, Sollers Point, Sparrows Point, Dead Ship Anchorage
Chesape Bay, Dorchester Co	887	887	Summer Goose All
Chesapeake Bay, St. Marys_Co	93	93	Pt. No Point
Chester River	13437	2133	Spaniard Point, Emory Hollow, Ringgold Point, Strong Bay, Old Field and Hells Delight, Love Point, Corsica River, Copper Hill, Drum Point, Ebb Point, Hudson, Piney Point, Willow Bottom, East Neck Bay Bar, East Neck Bay Bar, Kent Narrows, Chester/Corsica River, Upper Chester River
Choptank River	27448	27156	Blunt Reserve, Mill Dam and Dixon, Lighthouse (Versar), Tilghman Wharf (Versar), Corners Wharf A1 (Versar), Logans Hill Benoni (Versar), Todd Point (Versar), Todd Point A1 (Versar), Sandy Hill (Versar), Church Hill (Versar), Cook Point (Versar), Turnrow (Versar), Sands (Versar), Todd Point, Cook Point Airplane_Site, Todd Point A2 (Versar), Todd Point (Versar),Irish Creek Addition (Versar), Corners Wharf (Versar), Irish Creek (Versar), Fox Hole (Versar), Bachelor Point (Versar), Todd Point 2 (Versar), France (Versar), Benoni (Versar), Logans Hill (Versar), Royston (Versar), Great Marsh (Versar), Back Shore (Versar), Back Shore 2 (Versar), Mares Point (Versar), Brannock A1 (Versar), Flatty (Versar), Bamings Cove (Versar), Castle Haven (Versar), Irish Creek upriver (Versar), Upper Choptank, Cook Pt Sanctuary, Todd Pt Sanctuary, Beacons (Verasr), Howells Pt (Versar), Chlora Pt Howell Pt, Bachelor Pt., Wild Cherry Tree, Sandy Hill, Harris Creek part 1, Harris Creek part 2, Harris Creek part 3, Harris Creek part 4, Harris Creek part 5, Broad Creek, The Black Buoy, Upper Choptank NOAA , Kirby, Bolingbroke Sand , Green Marsh, Shoal Creek
Eastern Bay	2634	2071	Cox Neck, Cox Neck Bar, Bugby Bar, Mill Hill
Hooper Strait	6308	5646	Hooper Strait Bar, Applegarth
Little Choptank River	7475	7475	Little Choptank Bar, Slaughter Creek, Little Choptank mouth part 1, Little Choptank mouth part 2, Little Choptank mouth part 3, Little Choptank mouth part 4
Magothy River	1439	478	Magothy River rubble, Magothy River rubble, Cypress Creek and Dividing Creek, Upper Magothy River, Sillery Bay tributaries, Parks Point, Ulmstead
Mainstem	102	102	Hackett Reef
Nanticoke River	183	183	Roaring Point
Patapsco River west	126	126	Masonville Cove
Patuxent River	8553	8553	Kitts Marsh, St. Leonards Creek Dominion Pipeline, Cedar Point, Hallowing Point (Holland Point), Cedar Point long lines, Broad Neck, Trent Hall Bar, Buzzard Island, Trent Hall, Hallowing Point (Holland Point), Bramleigh Creek, Patuxent mouth, south, Patuxent mouth, north, Patuxent River AEZ South, Patuxent River AEZ North
Poplar Island	3673	3673	Poplar Island, NOB 8 and 11, Poplar Island
Potomac River	6381	131	Calvert Bay Bar, Piney Point
Eastern Bay/Prospect Bay	157	0	Prospect Bar
Severn River	4128	3637	Asquith Creek, Chinks Point, Tolly Point, Sharp Pt, Severn River, Asquith Creek, Chinks Point, Tolly Point, Peach Tree Orchard and Weems Creek,Sharps Point,Severn River South,Tolly Point
South River	101	0	Larrimore Pt,Thunder and Lightning,Duvall
Tangier Sound	13024	13024	Deal Island Reef, Tangier Triangle Reef, Crisfield Reef, Drum Point, Deal Island Reef (proposed), Tangier - Bloodsworth south, Tangier - Bloodsworth north, Tangier - Deal north, Tangier - Deal south, Halls Point Bar, Little Annemeesex - Tangier Sound, Big Annemessex - Manokin, North Smith Island - Tangier Sound
Tred Avon River	1848	1848	Camden Point (Versar),Tred Avon River,Mares Point
Trippes Bay (Dorchester Co.)	1112	0	Hills Point
Wicomico River	414	414	Evans Bar
Total Area	**133304**	**91544**	

buried shell, sand, sand and mud, clay, gravel, stones, not surveyed, uncoded, occupied, and barren bottom. Figure 5-14 provides a map of the bottom types identified in the existing Baywide surveys that could support oysters: cultch (MD), oyster rock (VA), sand (MD and VA), sand with cultch (MD) or shell (VA), sand and mud (VA), mud with cultch (MD) or shell (VA), hard bottom (MD), buried shell (VA), not surveyed (VA), and barren bottom (VA) as well as the Yates and Baylor boundaries for comparison. Currently a small portion of what was once hard substrate remains in the Chesapeake that is suitable for oyster larval settlement. Further, it needs to be recognized, that at least in Maryland, this substrate mapping is 30-40 years old and the current habitat is even more reduced than Figure 5-14 shows. For this reason, a layer representative of suitable bottom based on the existing Baywide data was not included in the absolute criteria even though it is a critical factor to restoration. The bottom mapping being completed by NOAA and MGS will provide current maps of bottom habitat. Bottom surveys should be completed for each targeted tributary or sub-region prior to restoration to identify current hard substrate and other bottom features. Those areas in a tributary or sub-region that have remaining good substrate should be considered first for restoration. The investment needed to achieve restoration goals will largely be driven by the amount of hard substrate that needs to be constructed.

5.5.4.4 Water flow

As discussed in Section 4.4.4.1 proper water flow over an oyster bar is necessary to maintain a sediment free bar, provide food, and carry away waste products. Further discussion on this topic is also available in the Growth and the Physical Characteristics White Papers.

It will be important to consider the positioning of individual bars within the Bayscape as well as local currents and water flows when selecting specific restoration sites and designing individual tributary plans.

5.5.4.5 Sedimentation rate

Sediment poses a significant threat to oysters. Oyster growth must exceed sedimentation rates in order for oysters to survive. In the absence of a good representative data set for shallow water habitats, past restoration efforts have highlighted some areas that are prone to high sedimentation on oyster bars: Bailey's and Kitts Marsh bars in the Patuxent River experienced heavy sediment accumulation while France bar in the Choptank River was particularly unaffected by sediment (Paynter 2008). Sedimentation poses a problem to these areas based on past restoration efforts. Sedimentation rates at potential oyster restoration sites should be investigated during the development of individual tributary plans. (Sediment is discussed in Section 4.1.1. CBP TSS data and a map of sampling stations are in Appendix C-5).

5.5.4.6 Phytoplankton resources

Phytoplankton data spanning 1980 to 2009 has been compiled from the CBP and MDR. These data are available in Appendix C-2 Attachment 2-B, but were not used quantitatively because they were not comprehensive enough to be applied in all areas being evaluated. Phytoplankton resources (including the compiled data set) should be further considered when individual tributary plans are being developed.

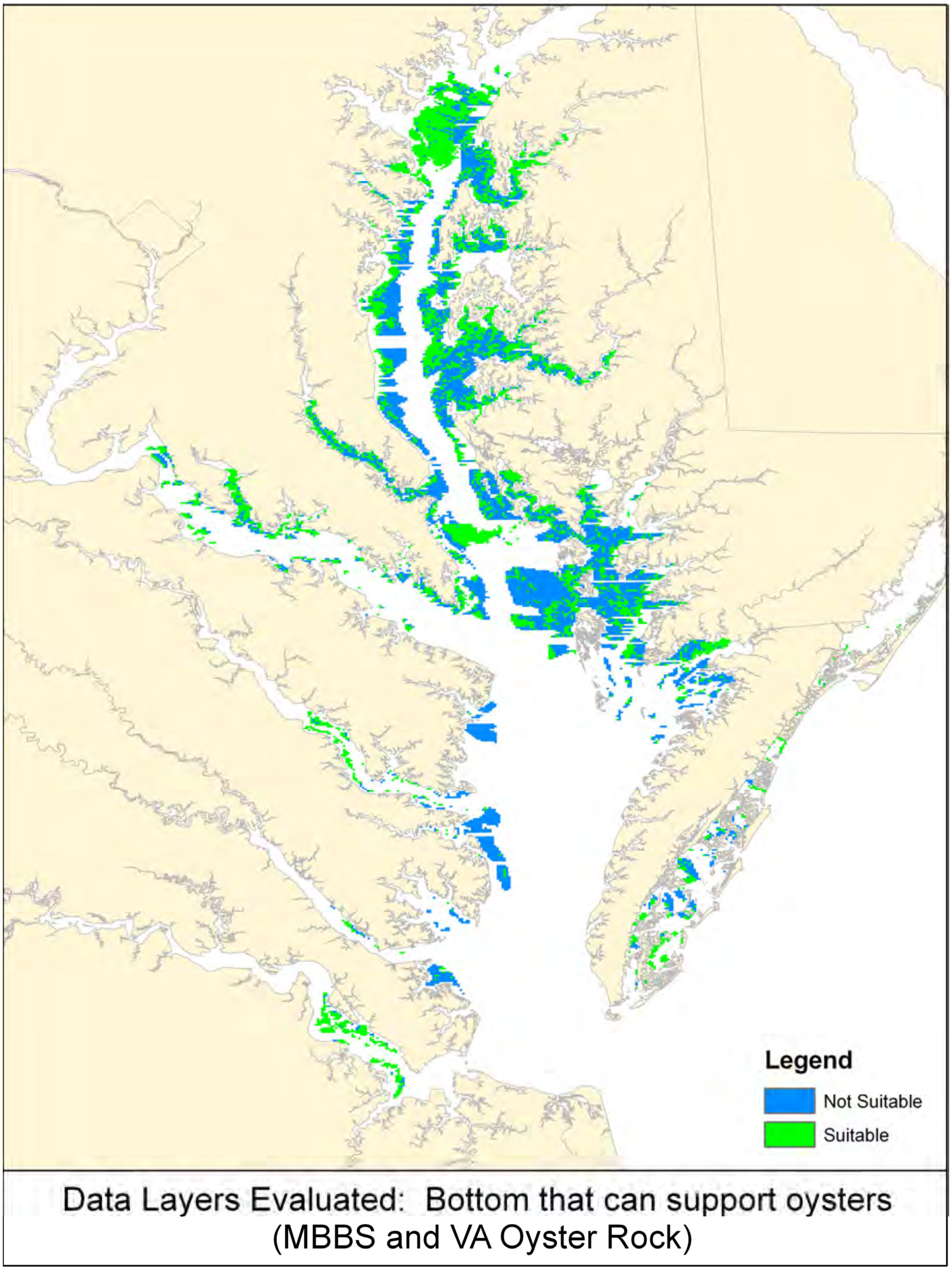


Figure 5-14. Suitability of Mapped Areas of the Bottom of the Chesapeake Bay to Support Oysters. No mapping is available for areas in white.

5.5.4.7 Harmful Algal Blooms

Harmful algal blooms are discussed in Section 4.6.4. Some dinoflagellates that cause HAB may provide a beneficial food source for oyster growth while others are toxic (Wikfors 2005). Shallow, poorly flushed systems are particularly at risk for HAB. *P. minimum* blooms have been documented across extensive reaches of the mesohaline (moderate salinity) Bay, the lower Patuxent River, the upper Severn River oligohaline area (low salinity), and the Choptank River (Brownlee et al. 2005; Glibert et al. 2001). HABs have been very abundant in the York River since the 1970s and recently have been prevalent in Mobjack Bay, the Lynnhaven River, and the entire Elizabeth River system without any perceivable harm to the oysters in those systems (Leggett, pers. comm). Glibert et al. (2007) discussed a July 1995 outbreak of *P. minimum* that was most prevalent in the Northern Bay. Glibert et al. (2001) studied a P*fiesteria piscicida* outbreak in multiple Eastern shore tributaries in 1997 including the Pocomoke River, Chicamacomico River, and Kings Creek (MDNR 1999), a dense bloom of *P. minimum* in the Choptank River in 1998, and a brown tide caused by *Aureococcus anophagefferens*, in the coastal bays in 1999. They concluded that the ability of HAB forming species to graze and use organic substrates in addition to photosynthesis may promote the development and persistence of blooms. The potential for HABs to develop in a tributary or sub-region should be considered further during development of individual tributary plans.

5.5.4.8 Proximity, position, and quantity of existing broodstock populations

A goal of the master plan is to develop a sustained concentrated network of oyster habitat. Therefore, the location and quantity of existing oyster bars should be considered when locating restoration projects. However, surveys identifying current healthy oyster habitat in the Bay have not been performed. Oyster bars should be positioned within a tributary or sub-region to enhance and supplement existing habitat. The bottom mapping done towards developing individual tributary plans identifies current shell bottom, but population surveys need to be completed to identify healthy oyster bars. The cost of restoration in a tributary or sub-region is tied to the extent of existing oyster habitat.

5.5.4.9 Shellfish harvesting closures and sanctuaries

Many areas, typically in urbanized watersheds, are condemned or closed for shellfish harvesting due to high levels of *E. coli*, a bacterium that is transported into Chesapeake Bay waters by sewage, septic systems, and wild animals. *E. coli* is not harmful to the oyster itself, but people who consume oysters that have the bacterium present in their tissues can become ill. MDE designates waters as either approved/conditionally approved, restricted, or prohibited. No harvests are permitted in prohibited waters. A relay is required in restricted waters, and approved/conditionally approved waters are open to direct harvest. Many of the areas that have traditionally been closed for health reasons have been incorporated into the current sanctuary boundaries.

Locating designated sanctuary projects with areas closed to harvest due to bacterial contamination could actually be advantageous due to the state-mandated prohibition on all shellfish harvesting. As these sites are already closed to harvesting, it would not reduce the amount of acreage open to harvest. However, there would be human health risks if the area were to be poached.

Sanctuaries were discussed in Section 4.5 and a map is provided in Figure 4-6. The use of large sanctuaries is key to the future of oyster restoration. Sanctuaries as well as areas closed to harvests for human health reasons should be incorporated into tributary plans.

5.5.4.10 Watershed Suitability

The percent impervious surface in the watershed is a proxy for the suitability of the watershed as it represents the amount of development in a tributary or sub-region. As amount of impervious surface in a watershed increases, runoff amounts increase as well as contaminants, sediment and nutrients carried with the runoff; streams become impaired; and there is a general degradation of the quality and diversity of the watershed's natural resources. It is also reasonable to assume that areas with increased impervious surface will have greater freshwater discharges from stormwater runoff compared to more rural areas. These freshwater discharges reduce salinity and contribute nutrients that affect oyster survival. Watersheds begin to show signs of degradation to their non-tidal freshwater stream networks with as little as 10 percent imperviousness. At 25 percent impervious surface, a watershed is considered 'impacted' (Schueler 2005). Table 4-2a and b in Section 4 provides the land use of each tributary or sub-region.

> The amount of impervious surface in a watershed is linked to the quality and diversity of a watershed's natural resources. The success of oyster restoration will be tied to the land-based protections provided to a waterbody.

5.5.4.11 Position relative to other estuarine habitats

The location of oyster bars adjacent to other estuarine habitats such as shorelines and SAV has the potential to provide cumulative benefit to these habitats and the Bay. Oyster reef structure may protect shorelines and SAV beds by reducing the force of wave action, particularly in the southern Bay where intertidal bars were historically present. SAV beds have the potential to benefit oyster habitat by reducing suspended sediment in the water column. SAV and oysters both positively impact local water quality which in turn benefits the other species. Alternatively, oyster restoration should not be undertaken within the footprint where SAV beds typically occur (Figure 4-3). Efforts should be made to design oyster restoration projects as to facilitate SAV recovery in the areas adjacent to oyster restoration sites. In the Chesapeake Bay, SAV habitat is typically confined to waters less than 2 m in depth. The SAV and shoreline of a tributary or sub-region should be considered when developing individual tributary plans.

5.5.5 CONCLUSION OF SITE SELECTION

The master plan approach stresses the importance of appropriate hydrodynamics (retention) and water quality, including sedimentation, to the success of oyster restoration efforts (see Figure 3.1 for the Master Plan Conceptual Model for a visual depiction of these factors). Suitable retentive systems require local water quality and adequate water flow that will support healthy reefs. Adequate flow promotes the growth of shell in excess of sedimentation rates, and as a result, maintains a sediment-free reef surface.

The product of the sequential application of Layers 1-4 in the master plan is the assignment of each tributary or sub-region to a Tier. The tiers are defined as:

- Tier 1: A tributary or sub-region that has sufficient suitable area to develop a self-sustaining population, as well as desired hydrodynamic properties (High).

- Tier 2: A tributary or sub-region that has sufficient suitable area to develop a self-sustaining population, but does not have desired hydrodynamic properties (Medium or Low) or a tributary or sub-region that does not have sufficient suitable area to develop a self-sustaining population.

All tributaries pass through Layer 1 to determine the amount of suitable acreage based primarily on water quality, then move on to Layer 2. To pass Layer 2, a tributary must contain enough suitable acreage to meet the scale targeted for sustainability. At Layer 3, all tributaries that passed Layer 2 and are designated to have a 'high' hydrodynamic rating will be identified as Tier 1; others are identified as Tier 2. Layer 4 qualitative information is used primarily to identify "information gaps" which may be critical in the development of the individual tributary plans following the master plan.

Tier 1 tributaries meet all of the absolute and hydrodynamic criteria and are recommended for near term consideration for oyster restoration. Tier 2 locations are recommended for consideration following the completion of Tier 1 projects or improvements in existing conditions.

Tier 1 tributaries meet all of the absolute and hydrodynamic criteria and are recommended for near term consideration for oyster restoration. Tier 2 locations are recommended for consideration following the completion of Tier 1 projects or improvements in existing conditions.

Tier 2 tributaries could be targeted for future implementation when either: 1) water quality issues are addressed (addresses absolute criteria), or 2) adjacent restored river systems can provide sufficient recruits (i.e., established connectivity) such that larval retention is no longer an issue (addresses trap estuary effectiveness).

Figure 5-15 depicts the tier assignments spatially. Twenty-four Tier 1 tributaries were identified: 14 tributaries/DSS in Maryland and 10 in Virginia. Table 5-12 provides the Tiered tributary or region list and Table 5-13 provides a summary of the restoration targets identified for Tier 1 tributaries.

As discussed in Section 5.5.4.3, this evaluation did not factor in the presence of viable bottom that can support restoration. USACE recognizes that 'restorable bottom' will be a limiting factor. The first step in developing tributary plans should be to evaluate existing bathymetric surveys or perform bathymetric surveys if recent data is not available. It is expected that the restoration target will be unachievable in some of the Tier 1 tributaries once hard bottom is mapped and quantified.

Another aspect that affected the site selection results is the available water quality data and more specifically, the location of the data collection stations. The available Bay-wide station network is largely located in the deeper water of each tributary's channel. For the most part, these stations are not co-located with oyster habitat. It is evident that in some tributaries, the GIS analysis is very conservative, particularly for DO, and that in fact it is known that there is more expansive suitable acreage than what is identified in the suitability maps. A clear example of this is in the Rappahannock River. The GIS analysis identified no suitable acreage in the middle region of the Rappahannock due to DO. However, oyster populations do exist in the middle Rappahannock River. As a result, dissolved oxygen should be specifically investigated in the middle Rappahannock if restoration partners are interested in pursuing restoration in this sub-segment. It is anticipated that DO conditions are not as poor in the middle Rappahannock as the GIS analysis shows. If subsequent DO investigations support restoration, the middle Rappahannock should be changed to a Tier 1 tributary. Alternatively, the upper Rappahannock River violated the absolute criteria for salinity. Existing conditions in the upper region do not validate the upper Rappahannock as a suitable restoration site and therefore it is not recommended as Tier 1. The other large tributaries that were subdivided into regions were further considered for partial recommendation, but all data and information supported making tier recommendations on the full tributary.

Further, new information may come to light to justify changes to the tiered list. For example, historical accounts have recently been found that indicate extensive reefs were once found on the Virginia Eastern Shore, but that the oysters were long depleted before the Baylor survey (Paxton 1858). In the future, this additional information may warrant reconsidering the tier assignment of the tributaries of the Virginia Eastern Shore. Additionally, information on hydrodynamics, larval transport, and retention was limited for a number of tributaries that had ample suitable acreage. Further investigations into the hydrodynamics of the Nanticoke River, Fishing Bay, and Honga River, for example, may provide sufficient evidence to redesignate the tributary as Tier 1.

Oyster shell with spat. (Photograph courtesy of USACE- Norfolk.)

Table 5-12. Tiered List of Tributaries by State

(Tributaries that are entirely or contain sanctuaries are designated with an 'S')

Tier 1	Tier 2
Maryland	
· Severn R (S) · South (S) · Chester R (lower) (S) · Eastern Bay (lower, upper) (S) · Choptank R (lower, upper) (S) · Harris Creek (S) · Broad Creek · Little Choptank (S) · St. Mary's R (S) · Tangier Sound (lower, upper) · Manokin R (S)	· Magothy R (S) · Rhode R · West R · Chester R (upper) (S) · Corsica R (S) · Honga R · Potomac R · Fishing Bay · Nanticoke R (S) · Monie Bay · Big Annemessex R · Little Annemessex R · Patuxent R (S) · All MD Mainstem Segments (S)
Virginia	
· Great Wicomico R (S) · Rappahannock R (lower) · Piankatank R · Mobjack Bay · York R (lower) · Pocomoke/Tangier Sound · James R (lower, upper) · Elizabeth R · Lynnhaven R	· VA Mainstem · Little Wicomico R · Cockrell Creek · Rappahannock R (middle, upper) · Corrotoman R · Severn R · York R (upper) · Poquoson R · Back R · Onancock Creek · Nassawaddox Creek · Hungars Creek · Cherrystone Inlet · Old Plantation Creek · Nansemond R

Table 5-13. Restoration Targets of Tier 1 Tributaries

Tier 1 Tributaries/Areas	*Restoration Target (Acres)*
Maryland	
Severn River	190 – 290
South River	90 – 200
Lower Chester River	500 – 1,100
Lower Eastern Bay	700 – 1,400
Upper Eastern Bay	800 – 1,600
Lower Choptank River	1,400 – 2,800
Upper Choptank River	400 – 800
Harris Creek	300 – 600
Broad Creek	200 – 400
Little Choptank	400 – 700
St. Mary's River	200 – 400
Lower Tangier Sound	800 – 1,700
Upper Tangier Sound	900 – 1,800
Manokin River	400 – 800
Virginia	
Great Wicomico River	100 – 400
Lower Rappahannock River	1,300 – 2,600
Piankatank River	700 – 1,300
Mobjack Bay	800 – 1,700
Lower York River	1,100 – 2,100
Pocomoke/Tangier Sound	3,000 – 5,900
Lower James River	900 – 1,800
Upper James River	2,000 – 3,900
Elizabeth River	200 – 500
Lynnhaven River	40 – 150

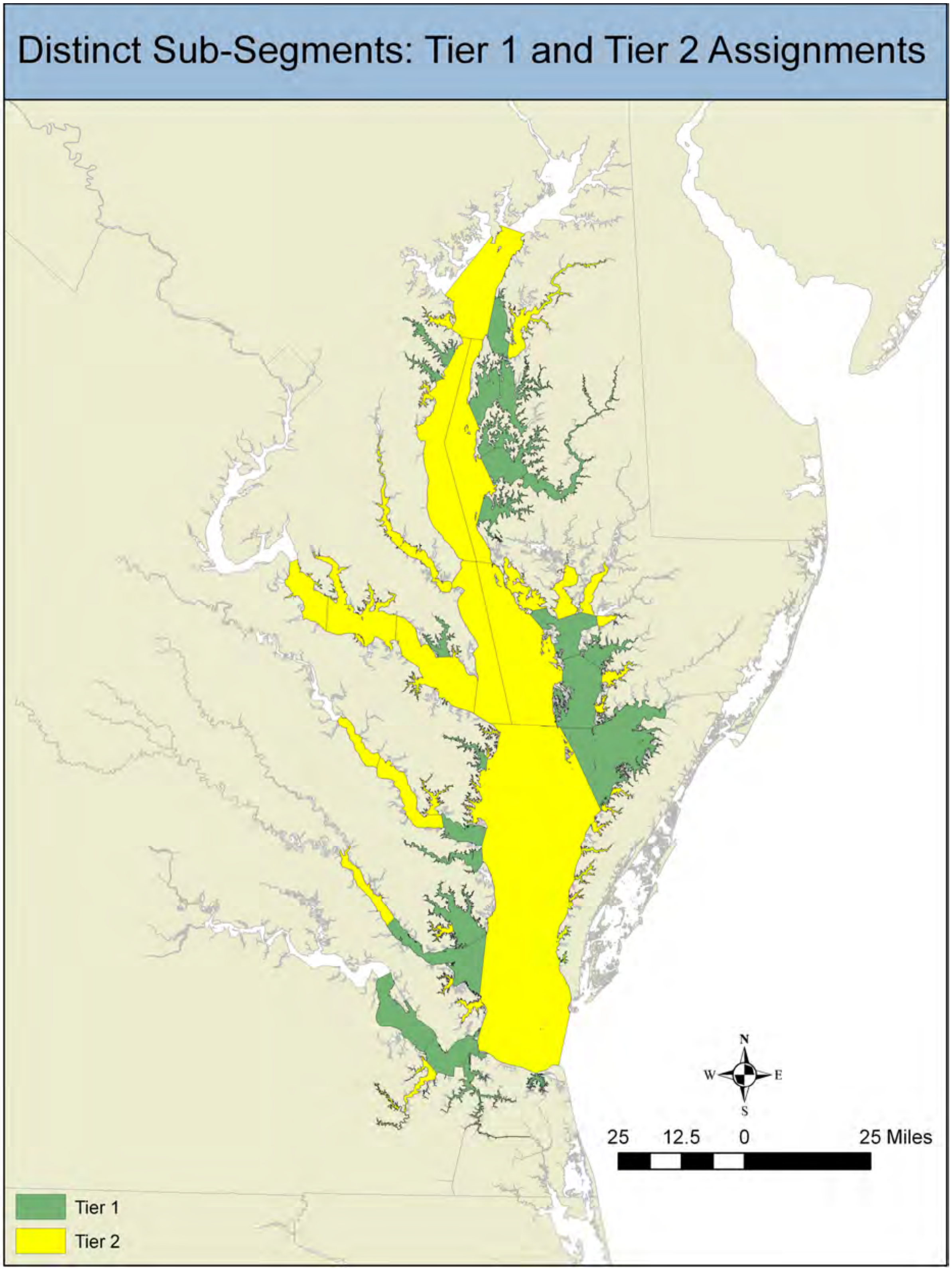


Figure 5-15. Tier Assignment by Tributary or Sub-Segment

The Tier 1 tributaries are consistent with the recommendations of the Maryland Oyster Advisory Commission Report (OAC 2009), the Maryland Oyster Restoration and Aquaculture Development Plan (MDNR 2009), and the Virginia Blue Ribbon Oyster Panel (VA Blue Ribbon Oyster Panel 2007).

5.5.5.1 Challenges to Achieving Restoration Success

The challenges to achieving the goals presented in this master plan in the face of disease, specifically self-sustaining oyster populations, should not be understated. Table 5-14 identifies the main challenges and risks for restoration in each Tier 1 tributary. Achieving self-sustainability will be particularly challenging in the lower salinity tributaries (i.e. Severn, South, lower Chester, upper Choptank) which historically had low spatsets. Those tributaries did, however, have healthy, functioning oyster populations that did not rely on humans to keep in existence. Restoration of significant levels of oysters in these lower salinity populations will provide a broad spectrum of ecosystem services as well as develop an oyster population that is conditioned to the low salinity environment. Healthy, low salinity populations will add diversity and resiliency to the Bay's oyster population. These low salinity tributaries are not expected to be the first selected from the Tier 1 list. Due to the challenges of low reproduction expected, it is anticipated that they would follow, at some point in the future, efforts in other tributaries. It is expected that restoration in the low salinity tributaries will require an increased effort compared to high salinity tributaries because the reduced reproduction will result in a need for more habitat and broodstock to be provided. This is tied to the restoration target. Low salinity tributaries will likely need to be restored to the higher end of the restoration target, while high salinity tributaries may only need to reach the low end of the restoration target. Increased habitat will require higher amounts of investment. Sound planning will rely on lessons learned from working in the other tributaries to help guide restoration in these very challenging, low salinity tributaries. Further, it would benefit restoration efforts if larval transport were investigated in more depth, particularly in low salinity tributaries.

Table 5-14. Tributary-specific Challenges and Risks to Achieving Restoration Goals

	Challenges and Risks to Restoration
Maryland	
Severn River	lower reproduction due to lower salinity; reduced reproduction expected to require higher amounts of habitat to be restored to reach objectives; low reproduction will make achieving self-sustainability more challenging and uncertain; conflict of use with navigation
South River	lower reproduction due to lower salinity; reduced reproduction expected to require higher amounts of habitat to be restored to reach objectives; low reproduction will make achieving self-sustainability more challenging and uncertain; conflict of use with navigation
Chester River - lower	lower reproduction due to lower salinity; reduced reproduction expected to require higher amounts of habitat to be restored to reach objectives; low reproduction will make achieving self-sustainability more challenging and uncertain; poaching; conflict of interest with other fisheries and navigation
Eastern Bay- lower	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation; historically high but inconsistent spatsets; poaching

	Challenges and Risks to Restoration
Eastern Bay - upper	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation; poaching
Choptank River - lower	historically low to medium spatsets may result in needing higher amounts of habitat to be restored to reach objectives; need to better understand hydrodynamic interactions between upper and lower sub-segments; conflict of use with other fisheries and navigation; poaching
Choptank River - upper	lower reproduction due to lower salinity; reduced reproduction expected to require higher amounts of habitat to be restored to reach objectives; low reproduction will make achieving self-sustainability more challenging and uncertain; need to better understand hydrodynamic interactions between upper; conflict of use with other fisheries and navigation; poaching
Harris Creek	restorable bottom may be limiting; conflict of use with other fisheries and navigation
Little Choptank	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation
Broad Creek	no sanctuary designation; conflict of use with other fisheries, navigation
St. Mary's River	conflict of use with other fisheries, navigation; disease pressure; dissolved oxygen; poaching
Tangier Sound - lower	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation; no sanctuary designation
Tangier Sound - upper	conflict of use with other fisheries and navigation; poaching; no sanctuary designation
Manokin River	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation; further investigation into retention is needed
Virginia	
Great Wicomico River	higher salinity could result in increased risk of disease; poaching; potential for hypoxia in deep (> 15 feet) waters when Bay "dead zone" is above average
Rappahannock River - lower	higher salinity could result in increased risk of disease; poaching; predation (cow-nose rays); sanctuary areas not clearly defined; anoxia when Bay "dead zone" is above average
Piankatank River	higher salinity could result in increased risk of disease; conflict of use with leaseholders; poaching; predation; sanctuary areas not clearly defined; deep waters in much of the Baylor grounds limits restoration options
Pocomoke/ Tangier Sound	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation; poaching; predation; sanctuary areas not clearly defined; shifting sands due to openness of region, conflict of use with other fisheries
Mobjack Bay	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation; poaching; predation; sanctuary areas not clearly defined; poor records of potential restoration sites
York River - lower	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation; predation; sanctuary areas not clearly defined; closed military areas
James River - lower	higher salinity could result in increased risk of disease; conflict of use with other fisheries (hard clam) and navigation; poaching; predation; sanctuary areas not clearly defined; region of shell mining

	Challenges and Risks to Restoration
James River - upper	moderate salinity results in limited risk of disease; conflict of use with other fisheries; significant navigation issues; poaching; predation; sanctuary areas not clearly defined; region of shell mining
Lynnhaven River	higher salinity could result in increased risk of disease; conflict of use with other fisheries and navigation; heavy recreational use; shallow waters; shifting sand bottom in many areas; conflicts with leaseholders; predation
Elizabeth River	higher salinity could result in increased risk of disease; navigation issues; heavy shipping and heavy industry; poor quality of habitat within Baylor grounds (never subject to maintenance repletion) which could increase restoration costs; predation

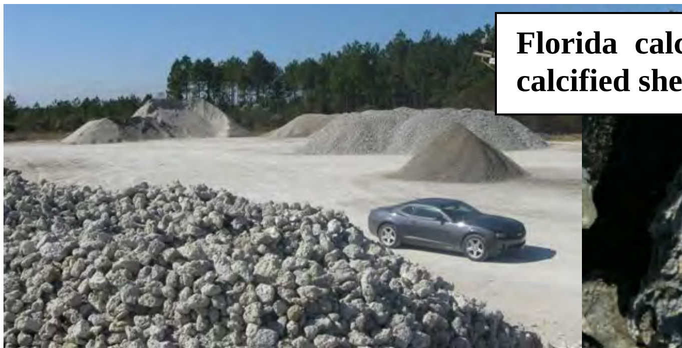
5.6 SUBSTRATE EVALUATION

Because of the need to rebuild significantly large areas of oyster habitat in Chesapeake Bay the master plan must address what materials, in addition to oyster shell, could be used effectively to meet these demands.

> Undertaking large-scale oyster restoration will require a large amount of substrate material. There is currently no available source of oyster shell for use in large-scale oyster restoration. Restoration will require the use of multiple substrates to achieve goals.

Oysters require a hard substrate for larval settlement (usually the shells of dead or living oysters). The increasing scarcity of shell in many areas has seriously limited or increased the costs of oyster habitat restoration. Past restoration efforts have largely used dredged fossil shell. However, this material is currently not available in large quantities mainly due to the non-renewable nature of the resource and the dredging impacts. Undertaking large-scale oyster restoration will require a large amount of substrate material. The specific sources and types of substrate to be used to construct reefs needs to be further considered. There is currently no available source of oyster shell that will permit large-scale oyster restoration.

There are four main substrate options: shell reclamation, fossil shell from other regions, dredging fossil shell within Chesapeake Bay, and alternate substrates. The first is 'shell reclamation' where previously placed shell is recovered from portions of the Bay bottom that are covered with a foot or less of sediment and used for restoration in other suitable areas. This holds promise because an enormous amount of shell, at least 196 million bushels in MD between 1960 and 2006 (Waldbusser et al. 2011), has been placed in past decades for state repletion programs. However, shell reclamation is only beginning to be undertaken and the actual quantity and quality of shell that can be produced through this technique is unproven. The second option is to use fossil shell from surface mines. Currently, there is a potential to purchase fossil oyster shell from the Florida panhandle region and mixed shell from a mine in Virginia. The Florida option is just as costly if not more costly than other alternate substrates due to the distance of the source from the Chesapeake and transportation costs. However, the Virginia shell has great potential. This option is expected to be a much more publicly acceptable substrate to place in large quantities throughout the Bay.



Florida calcified shell mine (right) and Florida calcified shell (below). Photographs courtesy of MDNR.

The third alternative is to permit the dredging of fossil shell. This practice continues in Virginia, but is currently not permitted in Maryland due to impacts from dredging to nursery grounds of various fish. However, shell is the best substrate for oyster setting and the fossil shell is much less expensive than other alternate substrates. Additionally, Waldbusser et al. (2011) identified that fossil shell exhibited slower dissolution rates under increasing pH compared to fresh and weathered shell. Given the benefits of oyster restoration and the costs of using alternate substrates on a large-scale, reconsidering the impacts associated with dredging fossil shell may be warranted. VMRC and USACE-Norfolk are performing a fossil shell survey as part of their common ground activities. This effort will survey Virginia waters to better define the quantity and quality of buried fossil shell. There is much debate over the amount of fossil shell still available for use as a building material for oyster reefs. Because fossil shell currently serves as the main source of cost share credit for VMRC, it is in the interest of both USACE and the Commonwealth of Virginia to better characterize the existing fossil shell reserves. Regardless of the source, adding vast quantities of shell material within a tributary may have significant geochemical implications and affect how the restoration efforts are impacted by ocean acidification (Waldbusser et al. 2011) (see Section 6.3.11.2.b).

The final option is the use of alternate substrates such as concrete, granite, and limestone marl. [The following discussion is based on Schulte et al. (2009b)]. Due to shell shortages, the use of alternate materials for creation or restoration of oyster reefs has become of increasing interest to resource managers and scientists nationwide. There are a number of potential substrates with varying performance, costs and public perception. Reefs made from alternate material have a long history of use. In Europe, such reefs have been constructed for over 30 years, with a positive track record of attracting high densities of marine life, both pelagic and sessile (mainly bivalves) (Jensen 2002; Boaventura et al. 2006). Significant differences exist, however, in the setting density and subsequent survival of those oyster spat. This apparently results from the significant differences in surface area of the various substrates, both of the individual pieces, and of the interstitial space between piles or layers of the material. Monitoring also suggests that the refuge provided by the irregular surfaces and pore spaces of certain materials (natural oyster shell, stone, crushed concrete, and marl) provide better predation protection than those materials that eventually align themselves such that surface area and crevices are minimized (hard clam shell and surf clam shell).

One of the primary advantages of alternate materials is their long-term persistence in estuarine and marine environments. Materials such as granite, limestone marl, and appropriate types of concrete can persist for decades, even centuries, in these ecosystems. Various alternate substrates are discussed in the following paragraphs.

5.6.1 Concrete

Recently, two large-scale oyster restoration projects initiated in the lower Rappahannock River, Virginia provided an opportunity to compare the effectiveness of concrete versus shell for oyster reef construction.

The first project placed shells on former reef footprints in an effort to augment the commercial fishery and provide a small sanctuary component; the second project constructed a large concrete reef network using both materials of opportunity (a deconstructed bridge) as well as formed concrete modular reefs.

On the shell sanctuary reefs of this study, an average of only 9 oysters per m^2 was observed. Of these, most were classified as “small” oysters (representing reproductive oysters from 35-75 mm in total length) and were smaller than the legal market size (76 mm). The concrete reefs supported a much higher population of oysters of various size classes, and averaged 73 oysters per m^2 of concrete surface (Lipcius and Burke 2006). Also, the presence of much larger oysters than on the nearby constructed shell reefs indicated higher survival over time, and healthier, more disease-resistant oysters. The modular surface area of the concrete reefs allowed very high oyster densities (> 1,000 oysters per m^2 of bottom) to be achieved. Another investigation in the Lynnhaven River whose results are provided in Table 5-15, identified that crushed concrete performance was comparable to oyster shell and granite (Burke 2007).

These results indicate that alternate materials can not only work in subtidal environments, but could potentially perform better than shell reefs in low recruitment situations. The effectiveness of concrete as a substrate for oyster attachment may also be increased if calcium carbonate is added to the mixture, either as gypsum or shell fragments (Louisiana Department of Fish and Wildlife 2004).

Concrete was also incorporated into the restoration of 13 acres of oyster reefs in the Severn River in 2009. Initial project monitoring identified that concrete performed equally well as stone and shell in providing oyster and reef habitat (USACE 2012).

5.6.2 Granite

Granite has shown excellent potential for oyster habitat restoration. In the Lynnhaven River, Virginia, a survey of rip-rap along shorelines found high densities of oysters on rock surfaces (978 oysters per m^2) (Burke 2007). Restored reefs constructed using oyster shells in the same river harbored much lower densities of oysters, ranging from 97-240 oysters per m^2 (Burke 2007). These observations, as well as a shortage of oyster shell, prompted further investigations into the potential use of alternate materials as shown in Table 5-15.

Granite has been employed in reef restoration in Maryland in the Severn River, at Mill Hill in Eastern Bay, at Cook Point in the Choptank River, and at a site in Harris Creek. Initial monitoring of the granite sites in the Severn River and at Mill Hill suggest that performance of granite is comparable to other substrates and dredged shell (USACE 2012).

5.6.3 Limestone

Despite the lower oyster recruitment rates on limestone marl shown in Table 5-15, excellent results have been achieved using limestone for oyster restoration in other areas. The North Carolina Division of Marine Fisheries (NCDMF) sanctuary program has successfully constructed several reefs with a combination of natural oyster shell and/or Class B limestone rip-rap. Haywood et al. (1999) reported successful settlement of oyster larvae on crushed limestone. Another study in Louisiana found limestone marl attracted large numbers of spat (> 2,000 spat / bag (a bag covered 0.3 m^2 of marl bottom area)); the limestone appeared to attract more oyster spat than the *Rangia* clam shells that had been used in the region (Burton and Soniat 2005).

Table 5-15. Comparison of Oyster Densities (per m^2)
(± standard error) on various alternate materials in the Lynnhaven River, Virginia
(Burke 2007)

Substrate Type	Oyster Density				
	Fall 2005	Spring 2006	Fall 2006	Spring 2007	Fall 2007
Crushed Concrete – Very Small (CVS)	284 ± 99	304 ± 97	1,052 ± 174	858 ± 215	1080 ± 203
Granite Large (GL)	747 ± 119	696 ± 120	1,620 ± 273	1,288 ± 235	2083 ± 235
Granite Small (GS)	781 ± 141	695 ± 111	1,649 ± 262	1,330 ± 272	2299 ± 215
Limestone Marl Large (LML)	144 ± 42	193 ± 66	284 ± 91	277 ± 54	451 ± 110
Limestone Marl Small (LMS)	143 ± 42	189 ± 57	327 ± 101	305 ± 44	439 ± 95
Oyster Shell Unconsolidated (OSU)	316 ± 89	226 ± 62	753 ± 118	748 ± 142	1678 ± 159

A larger study, also in Louisiana, compared costs and effectiveness of crushed concrete, crushed limestone, and oyster shell fragments (Louisiana Department of Fish and Wildlife 2004). Costs of the various materials were roughly equivalent at approximately $50.00 per cubic yard. Monitoring results found approximately 3-4 times as many live oysters on the alternate materials compared to the oyster shells (Louisiana Department of Fish and Wildlife 2004). They found 429.6 oysters per square meter on concrete, 309.6 on limestone, and 86.4 on oyster shells.

5.6.4 Pelletized Coal Ash

Pelletized coal ash has been used as a substrate for oyster habitat, but results have been mixed. In some cases, pelletized coal ash has performed at least as well as oyster shell (Mueller 1989). In other cases, coal ash reefs experienced lower oyster survival rates than nearby restored shell reefs (O'Beirn et al. 2000), with roughly a six fold higher number of oysters on the shell reefs compared to the coal ash reefs. Large reefs constructed out of this material in Galveston Bay, Texas in 1993 performed exceptionally well, experiencing oyster recruitment and survival not seen in the area in 40 years (Baker 1993). The reefs were also colonized by other sessile marine fauna, with over 90 percent of the available attachment sites on the reef being occupied. Moreover, various structure dependent fish used the reefs for shelter and foraging sites.

From an environmental standpoint, issues have been raised regarding the potential for contamination. Coal ash contains environmental toxins, including various metals. However, this material appears to be stable in the marine environment and oysters growing on it do not appear excessively contaminated with metals or other toxins from the material (Homziak et al. 1989). Since this material is now often in demand for other purposes, particularly in construction as road bed material, supplies may be difficult to obtain. Due to mixed results, it might be worthwhile to consider using coal ash in conjunction with other alternate materials, or possibly as a base material upon which limited supplies of oyster shells could be placed, but not by itself.


Sampling trays of alternate substrates placed in Severn River for oyster monitoring. Trays were deployed for one year: concrete (top left), steel slag (top right), and granite (bottom left) (USACE 2012).

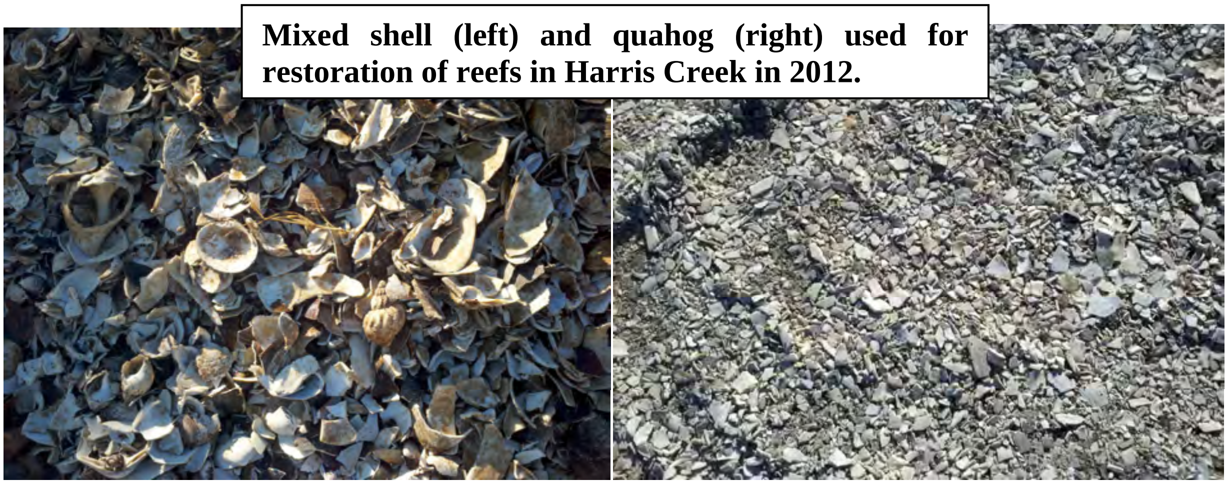
5.6.4 Steel Slag

In Chesapeake Bay, steel slag has been used for oyster reef restoration at Mill Hill Sanctuary in Eastern Bay in 2002 (2 ac) by Maryland Department of Natural Resources (MDNR) and by MDNR and USACE in the Severn River in 2009 (0.75 ac). At Mill Hill, a small set occurred in 2003. Concrete (32 oysters/m^2) and slag (44 oysters/m^2) attracted significantly more larvae, or at least resulted in more spat surviving on it, than stone, shell, concrete with shell, slag with shell or stone with shell (11 to 15 oysters/m^2). Few oysters were found on the reefballs at Mill Hill (<1 oyster/m^2). Concerns have been raised over the potential for steel slag to introduce heavy metals to oysters and the environment. These reefs at Mill Hill and in the Severn River were screened to gauge the performance of the steel slag at the two sites in 2011. Initial screening suggests that although the reef assemblages are comparable between substrates, the slag reefs at these two sites have fewer oysters than the stone and concrete sites. Also, monitoring of heavy metals in oysters, sediment, and water at the two sites showed mixed results, but warrants further study of slag prior to future use as an alternate substrate (USACE 2012).

5.6.5 Clam Shell

Hard clams and surf clam shells have been used for oyster restoration. Clam shell is available but has had limited success. Clam shells are more fragile than oyster shell and tend to break into small pieces. Also, clam shell provides less interstitial space for oysters.

Oyster recruitment, survival, and growth were monitored on reefs constructed of oyster and surf clam shell near the mouth of Chesapeake Bay and in one of its tributaries, the York River. The oyster shell reef supported greater oyster growth and survival and offered the highest degree of structural complexity. On the York River subtidal clam shell reef, the quality of the substrate varied with reef elevation with large shell fragments and intact valves scattered around the reef base and small, tightly packed shell fragments paving the crest and flank of the reef mound (Nestlerode 2004).



Mixed shell (left) and quahog (right) used for restoration of reefs in Harris Creek in 2012.

Oyster restoration in Harris Creek, a tributary of the Choptank River, has incorporated various types of shell (mixed shell- clam, scallop, and whelk; and quahog) for reef restoration due to opposition by commercial fisherman to other alternate substrates because of their concern that other substrates would negatively impact other fisheries, specifically crabbing (snagging of trot lines), in the tributary. Spat on oyster shell was placed upon the clam shell on some sites to evaluate whether this will improve the performance of the clam shell reefs.

5.6.6 Economic Considerations

Regardless of the materials used to construct reefs, substrate costs must be evaluated considering hauling distance to the site and local availability. Some types of material may be more readily accessible depending on the location of the work to be done resulting in cost savings at that particular location. One thing is certain, given current conditions, large-scale restoration using alternate substrates will be much more costly than using oyster shell. Compared to dredged or shucking house shell, alternate materials are usually more expensive. Typical costs to place dredged shell range from $20–25 per cubic yard. Costs to place a similar amount of granite or limestone marl are often more than double this cost. However, if transport is involved, shucking house shells can equal the cost to place some stone materials. Multiplied by the large number of acres that are required for large-scale restoration, the use of alternate substrates to construct reef habitat will be much more costly than using shell. The cost projections of Section 5.7 consider the economics in more detail.

5.6.7 Substrate Recommendations

Due to the large scale of restoration proposed to restore oyster populations, the current degraded state of oyster habitat, and oyster shell shortages, there will be a need to incorporate alternate substrates into restoration projects. Results and monitoring have shown that granite, limestone, and concrete are all suitable for restoration. Performance has varied, but typically is comparable, and in some cases outperforms, oyster shell. Coal ash is not recommended for use as a lone substrate. Steel slag requires additional investigations prior to any further use as a reef substrate. Although, alternate substrates have performed better than oyster shell reefs in some studies, oyster shell is preferred for the following reasons: it is a native product to the Bay, the high cost of alternate substrates, mixed public opinions of alternate substrates, and potential negative impacts from alternate substrates. The one benefit that alternate substrates have over oyster shell is the inherent protection from poaching they provide to sites targeting ecosystem restoration. Efforts are underway to evaluate the suitability of the expansive mixed shell deposits in Virginia for restoration including the cost-effectiveness of mining and transport to restoration sites. If determined to be suitable and cost-effective, the Virginia shell deposits have the potential to greatly expand the substrate options available for restoration.

Mixed shell deposit at mine in Virginia.

Mixed shell deposit at mine in Virginia.

5.7 BENEFIT AND COST PROJECTIONS

5.7.1 BENEFITS OF OYSTER RESTORATION

Oysters can affect other organisms by changing the physical and chemical environment of the Bay ecosystem. Oyster bars and reefs are such important components of the Bay ecosystem that oysters have been considered “keystone species” and “ecosystem engineers” (Jones et al. 1994; NRC 2004). When oysters were abundant, expansive areas of reef habitat, relatively clear water, and large areas of SAV characterized the Bay. Now that oyster abundance is low, the density of phytoplankton has increased, areas covered by reef and SAV have contracted, and the species composition of the Bay has changed in response to the altered conditions (Newell 1988). The Bay system has been further altered by large increases in nutrient loads following World War II.

Grabowski and Peterson (2007) have identified 7 categories of ecosystem services provided by oysters: (1) production of oysters; (2) water filtration and concentration of biodeposits (largely as they affect local water quality); (3) provision of habitat for epibenthic fishes (and other vertebrates and invertebrates- (Coen et a1. 1999; ASMFC 2007); (4) sequestration of carbon; (5) augmentation of fishery resources in general, (6) stabilization of benthic or intertidal habitat (e.g. marsh); and (7) increase of landscape diversity (see also reviews by Coen et a1. 1999, Coen et al. 2007, Coen and Luckenbach 2000, ASMFC 2007). Additionally, Ulanowicz and Tuttle (1992) discussed how oyster restoration would promote beneficial food web dynamics in the Chesapeake system. Table 5-16 discusses the ecosystem services in detail.

Table 5-16. Ecosystem Benefits of Oyster Restoration

Ecosystem Benefits	
Production of oysters	Large populations of oysters create bars and reefs of accumulated shell that are unique habitat in Chesapeake Bay. Successive generations of oysters growing on the shells of previous generations gradually accrete large, three-dimensional structures that can compensate for sedimentation if the rate of growth of the oyster bar exceeds the rate of sedimentation. Fecundity of oysters increases with age and therefore size of the oyster. Paynter et al. (2010) calculated that a two year old oyster would produce 7.61 million eggs compared to an eight year old oyster that would produce 58.3 million eggs. Oyster resources in the Chesapeake Bay have ecological, economic, and social significance.
Water filtration and concentration of biodeposits	Oysters filter water while feeding, thereby removing sediment and other particles from the water and depositing it on the bottom in pellets called pseudo-feces. Adult oyster can filter up to 50 gallons of water a day (Luckenbach 2009). A 2 year old oyster filters 4.09 L/hr while an 8 year old oyster is capable of filtering 13.29 L/hr (Paynter et al. 2010). Filtration by large numbers of oysters can reduce the time that sediment remains suspended in the water column and increase the clarity of the filtered water. Recent modeling evaluated an increase of up to fifty times the 1994 oyster biomass and estimated such increases would increase summer bottom DO, summer average surface chlorophyll, and summer average light attenuation (Cerco and Noel 2005). Oysters' pseudo-feces are rich in nutrients and, therefore, help to support primary production among bottom-dwelling organisms in areas immediately surrounding oyster bars. Local nutrient enrichment also stimulates the exchange of various forms of nitrogen and nitrogen compounds from one part of the system to another (Newell et al. 2002). Oyster populations remove substantial amounts of planktonic N and P from the water column and enrich bottom sediments (Newell et al. 2004). Oysters produce feces (digested particles) as well as pseudofeces (ingested particles that are not digested). Oysters (and mussels) maintain high clearance rates even when seston concentrations are high and therefore, have the unique ability to greatly influence benthic-pelagic coupling (Newell et al. 2004). The natural processing of the oyster's pseudofeces in shallow water can result in denitrification (the direct removal of nitrogen from the water) under aerobic conditions (Newell et al. 2002). Under aerobic conditions, P release to the water column from bivalve deposits is negligible (Newell et al. 2004). As an example, the historic population of oysters in the upper Choptank River, which once covered about 5,000 acres, might have had the capacity to remove 30% of all the nitrogen entering the river today, if they were still present (Newell 2004). At the time of the study, seasonal N and P removal of the current oyster densities in summer in Choptank River was ~5% N and ~34 % P. Newell et al. (2004) determined that if oyster density was increased to 10/m^2 (still below historic densities), ~50% N and ~350% P of monthly summer inputs could be removed. In other words, P would be removed faster than current inputs, and half of N inputs would be removed. On an annual basis, Newell et al. (2004) estimated that current oyster populations remove 0.6% and 8% of annual

Table 5-16. Ecosystem Benefits (con't)	
Water filtration and concentration of biodeposits (con't)	N and P inputs, respectively. On a restored reef with 10 oysters /m^2 expected removal is 6% N and 80% P. Newell et al. (2004) estimated the value of the current oyster population in the upper Choptank River at $1.5 million if it were to be harvested. Once adjusted for the costs of harvesting, it was estimated that the value to the harvesters is $750,000. Using Chesapeake Bay Program estimated costs for nutrient removal, Newell et al. (2004) estimate that the value of Choptank R stock to remove 13, 080 kg N/yr is $314,836; and over a 10-year lifetime equates to $3.1 M.
Provision of habitat for epibenthic fishes (and other vertebrates and invertebrates)	A healthy oyster bar provides habitat to a diverse and abundant community of organisms including epibenthic fish and decapods (Posey et al. 1999). Oyster bar is the principal hard habitat in the Chesapeake. Rodney and Paynter (2006) showed that the total macrofaunal abundance (free living macrofauna + fouling organisms) was an order of magnitude higher on restored bars compared to unrestored reefs. Further, many organisms that were significantly more abundant on restored reefs are also known to be important food items for several commercially and recreationally important finfish species. Harwell et al. (2010) identified 78 different species utilizing caged oyster reefs at four sites of varying salinity (low to high). Breitburg and Fulford (2006) identified the significance of hard oyster substrate to sea nettle (*Chrysaora quinquecirrha*) and another food web ramification associated with the degradation of oyster reef. Oyster reef provides hard substrate for the overwintering polyp stage of sea nettles. Sea nettles consume zooplankton, ctenophores, and icthyoplankton. Sea nettle abundance decreased in the mid 1980s following sharp declines in the oyster population. With the decline in sea nettles, ctenophores (*Mnemiopsis leidyi*) a voracious consumer of icthyoplankton and oyster larvae increased, posing another potential problem for oyster recovery.
Sequestration of carbon	Fully functioning, biogenic oyster reefs engage in a form of biosequestration, acting to store carbon dioxide by fixing carbon into their $CaCO_3$ shells. The fixed carbon is effectively removed from the carbon cycle and eventually fixed into limestone. Estimates (below) project that oysters are capable of sequestering carbon at a rate comparable to other high-performing carbon sequestration restoration efforts such as reforestation. High salinity oyster bars with dense oysters have the greatest potential to play a serious role in carbon sequestration and efforts to abate climate change.
Augmentation of fishery resources, in general	The value of oyster bars to provide habitat and refuge to diverse fishery resources is well documented (Peterson et al. 2003; Grabowski and Peterson 2007; Luckenbach et al. 1997; Coen et al. 1999; Coen and Luckenbach 2000; Rodney and Paynter 2006; Dame 1979; Harding and Mann 1999, 2000; Breitburg 1999; Meyer and Townsend 2000; Zimmerman et al. 1989; Wenner et al. 1996; and Harding 2001). Peterson et al. (2003) documented increased fisheries production stemming from the restoration of oyster reefs. Nineteen species of fish and large mobile crustaceans were judged enhanced in abundance by the presence of oyster reef habitat. Additionally, the 10m^2 of restored oyster reef studied in the southeast US is expected to yield an additional production of 2.6 kg/yr of fish and large mobile crustaceans for the

	functional lifetime of reef. Grabowski and Peterson (2007) investigated the fishery benefits provided by oyster reefs situated in different positions in the seascape and concluded that restoration of oyster reefs could extend the range of juvenile fish by redistributing them more evenly across estuarine landscapes which could increase secondary productivity. Further, Harding and Mann (2000) found that fish densities were up to 14 times greater in areas where shell substrate dominated the bottom as compared to habitat areas lacking shell.
Stabilization of benthic and intertidal habitat	Oyster reef structure stabilizes benthic and intertidal habitats in a variety of ways. The physical presence of oyster reef can reduce wave energy on the leeward side of reefs. Oyster filtration aggregates small seston particles. As a result, both feces and pseudofeces, biodeposits sink faster than non-aggregated particles (Kautsky and Evans 1987, Widdows et al. 1998, Newell et al. 2004). The aggregated particles are consolidated into cohesive sediments and are more difficult to resuspend, providing water clarity benefits. Further, Newell et al. (2004) states that oyster shells and reefs add to bed roughness and increase friction velocity (Wildish and Kristmanson 1997), which improves the transport of biodeposits to sediments away from the reef.
Increase of landscape diversity	Oyster bars provide important and unique structural habitat for fish and invertebrates, as illustrated by the large variety of organisms that can be found on these structures (Rodney and Paynter 2006). In the absence of functioning oyster bars, some organisms compete with oysters for limited space on hard surfaces such as pilings, rip-rap, and boat bottoms. Oyster bar is the only natural hard substrate in the Chesapeake Bay. As mentioned above, elevated, hard substrate attracts a diverse assemblage of organisms, and provides a refuge from predation to many small fish and invertebrates.
Food Web Dynamics	With eutrophication, the Chesapeake Bay food web has shifted from a benthic autotrophic system to a planktonic heterotrophic system (D'Elia et al.1992; Jackson et al. 2001). Historically, the basic Chesapeake food web consisted of phytoplankton consumed by benthic and pelagic filter feeders, including oysters and zooplankton, which were then preyed upon by fish and invertebrates (Baird and Ulanowicz 1989; Hagy 2002). There has been a shift to heterotrophy, dominated by microbial pathways (D'Elia et al. 1992; Verity 1988), with eutrophication and over-fishing. Species of gelatinous zooplankton, unpalatable to most organisms, are now significant grazers of zooplankton (Newell 1988; Verity 1988) and bacteria process much of the organic matter previously eaten by invertebrates (Hagy 2002; Jonas and Tuttle 1991). Energy transfers to gelatinous zooplankton such as ctenophores reduce energy flows to higher trophic species (Breitburg and Fulford 2006). Ulanowicz and Tuttle (1992) demonstrated the positive effects oyster restoration could have on food web dynamics. Their work projected that increased oyster abundance led to decreases in unwanted species (phytoplankton productivity, pelagic microbes, ctenophores, medusa, and particulate organic carbon) as well as increases in desired species (benthic primary production, fish stocks, and mesozooplankton densities) and thus resulted in a mitigation of eutrophication.

In addition to the ecosystem benefits from oyster restoration, another significant benefit that can be expected from restoring a protected network of oyster reefs throughout the Bay is enhanced leaseholder production. Leases within restored tributaries should see increased recruitment produced from the sanctuaries. This is evident the Great Wicomico River restoration efforts.

There is no existing model to adequately document the diverse benefits and value of oyster restoration to meet USACE cost-benefit analysis requirements. However, USACE-Norfolk and USACE's Engineer Research and Development Center (ERDC) in coordination with VMRC are working to develop a model to estimate ecosystem benefits and services from oyster restoration as part of their common ground activities. This effort will include hydrodynamic and ecological modeling to better define the benefits of oyster restoration. The modeling will look at two main questions and will include modeling of both the Great Wicomico as well as the Rappahannock Rivers. First, it will forecast the environmental and commercial benefits that the constructed oyster sanctuaries provide to the nearby harvest areas. Secondly, it will forecast the environmental benefits that the rotational harvest oyster grounds provide to the Chesapeake Bay. This modeling will be used for decision making as well as further economic analysis. Findings of the ERDC modeling effort will be incorporated as appropriate into development of tributary plans when that information becomes available.

Documented efforts at quantifying the economic benefits of restored oyster habitat include:

- Newell et al. (2004) estimated the value of the current oyster population (1 oyster/m^2) in the upper Choptank River at $1.5 million if it were to be harvested with a value of $750,000 to harvesters when adjusted. The value of existing Choptank River oyster stock to remove 13,080 kg N/yr is $314,836 (based on the average cost of $24.07 to remove 1 kg of N from the Chesapeake Bay); and over a 10-year lifetime equates to $3.1 million.
- Kahn and Kemp (1985 as cited by Grabowski and Peterson 2007) estimated that a 20 percent decrease in SAV in the Chesapeake equaled a loss of $1-4 million annually in fishery value; Cerco and Noel (2007) determined that an increase in oyster biomass of 10 percent would result in a 20 percent increase in summer SAV biomass.
- On a restored reef with 10 oysters /m^2 expected nutrient removal is 6 percent N and 80 percent P of annual inputs and ~50 percent N and ~350 percent P of monthly summer inputs (Newell et al. 2004).
- A 10 m^2 restored reef in the southeast U.S produced 2.6 kg/yr of additional fish and crustacean production (Peterson et al. 2003).
- Grabowski and Peterson (2007) estimated that preserving a 1 acre oyster sanctuary for 50 years would result in an additional value of ~$40,000 from commercial finfish and crustacean fisheries.
- Example of value associated with improvements in water quality- Survey of Baltimore-Washington residents in 1984 (Bockstael et al. 1988, 1989 as cited by Grabowski and Peterson 2007) showed that a 20 percent increase in water quality (relative to 1980 conditions) is worth $188 million for beach users, $26 million for recreational boaters, and $8 million for striped bass sportsfishermen [price adjusted to 2002 by NRC (2004)].

Additionally, the potential of oyster reefs to sequester carbon can be quantified. Example calculations and further discussion are presented in the following section.

5.7.1.1 Carbon Sequestration

Calcium carbonate ($CaCO_3$) produced by marine life can become incorporated into the sediment that over time can be transformed into limestone by sedimentary processes. Extensive limestone deposits today are primarily of shelly debris from marine organisms. The reef-forming habitat of many sessile invertebrates that produce $CaCO_3$ shells leads to limestone formation as new organisms settle on top of one another. Dying animals leave behind their shells, which become incorporated into the reef matrix. As more and more live animals settle on the reef, the matrix grows higher in the water column while the base gets pushed below the sediment-water interface. Once there, such shell debris is not vulnerable to dissolution by surface waters and may, over time, become marine limestone.

This is a potential benefit of great importance. Fully functioning, biogenic oyster reefs engage in a form of biosequestration, acting to store carbon dioxide by fixing carbon into their $CaCO_3$ shells. The fixed carbon is effectively removed from the carbon cycle and eventually fixed into limestone. Some CO_2 is released into the water during the production of $CaCO_3$ by oysters. However, the amount of carbon fixed into shell is approximately12 percent of the shell, by weight. If this shell were to become fixed into a reef such that it is not subject to dissolution by seawater, then this carbon can become sequestered for long periods of time. If transformed into limestone, perhaps for millions of years.

This benefit can be significant. For example, the amount of shell removed from the James River due to harvesting would have become incorporated into the reef matrix and ultimately have become deposited below the sediment-water interface as new reef formed on top. Approximately, 75.7 million cubic yards of shell have been lost from the James River system, equating to 4.12 million metric tons of carbon that would have been sequestered (1 cubic yard shell weighs 460 kilograms (kg)).

For the Piankatank River, a much smaller reef footprint is possible, relative to the original extent of oyster reefs in the James River. However, the carbon sequestration could be substantial if reefs deposit dead shell into an anoxic reef matrix such that shells are not subject to dissolution by contact with surface waters and destructive epifauna, such as the boring sponge.

The carbon sequestration potential of oyster reef restoration can be projected. Schulte et al. (2009a) determined that high-relief oyster reefs had mean annual accretion rates of 10.7 L/m^2. To correct for the fact that this measurement is of water displaced by the shells, not the total volume taken up by the shells in a bushel basket, this number is multiplied by 3, providing an accretion rate of 32 L/m^2 over a 3-year period. This shell could be ultimately dissolved by the water, or alternatively incorporated into the reef matrix. Field observations of intact, dead oyster shells below the living veneer of the reef suggests the bulk of this shell becomes incorporated into the anoxic portion of the reef base over time.

To illustrate the potential of oyster reefs to sequester carbon, it is assumed here that 25 percent of the shell dissolves or is degraded by other erosive forces. As a result, the annual accretion rate of shell is reduced to 8.02 $L/m^2/yr$. Restoration of 300 acres of oyster reef could produce 9.74 million L of reef matrix shell/year. A cubic yard of shell is equivalent to 765 L, and weighs 460 kg, resulting in 5,860 metric tons of reef matrix shell per year. At ~ 12 percent carbon by weight, 703 metric tons carbon per year (C/yr) is sequestered by this reef. For comparison, an average American (2007 data) produces 5.2 metric tons C/yr.

A biogenic reef with high oyster biomass can deposit an impressive amount of carbon in the form of $CaCO_3$. If unharvested and allowed to accumulate over time much of this shell would be deposited under the sediment surface. Evidence of such shell deposits is clear, and such deposits can be several meters in thickness; 3.8 m in the case of a fossil shell bed dredged off of the Craney Island Dredged Material Management Area near Norfolk, VA in the 1960's (Pharr 1965).

A successful high-relief (approximately 12 inches) oyster project of 300 acres could compensate for the carbon production of 135 people on an annual basis. Reforestation (allowing trees to grow back after timber harvest) is estimated at being capable of sequestering 0.3 to 2.1 metric tons C/ac/yr and conversion of crop or pasture land to forest can sequester 0.6 to 2.6 metric tons C/ac/yr (Gorte 2009). Oyster reef restoration equates to 2.34 metric tons of C/ac/yr (700 metric tons for 300 acres), a value comparable to high-end reforestation efforts. If this is reduced by 10 percent due to ocean acidification by 2100 as predicted for the closely related *Crassostrea gigas* by Gazeau et al. (2007), the restored reefs would still be projected to sequester 2.11 metric tons C/ac/yr. Even if 50% of the shell is lost to dissolution or degradation prior to sequestration, oyster restoration results in a significant amount of carbon sequestration (1.53 metric tons C/ac/yr) that remains comparable to other practices being considered to reduce the buildup of greenhouse gases in the atmosphere. The example discussed is a best case scenario resulting in 8 mm of shell deposition over the reef surface in a year; a 4 mm/yr rate of deposition is more typical of the average restoration project. The carbon sequestration rate and shell deposition of projects in lower salinity waters or of lower relief would be expected to be reduced compared to the example provided.

> The carbon sequestration potential of oyster reefs is comparable other practices being considered to reduce the buildup of greenhouse gases in the atmosphere, such as reforestation.

The dredging and movement of fossil shell or placement of alternate substrate does result in the production of C via combustion of fossil fuel. A dredging project can produce tons of C via the diesel engines used to do the dredging as well as move the material. A project of the example size given previously (300 acres) will require an amount of shell to be dredged and moved such that C emissions will be in the range of 15 to 30 metric tons of C, much less than could be deposited in one year by a biogenic reef of 300 acres.

Consideration should be given to all of these climate change issues for candidate sites as specific tributary plans are developed. The restoration team should stay abreast of new technologies and scientific findings that can improve our understanding of the impacts of climate change on oyster populations.

5.7.2 DESCRIPTION OF COSTS

There are several factors to consider when estimating the construction costs of an oyster restoration project. The distance traveled to the site, the source of the substrate, the source of any seeding that may be done and the construction itself are just a few of the different aspects that play a part in the construction costs. Considering the number of tributaries in this programmatic evaluation, an effort was made to simplify the development of the cost estimates for each tributary by using regional centroids to determine the construction costs.

The Commonwealth of Virginia and the State of Maryland were each separated into three regions: upper, middle and lower. Each region had a centroid selected to represent where the cost of construction for that region would take place. Figure 5-16 shows the location of each centroid used in the development of the cost estimates. The centroid was selected based on where the tributaries in that region were located and which tributary would provide the best approximation for construction in the other tributaries.

At each of the sites shown in Figure 5-16, estimates for three different footprints of 25 acres, 50 acres and 100 acres were developed for a high relief reef design with an approximate reef height of 12 inches. USACE recognizes that reef height is a parameter that should be evaluated for each site within the development of the tributary plans, but assumes a height of 12 inches for purposes of developing a cost estimate. Additionally, due to the scarcity of some substrates used in the construction of oyster reefs, costs were developed for four different substrates. Those substrates are fossil shell, limestone, concrete rubble and rock, such as granite. The average cost per acre to construct a reef with a height of 12 inches is shown below in Table 5-17 for each substrate. Once the construction costs were developed, they were applied to the restoration targets acreage for each of the Tier 1 tributaries. Tables 5-18 and 5-19 show the initial construction cost of the low range acreage and high range acreage of the restoration targets. Cost projection calculations and further details are provided in Appendix G.

Table 5-17. Average Initial Cost Per Acre for Various Substrates

Maryland				
	Limestone	Granite	Concrete	Fossil Shell
Average Cost Per Acre	$137,400	$133,400	$86,700	$58,300
Virginia				
	Limestone	Granite	Concrete	Fossil Shell
Average Cost Per Acre	$148,800	$141,200	$93,000	$59,400

As shown in the Tables 5-18 and 5-19, the lowest cost substrate for constructing the reefs is fossil shell. However, fossil shell may be a scarce resource. There are a limited number of areas available for the dredging of fossil shell for reef construction. Therefore, additional substrates are presented. It is assumed that the most cost effective methods, which maximize the level of output versus cost will be utilized for restoration until exhausted. While it is difficult to ascertain which of the methods will be the prevailing construction technique, if the opportunity to take advantage of economies of scale exists in the construction of proposed projects, they should be pursued. This could provide savings in the construction of projects that would provide further economic justification for their construction. In evaluating ecosystem restoration projects for cost effectiveness and economic justification, it is assumed that ecosystem outputs (benefits) are at least equal to the construction cost.

Figure 5-16. Cost Estimate Centroids

Table 5-18. Total Initial Construction Costs for Low-Range Acreage Estimates

Maryland	Acres	Limestone	Granite	Concrete	Fossil Shell
Severn River	190	$24,800,000	$24,400,000	$15,700,000	$11,500,000
South River	90	$11,700,000	$11,600,000	$7,500,000	$5,500,000
Lower Chester River	500	$65,100,000	$64,300,000	$41,400,000	$30,300,000
Lower Eastern Bay	700	$95,300,000	$92,700,000	$60,200,000	$44,300,000
Lower Eastern Bay	800	$108,900,000	$106,000,000	$68,800,000	$50,700,000
Lower Choptank River	1,400	$190,500,000	$185,500,000	$120,400,000	$88,700,000
Upper Choptank River	400	$54,400,000	$53,000,000	$34,400,000	$25,300,000
Harris Creek	300	$40,800,000	$39,800,000	$25,800,000	$19,000,000
Little Choptank River	400	$54,400,000	$53,000,000	$34,400,000	$25,300,000
Broad Creek	200	$27,200,000	$26,500,000	$17,200,000	$12,700,000
St. Mary's River	200	$28,800,000	$27,600,000	$18,100,000	$9,600,000
Lower Tangier Sound	800	$115,200,000	$110,300,000	$72,300,000	$38,500,000
Upper Tangier Sound	900	$129,600,000	$124,100,000	$81,300,000	$43,300,000
Manokin River	400	$57,600,000	$55,100,000	$36,100,000	$19,300,000
Total	**7,300**	**$1,004,000,000**	**$974,000,000**	**$634,000,000**	**$424,000,000**
Virginia	**Acres**	**Limestone**	**Granite**	**Concrete**	**Fossil Shell**
Great Wicomico River	100	$15,400,000	$14,500,000	$9,600,000	$5,900,000
Lower Rappahannock River	1,300	$194,500,000	$184,200,000	$121,400,000	$78,300,000
Piankatank River	700	$104,700,000	$99,200,000	$65,400,000	$42,200,000
Tangier/Pocomoke	3,000	$461,500,000	$433,600,000	$287,100,000	$176,000,000
Mobjack Bay	800	$119,700,000	$113,300,000	$74,700,000	$48,200,000
Lower York River	1,100	$164,500,000	$155,800,000	$102,700,000	$66,300,000
Lower James River	900	$126,100,000	$121,700,000	$79,400,000	$51,700,000
Upper James River	2,000	$280,100,000	$270,400,000	$176,400,000	$114,900,000
Elizabeth River	200	$28,000,000	$27,000,000	$17,600,000	$11,500,000
Lynnhaven River	40	$5,600,000	$5,400,000	$3,500,000	$2,300,000
Total	**10,100**	**$1,500,100,000**	**$1,425,000,000**	**$938,000,000**	**$597,000,000**

*For summary, acres are rounded to nearest hundred and dollars are rounded to nearest million.

Table 5-19. Total Initial Construction Costs for High-Range Acreage Estimates

Maryland	Acres	Limestone	Granite	Concrete	Fossil Shell
Severn River	290	$37,800,000	$37,300,000	$24,000,000	$17,600,000
South River	200	$26,100,000	$25,700,000	$16,600,000	$12,100,000
Lower Chester River	1,100	$143,300,000	$141,400,000	$91,200,000	$66,800,000
Lower Eastern Bay	1,400	$190,500,000	$185,500,000	$120,400,000	$88,700,000
Lower Eastern Bay	1,600	$217,700,000	$212,000,000	$137,600,000	$101,300,000
Lower Choptank River	2,800	$381,000,000	$371,000,000	$240,900,000	$177,300,000
Upper Choptank River	800	$108,900,000	$106,000,000	$68,800,000	$50,700,000
Harris Creek	600	$81,700,000	$79,500,000	$51,600,000	$38,000,000
Little Choptank River	700	$95,300,000	$92,800,000	$60,200,000	$44,300,000
Broad Creek	400	$54,400,000	$53,000,000	$34,400,000	$25,300,000
St. Mary's River	400	$57,600,000	$55,100,000	$36,100,000	$19,300,000
Lower Tangier Sound	1,700	$244,700,000	$234,300,000	$153,500,000	$81,900,000
Upper Tangier Sound	1,800	$259,100,000	$248,100,000	$162,600,000	$86,700,000
Manokin River	800	$115,200,000	$110,300,000	$72,300,000	$38,500,000
Total*	**14,600**	**$2,013,000,000**	**$1,952,000,000**	**$1,270,000,000**	**$849,000,000**
Virginia	**Acres**	**Limestone**	**Granite**	**Concrete**	**Fossil Shell**
Great Wicomico River	400	$61,500,000	$57,800,000	$38,300,000	$23,500,000
Lower Rappahannock River	2,600	$388,900,000	$368,300,000	$242,800,000	$156,600,000
Piankatank River	1,300	$194,500,000	$184,200,000	$121,400,000	$78,300,000
Tangier/Pocomoke	5,900	$907,700,000	$852,800,000	$564,600,000	$346,200,000
Mobjack Bay	1,700	$254,300,000	$240,800,000	$158,700,000	$102,400,000
Lower York River	2,100	$314,100,000	$297,500,000	$196,100,000	$126,500,000
Lower James River	1,800	$252,100,000	$243,400,000	$158,800,000	$103,400,000
Upper James River	3,900	$546,200,000	$527,300,000	$344,000,000	$224,100,000
Elizabeth River	500	$70,000,000	$67,600,000	$44,100,000	$28,700,000
Lynnhaven River	150	$42,000,000	$40,600,000	$26,500,000	$17,200,000
Total*	**20,400**	**$3,031,000,000**	**$2,880,000,000**	**$1,895,000,000**	**$1,207,000,000**

*For summary, acres are rounded to nearest hundred and dollars are rounded to nearest million.

5.7.2.2 Seeding Costs

Estimates for potential seeding costs were developed for high and low salinity regions. Initial seeding costs for the low and high ranges of the restoration targets are presented in Table 5-20. As discussed in Section 5.2.3, the need for initial stocking and restocking is expected to vary based on salinity. The team estimated that reefs in low salinity areas (less than 12 ppt) would need to be stocked with spat-on-shell at a rate of 4 to 5 million spat/ac when the substrate was initially placed. Reefs in low salinity areas could be restocked at the same rate 2 to 3 years following initial planting if indicated by monitoring results. The cost estimates provided in this section are based on an estimate that one-half of low salinity reefs would have to be restocked following initial stocking. Based on this assumption, low salinity tributaries were considered to need approximately 6.75 million spat/ac.

Table 5-20. Low and High-Range Seeding Estimates

	Low Range Estimates		High Range Estimates	
Maryland	**Acres**	**Seeding Costs**	**Acres**	**Seeding Costs**
Severn River	190	$21,200,000	290	$32,300,000
South River	90	$10,000,000	200	$22,300,000
Lower Chester River	500	$55,700,000	1,100	$122,500,000
Lower Eastern Bay	700	$77,900,000	1,400	$155,900,000
Lower Eastern Bay	800	$89,100,000	1,600	$178,100,000
Lower Choptank River	1,400	$52,000,000	2,800	$104,000,000
Upper Choptank River	400	$14,900,000	800	$29,700,000
Harris Creek	300	$11,100,000	600	$22,300,000
Little Choptank River	400	$14,900,000	700	$26,000,000
Broad Creek	200	$7,400,000	400	$14,900,000
St. Mary's River	200	$7,400,000	400	$14,900,000
Lower Tangier Sound	800	$29,700,000	1,700	$63,100,000
Upper Tangier Sound	900	$33,400,000	1,800	$66,800,000
Manokin River	400	$23,800,000	800	$47,600,000
Total	**7,300**	**$449,000,000**	**14,600**	**$900,000,000**
	Low Range Estimates		**High Range Estimates**	
Virginia	**Acres**	**Seeding Costs**	**Acres**	**Seeding Costs**
Great Wicomico River	100	$3,700,000	400	$14,900,000
Lower Rappahannock River	1,300	$48,300,000	2,600	$96,500,000
Piankatank River	700	$26,000,000	1,300	$48,300,000
Tangier/Pocomoke	3,000	$111,400,000	5,900	$219,000,000
Mobjack Bay	800	$29,700,000	1,700	$63,100,000
Lower York River	1,100	$40,800,000	2,100	$77,900,000
Lower James River	900	$33,400,000	1,800	$66,800,000
Upper James River	2,000	$74,200,000	3,900	$144,800,000
Elizabeth River	200	$5,900,000	500	$14,900,000
Lynnhaven River	40	$1,500,000	150	$5,600,000
Total	**10,100**	**$375,000,000**	**20,400**	**$752,000,000**

*For summary, acres are rounded to nearest hundred and dollars are rounded to nearest million.

The need for initial stocking of high salinity reefs (greater than 12 ppt) will be based on the results of pre-implementation recruitment monitoring. In some cases, stocking will not be required at all because of the capacity for natural recruitment. The cost estimates provided in this section are based on an estimate that 50 percent of high salinity reef acreage would have to be stocked with spat-on-shell at approximately 4.5 million spat/ac.

5.7.2.3 Monitoring Costs

Monitoring of restoration efforts is needed to determine success and health of the restored habitat and will add additional costs to restoration. The following discussion estimates monitoring costs for each tributary given what is projected by the master plan to be needed to achieve the restoration targets. Low and high-range cost-estimates are provided in Table 5-21 (rounded to nearest hundred). Specific monitoring plans with costs will need to be developed with tributary plans. Monitoring will be guided by the report developed by the Oyster Metrics Workgroup of the Sustainable Fisheries GIT of the CBP (OMW 2011). Additional discussion of monitoring and adaptive management is in Section 7 of this report.

Table 5-21. Low and High-Range Monitoring Estimates

	Low Range Estimates			High Range Estimates		
Maryland	**Acres**	**Sample Size**	**Monitoring Costs**	**Acres**	**Sample Size**	**Monitoring Costs**
Severn River	190	112	$39,000	290	141	$49,000
South River	90	68	$24,000	200	116	$41,000
Lower Chester River	500	176	$62,000	1,100	218	$76,000
Lower Eastern Bay	700	196	$69,000	1,400	228	$80,000
Lower Eastern Bay	800	203	$71,000	1,600	233	$82,000
Lower Choptank River	1,400	228	$80,000	2,800	248	$87,000
Upper Choptank River	400	162	$57,000	800	203	$71,000
Harris Creek	300	143	$50,000	600	187	$65,000
Little Choptank River	400	162	$57,000	700	196	$69,000
Broad Creek	200	116	$41,000	400	162	$57,000
St. Mary's River	200	116	$41,000	400	162	$57,000
Lower Tangier Sound	800	203	$71,000	1,700	235	$82,000
Upper Tangier Sound	900	209	$73,000	1,800	237	$83,000
Manokin River	400	162	$57,000	800	203	$71,000
Total*	**7,300**		**$800,000**	**14,600**		**$1,000,000**
	Low Range Estimates			**High Range Estimates**		
Virginia	**Acres**	**Sample Size**	**Monitoring Costs**	**Acres**	**Sample Size**	**Monitoring Costs**
Great Wicomico River	100	73	$26,000	400	162	$57,000
Lower Rappahannock River	1,300	225	$79,000	2,600	247	$86,000
Piankatank River	700	196	$69,000	1,300	225	$79,000
Tangier/Pocomoke	3,000	250	$88,000	5,900	260	$91,000
Mobjack Bay	800	203	$71,000	1,700	235	$82,000
Lower York River	1,100	218	$76,000	2,100	241	$84,000
Lower James River	900	209	$73,000	1,800	237	$83,000
Upper James River	2,000	240	$84,000	3,900	255	$89,000
Elizabeth River	200	116	$41,000	500	176	$62,000
Lynnhaven River	40	35	$12,000	150	97	$34,000
Total*	**10,100**		**$600,000**	**20,400**		**$700,000**

Monitoring costs for each tributary are considered based on the number of acres in the low and high range of each tributary and the sample size necessary for a 90 percent confidence level with a 5 percent interval. The sample size was calculated for each tributary and is represented in acres. It may be that sampling individual reefs is conducted in the future; however, the construction configuration and number of reefs to be built in any of the tributaries is unknown at this time. Therefore, the size of the potential restoration is used to determine the appropriate sample size and cost. Based on the report from the Oyster Metrics Workgroup, at minimum, monitoring would be conducted immediately after construction in year one and further monitoring would be conducted in years three and six.

5.7.2.4 Individual Tributary Cost Estimates

A range of costs is presented in Table 5-22 for each tributary. Estimated costs vary widely per tributary. Cost estimates project that investments ranging from $3.8 million to $46.2 million for the smallest Tier 1 tributary (Lynnhaven River, 40 to 150 ac) to $287.5 million to $1.07 billion for the largest Tier 1 tributary (Tangier/Pocomoke Sound 3,000 to 5,900 ac) are needed to achieve restoration targets. The low end of the cost range includes the estimated costs to construct high relief (12 inches) hard reef habitat on every acre of the low restoration target using fossil shell (least costly substrate), seeding, and monitoring. The high end of the cost range includes the estimated costs to construct high relief (12 inches) hard reef habitat on every acre of the high restoration target using granite (high cost substrate), seeding, and monitoring. Limestone is a slightly more expensive alternate substrate, but granite is the most likely alternate substrate to be used (and that has been used) in USACE restoration projects when shell is not available.

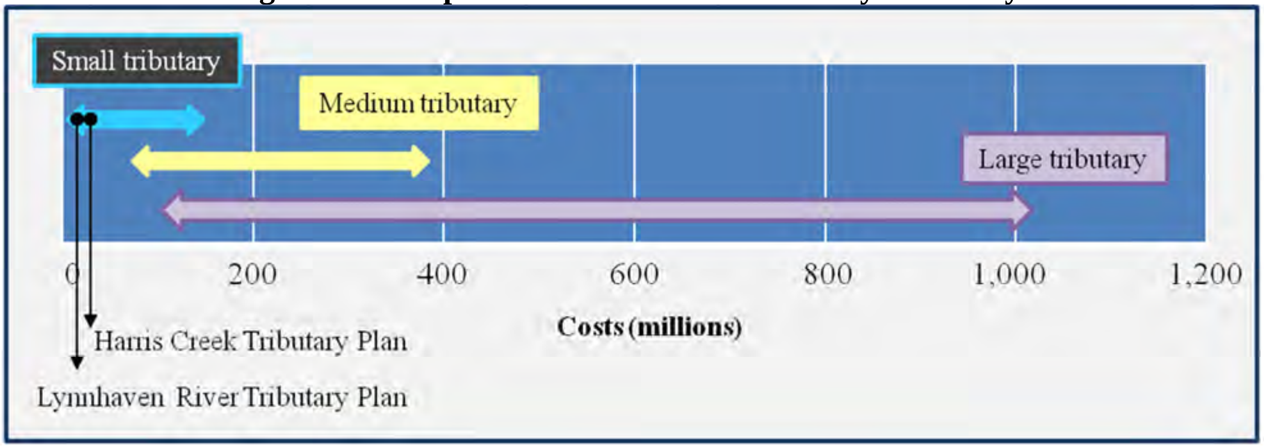
Tributary cost estimates are conservatively high in that the assumption was made to develop the cost estimates to include the cost for constructing high relief habitat on every acre targeted because at the time of master plan development it was not known how many acres of reef habitat exist in each tributary. The number of existing functioning oyster reefs is expected to vary widely by tributary. However, it is anticipated that restoration will not require the addition of substrate for every targeted acre. Population surveys completed prior to tributary plan development will be critical information to revise the cost estimates, and will likely lead to reduced costs estimates for specific tributary plans. Development of the Harris Creek Tributary Plan and Lynnhaven River Tributary Plan are examples of how cost estimates are refined further to produce lower total restoration costs. The Harris Creek Tributary Plan is being drafted. The preliminary cost estimate is $26 million and includes construction of approximately 100 acres of high relief habitat. Approximately 200 acres are planned to receive only seed for a total restoration target of 300 acres. In comparison, the master plan cost estimate was $30.2 (300 ac) to $101.8 million (600 ac). The reduction in cost for the Harris Creek Tributary Plan is largely due to the presence of 200 acres of marginal habitat that will not require substrate addition, as identified by a population survey. The Lynnhaven River Tributary Plan is estimated at $12 million to restore 111 acres of oyster reef. The master plan cost estimate range is $3.8 to $46.1 million.

Table 5-22. Cost Ranges by Individual Tributary

Maryland	**Cost range (millions)**	**Acreage range**
Severn River	$32.7 – $69.6	190 – 290
South River	$15.5 – $48.0	90 – 200
Lower Chester	$86.0 – $264.0	500 – 1,100
Lower Eastern Bay	$122.3 – $341.5	700 – 1,400
Upper Eastern Bay	$139.9 – $390.2	800 – 1,600
Lower Choptank	$140.8 – $475.0	1,400 – 2,800
Upper Choptank	$40.3 – $135.8	400 – 800
Harris Creek	$30.2 – $101.9	300 – 600
Little Choptank	$40.3 – $118.9	400 – 700
Broad Creek	$20.1 – $68.0	200 – 400
St. Mary's River	$17.1 – $70.0	200 – 400
Lower Tangier Sound	$68.3 – $297.5	800 – 1,700
Upper Tangier Sound	$76.8 – $315.0	900 – 1,800
Manokin River	$43.1 – $158.0	400 – 800
Total	$873.3 – $2,853.4	7,300 – 14,600
Virginia	**Cost range**	**Acreage range**
Great Wicomico River	$9.6 – $72.7	100 – 400
Rappahannock River- lower	$126.7 – $464.9	1,300 – 2,600
Piankatank River	$68.3 – $232.5	700 – 1,300
Tangier/Pocomoke	$287.5 – $1,071.8	3,000 – 5,900
Mobjack Bay	$78.0 – $304.0	800 – 1,700
York River- lower	$107.2 – $375.5	1,100 – 2,100
Lower James River	$85.2 – $310.2	900 – 1,800
Upper James River	$189.2 – $672.1	2,000 – 3,900
Elizabeth River	$19.0 – $ 123.3	200 – 500
Lynnhaven River	$3.8 – $46.2	40 – 150
Total	$972.9 – $3,632.8	10,100 – 20,400

The cost ranges by tributary size are depicted in Figure 5-17. Small tributaries have a maximum targeted acreage less than 1000 acres. Medium tributaries are defined as those with a maximum restoration target less than 2000 acres. Large tributaries have maximum restoration targets greater than 2000 acres. The cost estimate for the Harris Creek and Lynnhaven Tributary Plans are also depicted in Figure 5-17 to illustrate how they compare to the broader cost estimates of the master plan.

Figure 5-17. Implementation Cost Estimates by Tributary Size



5.7.2.5 Analysis of Implementation Scenarios

Three restoration scenarios are presented in the following discussion in an effort to communicate the costs needed for large-scale restoration. These scenarios are:

1. Restoration of all Tier 1 tributaries/DSS (low to high cost range as defined previously),
2. Salinity-based implementation, and
3. E.O. implementation of 20 tributaries/DSS

Table 5-23 presents the cost ranges for each scenario, the number of tributaries included in the scenario, and the targeted acres for restoration.

Table 5-23. Summary of Implementation Scenarios

	Number of Tier 1 Tributaries/ DSS	Acres of Oyster Reef Targeted	Total Estimated Low Range Cost	Total Estimated High Range Cost
Scenario 1 – All Tributaries	24	17,400–35,000	$ 1.85 billion	$ 6.50 billion
Scenario 2 – Salinity-based restoration	24	18,200	$ 1.99 billion	$ 3.42 billion
Scenario 3 – E.O. Implementation	20	14,400–28,400	$ 1.56 billion	$ 5.38 billion

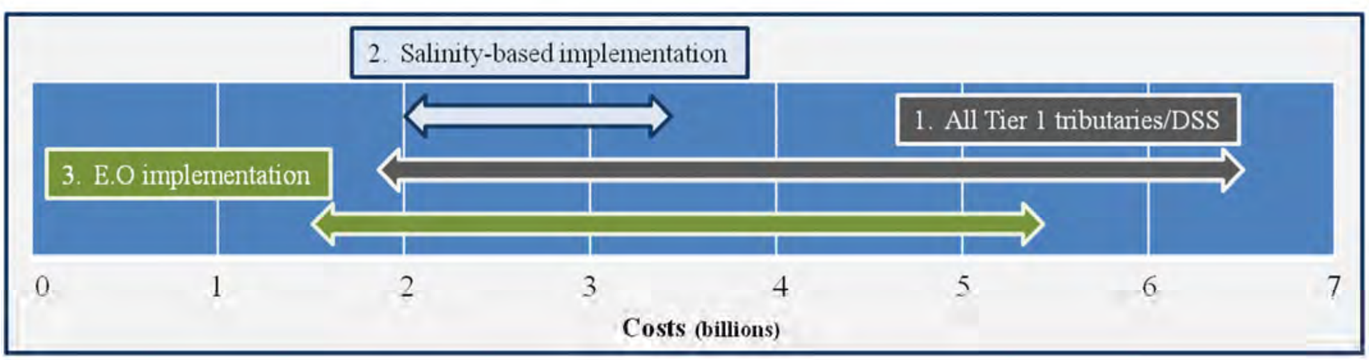
Scenario 1 – Restoration of all Tier 1 tributaries/DSS: Adding the low end of the cost range for all tributaries and then the high end of the cost range for all tributaries produces the total cost estimate range for restoration in all Tier 1 tributaries/DSS, $1.85 to $6.50 billion. The low end and high end of the cost range are calculated in the same manner as discussed previously. The high range of these cost estimates should also be viewed as highly conservative. Not only do the high estimates include construction of high relief reef on every targeted acre, but it is highly unlikely that every tributary will require restoration at the high acreage target. It is expected that most tributaries will be restored to the low acreage target initially and then additional acreage added if restoration is not performing and habitat limitation is determined to be the reason. Higher acreage would only be restored initially if planning efforts identify a need and support the investment. The acres restored under this scenario would range from 17,400 to 35,000 acres.

Scenario 2 – Salinity-based implementation: This scenario assumes that low salinity tributaries require more habitat acreage to be restored because reproduction is lower compared to high salinity tributaries. Therefore, the low salinity tributaries (Severn, South, and lower Chester) are implemented at the high acreage target and high salinity tributaries (all the remaining tributaries/DSS) are implemented at the low acreage target. This results in a restoration target of 18,200 acres, rather than an acreage range. All tributaries are included. The low end of the cost range incorporates costs for the least expensive alternate substrate (dredged fossil shell). The high end of the cost range incorporates costs for granite, a high cost alternate substrate. Under this scenario, implementation costs range from $1.99 to $3.42 billion.

Scenario 3 – E.O. Implementation: Executive Order 13508 established an oyster outcome of restoring 20 tributaries by 2025. The master plan and the Oyster Metrics Workgroup (OMW 2011) recommend focusing on smaller tributaries/DSS initially for restoration. For planning purposes, a number of combinations of 20 tributaries were evaluated to develop an approximate cost range for E.O. implementation. On average, costs for E.O. implementation are projected to range from $1.56 to $5.38 billion. The acres restored under this scenario would range from 14,400 to 28,400 acres.

Figure 5-18 depicts the cost estimate ranges for the three scenarios. Scenario 3, E.O. Implementation is the most likely and most relevant cost estimate range given the overarching focus to meet the E.O. oyster outcome. One should not assume that all tributaries need to be restored before benefits are achieved. Restoration will provide a wide-range of ecosystem services to individual tributaries prior to the E.O. outcome being achieved. Further, USACE is not recommending an investment of this magnitude at any one time. Restoration should progress tributary by tributary. Benefits are achieved with each reef and each tributary that is restored.

Figure 5-18. Cost Range Comparison for Implementation Scenarios



5.8 RISK AND UNCERTAINTY

As is the case with many ecosystem restoration efforts, there is a significant amount of risk and uncertainty associated with oyster restoration. Climate, alone, plays a major role and there is no way to control that factor. That is, the amount of rainfall will largely control the salinity of the restoration site and drive disease pressure, reproduction, and growth. Table 5-24 summarizes the various risk factors and the management measures the master plan is proposing to address each. The master plan focuses on addressing the stressors that are the source of the risk and uncertainty. For those factors that are part of the natural environment, such as salinity, the master plan attempts to lay out strategies that are best suited for the condition.

Table 5-24. Summary of Risk, Uncertainty, and Management Measures

Risk (Stressor)	Uncertainty and Description of Risk	Risk Management Measure
Disease	Risk is low in low salinity and high in high salinity. Risk increases in dry years, particularly in low salinity waters.	• Disease strategy • Plans will promote development of resistance • Use disease-resistant broodstock for hatchery production • Enhance recruitment to compensate for disease mortality
Salinity	Drives all aspects of oyster biology. Largely controlled by annual precipitation events. Risk greatest to low salinity waters in wet years when salinity decreases below level that can support reproduction. Dry years can drive disease risks up in low salinity waters.	• Evaluate salinity conditions of potential site prior to site selection • Screen region for average salinity • Locate reefs for enhancing reproduction at >8 ppt
Illegal Harvests	Oysters are removed from system. Habitat is degraded or lost. Risk is high throughout Bay.	• Restrict efforts to sanctuaries • Incorporate alternate substrates in high risk areas to discourage poaching • Encourage states to increase enforcement and monitoring
Predation	Oysters are consumed. Risk in low salinity is low. Risk increases as number of predators increase with increasing salinity (proximity to mouth of Bay). Risk is high in high salinity.	• Use predator exclusion devices in high risk areas • Use spat-on-shell for seeding • Include interstitial space in constructed reefs
Freshets	Prolonged low salinity events can kill oysters. Greatest risk is to low salinity waters furthest upriver and areas that receive a large amount of direct freshwater input from overland flow.	• Evaluate history of freshets in a potential site • Avoid areas known to have frequent freshets
Sediment	Sediment can smother oyster reefs. Risk can be very localized. Healthy reefs should be able to cope with sediment pressure.	• Evaluate available sedimentation data prior to site selection • Avoid high risk areas. Provide 3D reef structure
Shell Budget	A positive shell budget is needed to maintain a healthy oyster reef. Shell is lost by degradation stemming from predation, dissolution, sedimentation, and harvest. Spats sets are too low in many places to counter mortality. Sanctuaries may be a mechanism by which to slow rates of shell loss (Carnegie and Burreson 2011).	• Incorporate alternate substrates to provide reef base that will not degrade • Re-seed based on monitoring data to achieve a multi-age population • Initial focus on retentive systems • Support nutrient controls to reduce pressure from acidification.
Recruitment/ Depleted Broodstock	Broodstocks significantly depleted. Greatest risk in low salinity areas where reproduction is naturally low. Enhanced broodstocks needed to restore connectivity, sustain reefs, and reduce restoration costs.	• Reproduction Strategy • Initial focus on retentive systems to retain reproduction from efforts • Re-seed to achieve a multi-age population and sex structure where appropriate

Risk (Stressor)	Uncertainty and Description of Risk	Risk Management Measure
Habitat Loss	Oysters need hard substrate for spat to set. Hard bottom needed for placement of substrate for habitat. Benthic environment has been seriously degraded. Much lost to sedimentation and removed by harvest. Risk is greatest in tributaries that no longer have significant bottom that can support oysters.	• Construct habitat using available shell and alternate substrates • Obtain current bottom surveys to guide site selection
Sea Level Rise (SLR) and Climate Change	Risk to oyster reefs is uncertain. Water depth change is a low risk. Some aspects such as increased temperatures may help oysters. Increased acidification would increase risk of failure. Uncertain of salinity response to SLR/climate change.	• Monitor • Avoid areas on fringe of optimal range that would be the most likely to be negatively impacted

Oyster monitoring efforts. (Photographs courtesy of USACE-Norfolk).

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 RECOMMENDATIONS

Through this master plan, USACE is recommending large-scale tributary-based oyster restoration. The goals outlined in Section 3 are focused on restoration of oysters and reef habitat to the Chesapeake Bay, tributary by tributary, using a sanctuary-based approach. It is anticipated that these restored areas (if completed at a sufficient scale) have the ability to produce habitat and contribute to restoring populations in areas outside of sanctuaries. In Section 5.2, USACE outlined recommended salinity, disease, and reproduction strategies for large-scale restoration.

This master plan recommends 24 (Tier 1) tributaries of the Chesapeake Bay are currently suitable for large-scale oyster restoration. These sites (Figure 5-15) are distributed throughout the Bay with 14 sites in Maryland and 10 sites in Virginia (Table 5-13). Table 6-1 provides a summary of the restoration targets and costs for all the Tier 1 sites. If restoration of these tributaries were to be spread over a 20-year period to meet the goals of E.O. 13508, it would require approximate annual expenditures of $93 million to $325 million at October 2010 price levels and restoration of hundreds of acres. It is unlikely that funding and resources such as substrate and seed are available to do large-scale restoration on all the suitable tributaries within the 20-year timeframe. Further, only 12 of the 14 Maryland Tier 1 tributaries contain designated sanctuaries. None of the Tier 1 Virginia tributaries besides the Great Wicomico and Lynnhaven Rivers contain large sanctuaries.

Table 6-1. Summary of Restoration Area and Cost by State

	Number of Tier 1 Tributaries	Oyster Reef Restoration Target (acres)	Total Estimated Low Range Cost	Total Estimated High Range Cost
Maryland	14	7,300-14,600	$0.87 billion	$2.85 billion
Virginia	10	10,100-20,400	$0.97 billion	$3.63 billion
Total	24	17,400-35,000	$1.85 billion	$6.50 billion

In the future, the Tier 1 tributaries should be further prioritized with partners. Table 6-2 highlights the consistency between master plan tributary recommendations and those recommended by other agencies in recent oyster documents.

Given the vast resources required to complete restoration in all Tier 1 tributaries and the fact that large-scale restoration techniques are still being developed, USACE recommends choosing a tributary or two in each State for initial restoration efforts. Specific tributary plans should be developed for these tributaries and include a refinement of the restoration target. Construction would proceed in a selected tributary by constructing a portion of the target (25, 50, or 100 acres)

Table 6-2. Comparison of Recommended Tributaries by Various Oyster Restoration Plans

Tributary	*MD Oyster Advisory Commission*	*MD Oyster Restoration and Aquaculture Development Plan*	*VA Blue Ribbon Panel*	*USACE Native Oyster Restoration Master Plan*
MARYLAND				
Magothy River	X	X		
Chester River		X (upper and lower)		X (lower)
Little Choptank River		X		X
Patuxent River		X (upper and small area in lower)		
Choptank River	X	X (middle and lower)		X (lower and upper)
Broad Creek				X
Harris Creek		X		X
Tred Avon River		X (upper)		X (within lower Choptank)
Severn River	X	current sanctuary		X
South River	X	current sanctuary (upper)		X
Honga River	X			X
Eastern Bay		X (parts)		X (lower and upper)
Manokin River				X
Miles River		X (upper)		X (within Eastern Bay)
Wye River		X		X (within Eastern Bay)
St. Mary's River	X	X (upper)		X
Mainstem		X (Point Lookout)		
Breton Bay		X		
Tangier Sound				X (lower and upper)
Nanticoke River		X		
Manokin River		X		X
VIRGINIA				
Eastern Shore seaside coastal bays			X	(outside Master Plan study area)
Lynnhaven River			X	X
Great Wicomico River			X	X
Piankatank River			X	X
Rappahannock River				X (lower)
Mobjack Bay				X
York River				X (lower)
Pocomoke/Tangier Sound				X
James River				X (lower and upper)
Lynnhaven River				X

per year based on available resources until success metrics are achieved. Restoration efforts and resources should be concentrated in these tributaries to develop and prove methodology and provide the greatest possibility for success. A Bay strategy that involves starting work in the smaller tributaries/areas and then progressively moving to the larger tributaries may have merit for the following reasons:

- Getting the smaller trap estuary systems to full self-sustaining status would require less time and resources. This would include technical studies, design, construction, and monitoring.
- Once smaller systems are fully functional they could provide wild spat-on-shell to augment populations in the larger systems.
- Lessons learned in the smaller systems can be applied to the larger systems in the future, reducing the greater risk and uncertainty associated with large scales.
- Smaller scale projects provide a lower risk for demonstrating success.

The following sections outline areas that USACE views as critical in development of tributary-specific plans and to future project implementation. Given the amount of bottom habitat as well as substrate and seed inputs that will be required to complete restoration on a tributary level, mapping of current hard bottom that can support reef construction will be a critical next step. It will be imperative to identify tributaries that have sufficient hard bottom to meet the restoration target and enable restoration to be operationally feasible and cost-effective.

The breadth of the parameters that should be considered to develop tributary-specific plans speaks to the need to partner with other agencies and groups involved with Chesapeake Bay oyster restoration. Successful achievement of restoration goals and objectives will require a leveraging of the skills and resources of this diverse group of restoration partners.

6.2 IMPLEMENTATION CONSIDERATIONS FOR FUTURE TRIBUTARY-SPECIFIC PLANS

The master plan is a programmatic document which evaluates and prioritizes oyster restoration tributaries and areas throughout the Chesapeake Bay on a Bay-wide scale. As discussed previously, the document does not describe or evaluate specifically implementable projects. The age and accuracy of the information used to evaluate existing conditions and assign tributaries to tiers is quite variable from one tributary to the next and in some situations very limited. After the master plan is completed, follow-on tributary specific restoration plans will be developed by USACE and restoration partners. The investigations and data analysis undertaken as part of the tributary plan efforts may justify changing the tier classification of a tributary.

It is anticipated that other agencies and organizations involved with oyster restoration in the Bay will be closely involved with development of these plans and that these groups may implement projects in areas outlined in the master plan that support their own agency goals and objectives. The combined efforts should all be considered by the oyster restoration community in assessing progress toward long-term sustainable oyster restoration in the Chesapeake Bay.

NOAA has initiated the development of a draft tributary plan framework with USACE which incorporates the ideas in this section. This draft framework is presented in Appendix D. There are many issues and parameters to consider at the scale of a specific tributary plan. As previously discussed, the factors outlined in Table 5-10 and discussed in Section 5.5.4 should be considered further during the development of individual tributary plans. The surveys listed below and described in the subsequent sections are evaluations that serve as the foundation for the specific tributary planning process. They are specifically mentioned here because of their critical importance in locating reef sites. Current, accurate data for these specific factors will be key to site selection:

- Bottom condition surveys,
- Population surveys,
- Hydrodynamic and larval transport modeling,
- Bathymetric surveys,
- Recruitment surveys, and
- Biological and ecosystem benefit modeling.

6.2.1 BOTTOM CONDITION SURVEYS

It is more cost-effective to build reefs on hard bottom substrates that can support the addition of habitat structure rather than soft bottom because the reefs do not require overbuilding to accommodate subsidence. Bottom condition surveys would identify hard bottom areas and, in the softer substrates, those areas that may require overbuilding. NOAA, MGS, and others are using groundtruthed side-scan, multi beam, and single beam sonar to map Chesapeake Bay bottom areas. This information should be used as a screening tool for locating suitable bottom for oyster reefs.

6.2.2 POPULATION SURVEYS

Population surveys to identify the location and condition of existing oyster bars and reefs are the next step following bottom surveys. Bottom surveys will identify where the bottom is covered by shell, sand, mud, etc., but is unable to discern living oysters. Population surveys will provide this information. The location of oysters is needed to guide restoration site selection, is an input for larval transport modeling as larval release sites, and will help prevent the accidental degradation of existing oysters by poor site selection. Further, in order to best determine if and/or how much additional stocking of constructed reefs will be required, it will be important to understand the existing broodstock population and its contribution to recruitment in the system.

6.2.3 HYDRODYNAMIC AND LARVAL TRANSPORT MODELING

Understanding the hydrodynamics and larval transport within a tributary is critical to re-establish connectivity and reef networks and needs to be considered when laying out tributary specific restoration plans. Cost-effective and timely methods to evaluate tributary hydrodynamics and larval transport are needed. Lipcius et al. (2008) highlighted the importance of metapopulation connectivity within a tributary as well as source and sink dynamics. High-resolution, three-dimensional hydrodynamic modeling can confirm the retentiveness of the system. Larval transport modeling can assist with identifying source and sink metapopulation dynamics within a system in order to properly place specific reef types to achieve a connected reef network. Larval transport modeling in the Bay is relatively new, but offers much promise. Efforts to calibrate these models are underway (North, pers. Comm.) and need to be continued. These pieces of information are needed to site reefs to enhance the opportunity to achieve self-sustaining populations. All model components (circulation, larval transport, demographics) should be validated with observations from field programs as well as other ongoing monitoring programs in Virginia and Maryland. Linked larval transport-demographic models could be used to identify which factors influence spatial patterns in oyster abundances, which reefs are sources and sinks, and how environmental variability, habitat alteration, and potential climate change influence oyster populations.

Larval transport modeling will be strengthened by the incorporation of the location of current oysters within the modeling efforts. This information should be used as the release points for larvae and as a means to verify modeling results.

6.2.4 BATHYMETRIC SURVEYS

Bathymetric surveys will be needed to develop site-specific designs including horizontal and vertical dimensions of reefs in various locations and at various depths. This information will also be used to develop reef construction plans considering site logistical constraints such as navigation channels, wharfs, piers, and channel markers. Bathymetric and bottom surveys are interdependent. Bathymetry plays a key role in determining the condition of the bottom at a particular place. Acoustically, bottom that looks suitable from a side scan sonar survey may not have enough relief to be deemed suitable for restoration. In this situation, as with much of the information compiled to develop restoration plans, the data must be considered together to provide a complete picture of current conditions.

6.2.5 RECRUITMENT SURVEYS

Figure 6-1. Example of Shell-String Used for Recruitment Surveys.

Photograph provided by USACE-Norfolk.

Existing recruitment within a system can be determined through field measurements such as shell-string surveys. Monitoring and harvest data from recent years is also important to consider. For example, the VIMS spatfall survey deploys shell strings weekly from May through September at stations throughout the Chesapeake Bay to provide an annual index of oyster settlement and recruitment. Shell strings (12 shells on a wire; sample is shown in Figure 6-1) are suspended 0.5 meter from the bottom to provide settlement substrate for oyster veligers. After retrieval, oyster spat (recently settled oysters) on the undersides of 10 shells are counted under a dissecting microscope.

The average number of spat per shell is calculated for each time and place. This information (summarized in an annual report) is useful for deciding if the constructed reef structure may or may not require population augmentation via application of spat-on-shell. This information may not be available for every area or tributary and may require some additional field work during the study phase prior to implementation. A broodstock assessment for the Bay is currently being performed. This information will be beneficial to guide future restoration efforts. The bottom condition surveys discussed above can also play a role by identifying where current shell exists and thus narrowing the boundaries of further intensive investigations aimed at identifying the locations of current populations.

6.2.6 BIOLOGICAL AND ECOSYSTEM BENEFIT MODELING

A biological model is a representation of a biological system. Mathematical models use mathematical equations to represent systems. Many topics can be studied from within the framework of biological mathematical models. For example, oyster population growth and population dynamics lend themselves very well to mathematical modeling. The partners who developed the PEIS study, attempted to develop and apply an oyster demographic model, but were ultimately not successful because of the complexity of the system. This process highlighted that current data is not available on a Bay-wide scale to support such a model and USACE does not recommend undertaking a similar Bay-wide endeavor. However, mathematical models could be used to identify and quantify ecological benefits associated with specific oyster restoration sites and alternatives. These benefits, and the associated costs of the alternatives, would then be used to refine and select alternatives that yield the greatest benefit for the least cost. Currently, there is not a model available for oysters that could be used to project restoration benefits. It is recommended that a model be developed that could relate basic oyster measurements such as biomass or density to ecosystem services including, but not limited to water filtration, nutrient sequestration, and secondary production. This tool would enable the oyster restoration community to compare restoration projects and communicate the wide-ranging benefits of oyster restoration to the general public.

6.3 OYSTER REEF DESIGN RECOMMENDATIONS

This section provides recommendations for the distribution and design of reefs within an individual tributary.

Many factors must be considered in designing oyster reefs and implementing restoration plans. These factors are design factors that must be considered when siting individual reefs and their position in the water body. Also, USACE policy requires that all coastal water resources planning studies consider the effects of sea level rise. Together these factors help to define how the individual restoration projects will be carried out in each tributary. The factors and the master plan recommendations are presented in Table 6.3. The factors and their applications are explained in the sections that follow.

The plan formulation white papers (Appendix C) provide further details regarding many of these issues.

6.3.1 REEF MORPHOLOGY (SHAPE) AND SIZE

Two historical reef morphologies have been documented (Woods et al. 2004) in the Chesapeake Bay, a northern style and a southern style and described in Section 4.4. These historical characteristics will be applied when siting individual reefs under the master plan.

Table 6-3. Summary of Oyster Reef Design Recommendations for Tributary Plans

Design Factor	Recommendation
Reef morphology and size	Determine in tributary plans, will depend on historic size, currently suitable bottom, and quantity of hard substrate needed to provide suitable bottom habitat.
Reef fragmentation	Include fragmentation in designs during tributary plans, likely at intermediate levels (<50%).
Reef height	Elevate reefs off bottom, expect minimum needed is 1 foot. Determine specific height in tributary plans. Include heterogeneity.
Reef topography	Include heterogeneity. Provide for interstitial space within reef complex.
Orientation to flow	Determine in tributary plans based on historic position and current water flows and bathymetric gradients.
Water depth	Less than 20 feet MLLW.
Distance between reefs	Determine in tributary plans based on historic placement. Consider larval transport modeling findings.
Predator exclusion devices	Determine in tributary plans based on location in Bay, need and effectiveness of devices, costs, and available resources.
Poaching deterrents	Incorporate into future restoration plans.
Substrate	Determine in tributary plans, will depend on available resources and other users/activities in selected tributary.
Sea level rise and climate change	Evaluate proposed restoration plans for future sea level rise and climate change impacts in tributary plans. Incorporate alternate substrates to provide a reef base resilient to the risks posed from increasing acidity. Highlight the need for watershed management to reduce the pressure from increasing acidity from eutrophication. If available, addition of vast quantities of shell to tributaries should be considered for its potential to mitigate impacts of increasing acidification.

The size of individual reefs will be determined by follow-on tributary plans prior to construction. Reef size will vary within and among sites. Historical accounts such as Winslow (1882) will be used to guide decisions about reef size. Size of restored reefs will depend on the historic size of the reefs being restored, the currently available suitable bottom, and the amount of hard substrate (whether oyster shell or alternate substrate) needed to provide suitable bottom habitat. The size of individual restored reefs will likely be smaller than the smallest identified by Winslow (e.g. 25 acres vs. 41.5 acres) given current conditions in the Bay and available resources.

6.3.2 Reef Fragmentation

Based on the work of Harwell (2004) and Eggleston (1999) fragmentation should be included in reef design. Reefs should not be constructed in large continuous, uniform plots, but rather should allow for channels between restored areas. At this time, science has not provided specific guidance on the size of these channels and fragmented areas. Current construction methods inherently provide some fragmentation to a restored reef, but additional efforts should be made to establish dense plots within a restored area that are separated by defined channels of unrestored bottom. Evidence presented by Harwell (2004) suggests that fragmentation would need to be less than 50 percent, and Eggleston (1999) proposed that oyster density and diversity of the reef community would be greatest at intermediate levels of fragmentation. Smith et al. (2003) identified lumps ranging from 1 to 12 meters in diameter that ringed the main terrace reef, and had elevations similar to the terrace. Tributary plans will address the spatial design of individual reefs for restoration.

6.3.3 Reef Height

Regional oyster experts convened in 1999 determined that three-dimensional reefs substantially elevated off the bottom (CRC 1999 as cited by Carnegie and Burreson 2011) was one of the two critical features of oyster restoration and recent work by Jordan-Cooley et al. (2011) highlighted the need for high relief to offset sedimentation. Reef height elevates oysters out of the bottom sediments, into more oxygenated waters, and provides for suitable water currents that promote food delivery and waste removal, all resulting in more healthy oysters. Woods et al. (2004) does not define quantitatively the “little relief” of northern-style reefs or “significant relief" of southern-style reefs. McCormick-Ray (2005) identified that Tangier Sound oyster beds surveyed by Winslow had a substratum thickness that ranged from 0.3 meters (0.98 feet) to over 0.9 meters (2.95 feet). Using McCormick-Ray (2005) as a guide and applying lessons learned from the Great Wicomico River oyster restoration, the master plan recommends constructing reefs to at least a height of 1 foot with some minor variation in height across the reef to create topographic heterogeneity. However, the master plan recognizes that conditions will be unique at each restoration site. Therefore, reef height may vary depending on site conditions. Within the Chesapeake Bay, 1 foot of relief is expected to be sufficient to promote reef longevity, but appropriate heights for restoration should be determined during development of tributary plans. Following the initial construction phase, the reefs should be evaluated to determine if reef height needs to be adjusted for future reefs constructed in that tributary. Construction methods should continue to be evaluated and improved to fully understand our ability to adequately control placement of reef materials.

6.3.4 Reef Topography

Topographic heterogeneity (variability in the height of the reef surface) is an important feature to provide when restoring oyster reef. As discussed above, northern-style reefs exhibited fine-scale heterogeneity while southern-style reefs had lumps and ridges. Due to the current construction methods, some degree of fine-scale heterogeneity is likely to occur on all constructed reefs because shell and spat cannot be placed precisely or uniformly. However, the techniques are not available to directly control the creation of fine-scale heterogeneity. For southern-style reefs, placement techniques exist to construct lumps and ridges and these features should be incorporated into specific tributary restoration plans. Multi-beam seismic profiling can be incorporated into post-construction bottom mapping to determine the heterogeneity achieved by construction.

In order to provide refuge and promote successful spatsets, interstitial space needs to be incorporated into reef designs. Reefs constructed at least 1 foot in height should inherently achieve the recommended [6-inch (15-cm)] shell thickness and provide sufficient interstitial space. However, recognizing the limited shell resources, if alternate substrates are being used for construction, a veneer of clean oyster shell at least 6-inch (15-cm) thick should be placed upon the alternate substrate core, at least in low salinity areas where the rate of reproduction is slow where natural spatset is being sought (Jones and Rothschild 2009). The shell veneer would not be necessary when planting spat-on-shell on top of the alternate substrate.

6.3.5 ORIENTATION TO FLOW

Proper flow over an oyster reef will maintain a sediment-free reef, provide food, and carry away waste products. Typically northern-style reefs were oriented parallel to flow and southern-style reefs were perpendicular. Seliger and Boggs (1988) determined that the productive reefs remaining in Broad Creek and Tred Avon Rivers (tributaries to the lower Choptank River), were associated with a steep bathymetric gradient and hypothesized that this gradient permitted adequate flow to prevent siltation of the reefs. They identified that a bathymetric gradient (dz/dr x 10^3) greater than 20 maintained silt free reefs. [Bathymetric gradients are the slope of the Bay's floor. Seliger and Boggs (1988) calculated the bathymetry gradients from isobaths (depth, z) by measuring the projected distances (r) normal to the isobaths, expressing the gradient as noted above.)] The historic footprint of hard reef base and its orientation to flow should be the initial guide for restoration of a specific reef. Existing bottom surveying technology may be able to identify bathymetric gradients that promote successful restoration. Recognizing the significance of water flow upon restoration success, orientation to flow and bathymetric gradients should be a focus of tributary specific plans when individual reefs are sited.

6.3.6 WATER DEPTH

Due to concerns with hypoxia and anoxia, it is recommended that restoration be restricted to areas with water depths less than 20 feet MLLW (CBP 2004a). Potential impacts to navigation need to be considered when siting projects. Navigational impacts are expected to determine the shallow limit of water depths for restoration in some places. Proposed sites will be closely coordinated with the United States Coast Guard.

6.3.7 DISTANCE BETWEEN REEFS

With respect to distance between restored reefs, restoration studies of other sessile benthic invertebrates (red sea urchins) have recommended establishing multiple sanctuaries which are spaced at a distance less than the average larval dispersal distance of the target species (Smith et al. 1999). North et al. (2008) investigated larval transport in the Chesapeake Bay and determined that the average dispersal distance of all particles (representative of larvae) modeled during all hydrologic years was 9.0 km, but this distance is variable between tributaries. Investigations into the gene flow of oysters within the Chesapeake Bay identified that local gene flow predominates with the Chesapeake Bay (Rose et al. 2006). The average squared dispersal was determined to be 472 km^2, approximately 4 percent of the entire Chesapeake Bay or the area within a large tributary. Their estimate defined a geographic scale encompassing the bulk of dispersal from a central point source, implying that recruitment of oysters in the Chesapeake Bay is local within tributaries or regional sub-estuaries. Their investigations identified that reefs should be spaced at no greater than 9-km intervals, but further investigation into specific tributary larval transport dynamics is warranted. Further, Rose et al. (2006) by investigating oyster densities before 1900, proposes that larval behavior may be as important as hydrography, making local recruitment the rule, not a tributary-specific phenomenon.

6.3.8 *PREDATOR EXCLUSION DEVICES*

Predation potential as well as the use of predator exclusion devices should be considered when choosing a restoration site and designing restoration projects. There is typically greater predation pressure on oyster restoration projects in higher salinity regions. Thus far, in low and moderate salinity regions of Maryland, predation exclusion devices have not been necessary. There are several exclusion devices that may effectively curtail, or at least limit, oyster losses on constructed reefs due to predation including the use of nets, fencing, biodegradable mesh bags, light-shelling, cage and racks, and/or the use of spat-on-shell. Many of the options will likely prove to be too costly. Using spat-on-shell as opposed to cultchless spat has been shown to be a cost-effective method to reduce predation in some areas in Virginia (CBF, pers. comm.). In developing future projects, consideration must be given to the need, effectiveness and costs associated with these exclusion devices. Consideration must also be given to the inevitability that some predation is natural and will take place on constructed reefs. This could be addressed through adaptive management, or in the initial seeding of reefs to overcompensate for these inevitable losses.

When evaluating seeding of constructed reefs, it will be important to consider various size classes of spat-on-shell and/or materials that used for seeding reefs. Using spat–on-shell as opposed to cultchless oysters provides some protection from ray predation. Further, with multiple spat on a shell, the oysters grow into a clump that inhibits ray predation. Alternative materials such as granite and concrete, while more costly, may be less subject to predation than shell. Other questions that remain unanswered include whether there are other local conditions that make one area more prone to predation than another. This may require further research in coming years to better understand predation dynamics.

An effective means to exclude surface crawling predators, i.e. crabs, is netting or screening placed over the planting area. A net with a mesh size smaller than the size of the bivalves planted under it not only excludes predators but it also prevents the seed clams or oysters from washing out of the system if exposed to any wave or high current action. Maintenance is paramount to the successful exclusion of predators when using netting. The first concern is small predators that have recruited under the net and subsequently grown to a size large enough to consume the shellfish. The other concern is how to remove biofouling that can reduce water flow under the net and across the reef to the point where it can lead to impaired productivity and even mortality (excerpt from NRAC 2000).

Technologies to deter predation are emerging in the aquaculture industry, particularly in clam aquaculture. The continued research and future application of these emerging technologies should be supported. Through their research arms, agencies such as NOAA could provide support to oyster restoration.

6.3.9 *POACHING DETERRENTS*

Poaching has always been, and will likely continue to be, a threat to restored reef sanctuaries. The Maryland Oyster Advisory Commission and Virginia Blue Ribbon Panel recommended various laws and enforcement measures that could help to minimize this problem. The legislatures of both States have the authority to adopt these recommendations or other measures focused on reducing poaching. Other deterrents to poaching include using alternative substrates to build reefs in permanent sanctuaries such as granite or concrete. The size and weight of alternative materials make it much more difficult to use traditional methods of harvesting such as patent tongs or dredging. USACE will continue to incorporate alternative materials into restoration projects to minimize the risk of poaching to restored reefs.

6.3.10 SUBSTRATE RECOMMENDATIONS

Both shucking house oyster shell and fossil oyster shell are in very short supply and will likely not be able to meet the demands required for large-scale oyster reef restoration. Alternate materials may be able to provide both the quantity and quality of reef materials needed for large-scale restoration. In many cases, alternate materials such as granite and concrete appear to attract high numbers of oyster recruits. Despite the cost differences between dredged shells and alternate materials, the long-term persistence of the alternate materials compared to shells is an attractive feature. Alternate materials provide a longer window of opportunity to provide an effective substrate for oyster colonization and growth.

In addition, the use of alternate substrate materials prevents most types of oyster harvest, especially the two types commonly used throughout the Bay, oyster tongs and dredges. As a result, reefs formed partly or wholly out of alternate materials are less likely to be poached, or opened for harvest in the future. The relative longevity and resistance to harvesting of oyster reefs constructed from alternate materials seems ideally suited for incorporation in such efforts. Costs, however, associated with these materials will be much higher than constructing reefs from shell. Also, there may be public resistance to placing large quantities of these materials in the Chesapeake Bay. In these situations, other shell resources such as clam shell, viewed as natural to the Bay environment, may be a suitable alternative if oyster shell is unavailable. Surf clam shells are fragile and planted in large quantities pack tightly, offering little interstitial space. Hard clam shells are sturdier and a more suitable substrate for reef development compared to surf clam shell, but is in short supply due to depletion of that fishery. Surf clam shells could be added as a fresh layer of shell to an existing reef or could be used as a core material to provide elevation on which oyster shell could then be placed to achieve desired interstitial space.

At the very least, use of alternate materials in oyster reef restoration should play an important role in balanced efforts to restore both ecological and economic benefits associated with oyster reefs. USACE recommends incorporating all available and acceptable substrate options into a solution to substrate limitations and foresees that some sites will be better suited for alternate substrates than others.

6.3.11 SEA LEVEL RISE AND CLIMATE CHANGE

Oyster restoration plans must anticipate future climate change including relative sea level rise, increasing temperature, changes in species distribution, and changing ocean chemistry. Recent climate research by the Intergovernmental Panel on Climate Change (IPCC) predicts continued or accelerated global warming for the 21st century and possibly beyond, which will cause a continued or accelerated rise in global mean sea level. Potential relative sea level change must be considered in every USACE project.

A recent study by Boon et al. (2010) investigated absolute and relative sea level rise in the Chesapeake Bay. Absolute sea level is a measure of the volume and mass of ocean water. Relative sea level refers to the level of the ocean surface measured relative to land. Absolute sea level rise in the Chesapeake Bay is 1.8 mm/yr, compared to the global average of 3.1 mm/yr. Boon et al. (2010) analyzed data records spanning 35 years from 10 tide gauges between Baltimore and Norfolk to determine that rates of relative sea-level rise in Chesapeake Bay range from 2.91 to 5.80 mm/yr. This equates to a one (2.91 mm/yr) to two (5.80 mm/yr) foot increase in sea level rise over a century (Malmquist 2010). Comparing the absolute and relative sea level rise rates in the Chesapeake Bay it is approximated that 53 percent of the RSL rise measured at bay water level stations is, on average, due to local subsidence (Boon et al. 2010). The mid-Atlantic region is slowly sinking due to land movements associated with melting of the polar ice caps following the last Ice Age, faulting associated with the Chesapeake Bay Impact Crater, local groundwater withdrawals, and other factors (Malmquist 2010). Land subsidence will continue to be a major factor in sea level rise in the Chesapeake Bay as subsidence rates are not expected to change significantly in the future.

The National Research Council's (NRC) 1987 report, *Responding to Changes in Sea Level: Engineering Implications*, recommends a multiple scenario approach to deal with key uncertainties for which no reliable or credible probabilities can be obtained. The master plan recommends that restoration plans are assessed for the entire range of possible future rates of sea level change. Alternatives should be evaluated using "low," "intermediate," and "high" rates (i.e., scenarios) of future relative sea level change. Appendix C-6 describes one method for estimating sea level change for future projects. During the development of specific tributary plans, the master plan recommends using the historic rate of sea- level change as an estimate of the "low" rate, and the calculation of the "intermediate" and "high" projections for specific restoration sites.

6.3.11.1 Project Sensitivity to Sea Level Rise

Oysters grow over a wide range of depth (up to 30 feet) and should therefore be less sensitive to sea-level change than ecosystems that are finely tuned to specific elevations with respect to the tidal range. In general, healthy oysters are capable of keeping pace with sea level rise. Oyster larvae can locate and attach to other oyster shells allowing them to grow upward in the water column. Their ability to keep pace with sea level rise depends upon their capacity to grow upward from the bottom at a rate greater than the rate of sedimentation and find attachment sites above the pycnocline. Growth of the oysters themselves and their production of feces and dead shell create a hard bottom of increasing height that can potentially keep pace with sea level rise (DeAlteris 1988 in McCormick-Ray 1998). Studies by DeAlteris (1988) estimate that Wreck Shoal in the James River grew vertically at a rate of 50 cm per century (0.5 cm/yr) until 1855, and that this rate of rise kept pace with both sea level rise and the deposition of new sediment. More recently, the Great Wicomico reef constructed by USACE has been found to have shell material accreting at a rate of 6 to 16 $L/m^2/yr$ on the high relief reefs. In the Lynnhaven River system, monitoring has shown the reef there undergoing 3 inches of growth in individual oysters in one year. These particular reefs are developing vertically at a rate that would keep pace with sea level rise. Annual growth on reefs, 25 to 30 mm/yr (greater than 1 inch), restored in Maryland waters also shows that oysters are capable of keeping pace with sea level rise in less saline waters (Paynter 2008).

The pycnocline would be expected to gradually rise with respect to its current elevation with sea level rise, although it would still presumably be at the same depth below a new higher water surface. This increase would impact oyster beds at greater depths that would ultimately be below the new pycnocline depth. The pycnocline effectively prevents DO from mixing into bottom waters. Currently, the pycnocline typically occurs below about 18 feet in the middle and lower Bay, whereas historically preferred oyster habitat extended to about 30 feet depth.

The reefs restored in accordance with the master plan are anticipated to be capable of growing vertically and keeping pace with sea level rise; however, adaptive management and monitoring, typical of what is needed to monitor for success, will need to occur to confirm that accretion and reef growth is occurring. The recommendations in this document to restore high relief reefs in locations with high potential for success will promote a reef's ability to keep pace with sea level rise. That is, the considerations made in planning for successful restoration inherently consider sea level rise. Further caution can be included in future plans by avoiding the deepest waters within the planning range of water depth.

6.3.11.2 Potential Impacts of Climate Change

Climate change has the potential to alter many of the conditions under which oysters currently grow in the Chesapeake Bay. The specific impact of climate change to oysters is not certain because both positive and negative benefits could result from climate change-driven effects.

a. Temperature, Salinity, and Storm Frequency

Increased temperatures would likely provide a longer growing season and subsequent harvest benefit. Oysters would grow to market size over a shorter time period, and reduce the time that oysters are exposed to disease before they are available for harvest. Within sanctuaries, however, the exposure to disease would not be reduced. Alternatively, increased temperature may make oxygen conditions worse as warmer water holds less DO. This would likely lead to more severe anoxia and hypoxia, particularly in deeper waters. Salinity would likely increase as sea level rise pushes more ocean water into the Bay, but there could also be areas where salinity decreases.

Climate change is expected to lead to more frequent and stronger storms. These storms would provide more freshwater input and overland flow inputs presumable reducing salinity. More frequent storms would increase the risk of freshets to already susceptible low salinity populations. Overland flow inputs could be magnified if impervious surfaces continue to increase within the Bay watershed. However, increased temperatures may increase evapotranspiration and would have the effect of increasing salinity. It is uncertain how these varied processes, increased runoff, evapotranspiration, and saltwater intrusion+ would alter salinity in the Bay. New species, predators, and parasitic diseases could be introduced with temperature and salinity changes. Oyster prey species could be altered as the Bay's phytoplankton community undergoes changes driven by changing consumers, and shifts in temperature, salinity, and DO.

The habitat range of oysters could be altered if water depths increase as sea level rises. There could be expansion into newly created shallow water. However, the deep end of the habitat range would likely become unsuitable due to oxygen conditions.

b. Ocean Acidification

Potentially the greatest threat to oyster populations with respect to climate change is an expected increase in carbon dioxide in the water column due to increased atmospheric carbon dioxide (CO_2) levels from fossil fuel burning and excess nutrients. Increasing carbon dioxide may raise the acidity of the Bay. Increasing acidity, or in other words, a decrease in pH, is a process called ocean acidification. Although carbonate chemistry and shell formation are complicated processes, increasing acidity has the potential to reduce an oyster's ability to form calcium carbonate shells. Increasing acidity would also increase the dissolution of shell reefs within the Bay (Waldbusser et al. 2011).

Ocean acidification has been occurring for some time as a result of industrialization. Between 1751 and 1994, surface ocean pH decreased from 8.179 to 8.104. More recently, the pH has further decreased to 8.069 and continues to fall. By 2050, pH is expected to fall to 7.949. Overall, this represents a 69.8 percent increase in acidity in the ocean due to increasing CO_2 levels in the atmosphere due to human activity, a level not seen in the last 65 million years (Ridgwell and Schmidt 2010).

As CO_2 levels in the ocean increase, there is less and less carbonate, CO_3^{2-}, in the water column for shell-forming marine life to form their shells as shell-forming organisms, primarily mollusks, foraminifera, coccolithophores and cnidarians (coral reef animals), use $CaCO_3$, calcium carbonate (limestone) as the inorganic portion of their shells. This can adversely affect all shell-forming organisms, though sensitivity to increasing ocean acidity varies widely (Ries et al. 2009, Fabry et al. 2008). However, both Ries et al. (2009) and Fabry et al. (2008) note overall negative impacts for almost all shell-forming marine life, with crustaceans, whose shells are covered by an organic matrix being the least vulnerable and mollusks with $CaCO_3$ shells directly exposed to the water being the most vulnerable.

For oysters, all stages of the life cycle could be impacted, as oyster larvae also possess shells and need a shell for survival. One study (Gazeau et al. 2007) found that the Pacific oyster, *C. gigas*, experienced a 10 percent drop in calcification rate of their shells as adults, in waters mimicking the projected pH of 2100. Ries et al. (2009) found that the eastern oyster exhibits thinner shells as aragonite saturation levels drop due to ocean acidification. Oyster -larvae may be more vulnerable. Miller et al. (2009) found that larvae shells of the eastern oyster became significantly smaller and lighter as CO_2 levels increased, lowering pH accordingly.

Pre-industrial levels of CO_2 (280 atm) showed the largest and heaviest shells, indicating that present-day levels (380 atm) have already affected oyster larval shell development. Projected increases, based on expected rates of fossil fuel consumption by 2050 and 2100 are 560 and 800 atm, respectively. Comparing the pre-industrial conditions to projected 2100 conditions, eastern oyster larvae in 2100 had shells 16 percent smaller that contained 42 percent less $CaCO_3$. However, unlike some marine organisms, particularly some corals and pteropods (planktonic marine snails), oyster larvae were able to form shells successfully at all pH levels tested, perhaps indicative of their adaptability as primarily estuarine animals subject to a wide range of differing water qualities throughout their range, or perhaps another process in the estuarine system acts as a buffer. Overall, it appears that oysters will be negatively affected by the increasing acidity of the ocean and that the larvae are considerably more vulnerable than adults to these effects. The main impact is that their shells will probably become thinner at all stages of their life cycle. This is likely due to higher dissolution rates due to the exposed nature of the oyster's $CaCO_3$ shell directly to the water, not a slower rate of shell deposition, as has been seen in other mollusks with exposed shells (Nienhuis et al. 2010).

Within the Chesapeake Bay, nutrients from runoff and sewage produce more carbon dioxide than atmospheric CO_2 (Nash 2012). Excess nutrients generate CO_2 when they decompose. Mesohaline regions, in particular, are particularly susceptible to greater diurnal ranges in pH because these areas are typically the location of the chlorophyll maxima (Waldbusser et al. 2011). Due to the connection between eutrophication and acidity, oyster restoration efforts will benefit from increased efforts to control nutrients in the Chesapeake Bay watershed.

6.4 IDENTIFICATION OF THE LOCAL SPONSOR

The Commonwealth of Virginia and the State of Maryland have been the local sponsors for the preparation of the master plan. They are also the most likely cost-sharing sponsors for the specific projects, which will be developed following the master plan. During the master plan effort, VMRC and MDNR have been the agencies representing the two states' interests. Norfolk and Baltimore Districts have also worked with scientists at the VIMS, and the University of Maryland. The Potomac River Fisheries Commission and non-government organizations (NGO's) such as TNC, the Chesapeake Bay Foundation, and The Conservation Fund (TCF) have also expressed interest in partnering with USACE to plan, design, and construct oyster restoration projects in Chesapeake Bay. The following sections speak specifically to USACE oyster restoration efforts, although it is fully recognized that oyster agencies and groups may be carrying out restoration projects not involving USACE.

6.5 PROJECT COST-SHARING AND IMPLEMENTATION COSTS

6.5.1 COST-SHARE FOR PROJECT CONSTRUCTION, OPERATION, AND MAINTENANCE

It is recommended and expected that the current local sponsors, the Commonwealth of Virginia and the State of Maryland, will continue in this role for the follow-on tributary specific plans and restoration projects. Under the project authorization (Section 704(b) of WRDA 1986, as amended), the local sponsor must provide 25 percent of the project costs. As Virginia's representative, VMRC has historically furnished the local share in Virginia, and MDNR has furnished the local share as the state's representative in Maryland.

Section 113 of the Energy and Water Development Appropriations Act for FY 2002, Public Law 107-66, provides that the non-Federal sponsor's 25 percent share of the cost of a project, under Section 704(b) as amended, may be provided through in-kind services, including shell stock material provided by the non-Federal sponsor, if the Chief of Engineers determines the shell stock material is suitable for use in carrying out projects. In Virginia, the "fossil shell" that the non-Federal sponsor has offered from various locations in the lower Chesapeake Bay can be suitable shell stock material and has previously provided the majority of the Virginia's required local sponsor match. If other materials are used to partially or wholly construct future reefs, other match may be required if shell credits are insufficient to cover the total cost of the project.

In Maryland, the sponsor's share has been provided via in-kind services in the form of project monitoring, provision of hatchery spat, and technical support. This is expected to continue. In addition, credit for the use of fossil shell may be considered, if applicable in the future.

6.5.2 PROJECT SCHEDULE

This master plan is scheduled for internal and public review prior to completion in 2012. In the meantime, Baltimore and Norfolk Districts will continue construction efforts including development of initial tributary-specific plans in order to keep progress on oyster restoration moving forward, as Congress has directed. The future construction will be dependent on continued federal funds as well as the availability of the local sponsors to contribute appropriate in-kind services. It is anticipated that the completion of all of the necessary tributary restoration work will take several decades given current levels of funding.

6.5.3 SUMMARY OF RESPONSIBILITIES

Oyster restoration is a collaborative effort that requires the focus and missions of many agencies and NGOs. Figure 6-2 portrays the roles and contributions of the many agencies and groups that participate in oyster restoration in Maryland. A comparable process for Virginia is highlighted in Figure 6-3. These figures do not include all potential partners and stakeholders, but do illustrate many relationships and the collaboration inherent to oyster restoration. Additional potential contributing partners and possible restoration actions are listed in Table 6-4. Interested groups and partners may include regional organizations such as Lynnhaven River Now, the Elizabeth River Project, and local watershed organizations.

The views of the local sponsors have been expressed in recent documents including the 2007 *Virginia Blue Ribbon Oyster Panel Report and Recommendations* and the 2008 *Maryland Oyster Advisory Commission Report*. Both reports recommended the incorporation of large sanctuaries into restoration efforts.

It is important to note that strategic restoration methods, as presented in the master plan, are the best hope for restoring the native oyster and large-scale restoration is a necessary step to any significant fishery improvements. Also, increasing recruitment of the native oyster and survival of those recruits, which should accompany implementation of the master plan recommendations, should provide significant benefits to harvest areas outside USACE restoration sites. The local sponsors support oyster restoration, as any successful efforts to return the native oyster to its historical populations will not only provide ecological benefits but will also contribute to a public or private leasehold-based fishery in the future, and the restored habitat is expected to augment other fisheries, such as crabs and finfish resources.

USACE involvement in some aspects of oyster restoration has varied in the past largely due to project agreements and how the States manage their respective oyster resources. Based on

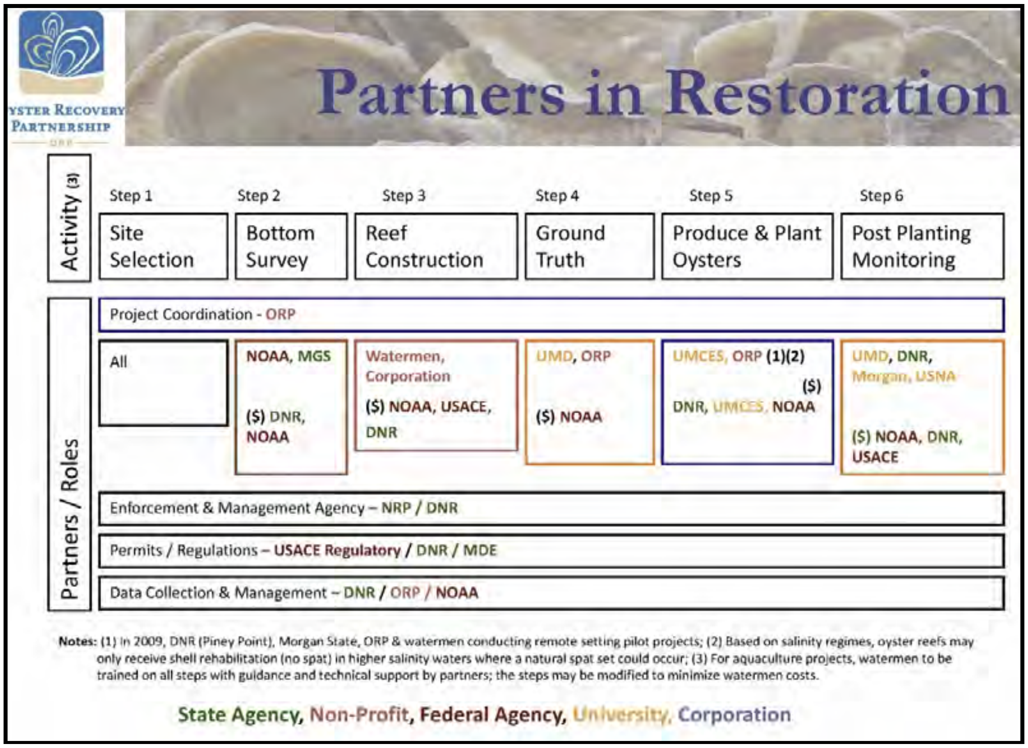


Figure 6-2. Roles and Responsibilities of Collaborating Oyster Restoration Partners in Maryland. (courtesy of Oyster Recovery Partnership)

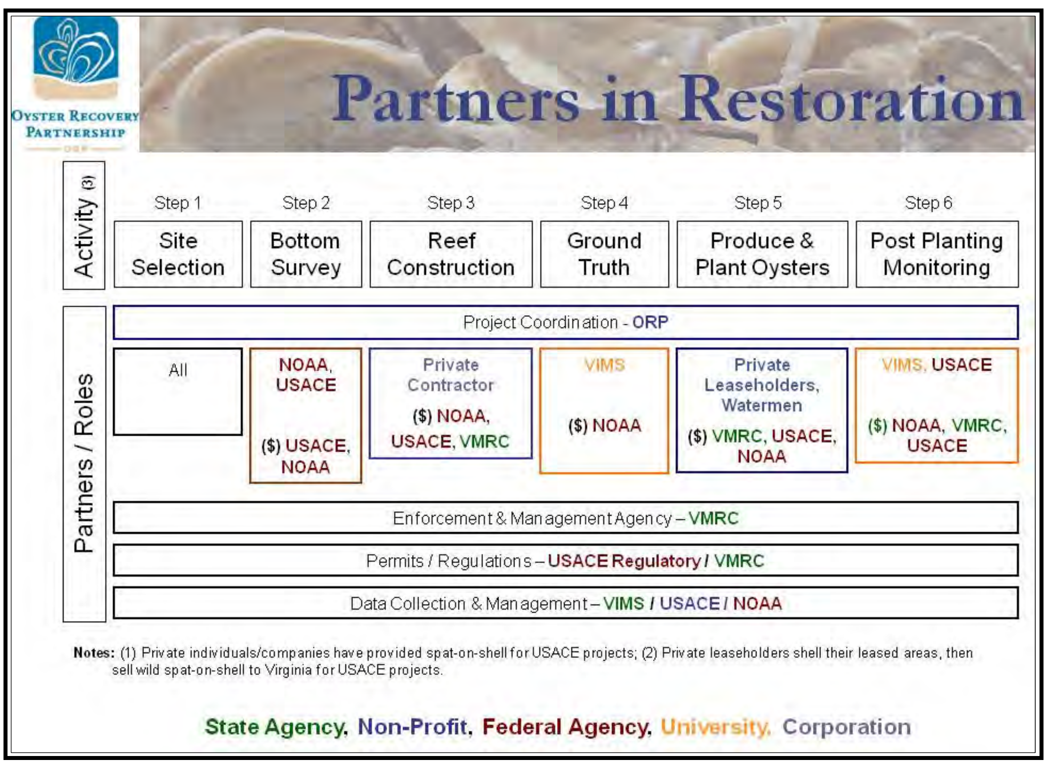


Figure 6-3. Roles and Responsibilities of Collaborating Oyster Restoration Partners in Virginia

(courtesy of Oyster Recovery Partnership)

Table 6-4. Potential Contributing Partners in Oyster Restoration

Action	Potential contributing partner
Measures to consider in tributary plans/pre-project evaluation	
Freshets	USGS, academia, MDNR, VMRC
Local Water Quality (salinity, DO, T, toxics)	States, CBP, local watershed organization, academia
Water Flow- measure currents/water flow	MDNR, VMRC, academia, USACE
Sedimentation Rate- measure sedimentation	MDNR, VMRC, academia, USACE
Phytoplankton- characterize phytoplankton community, food availability	CBP, academia, MDNR, VMRC
Harmful Algal Blooms- presence/absence, frequency, species	academia, MDNR, VMRC
History of disease in region	MDNR, VMRC
Position relative to other estuarine resources- map SAV, wetlands, etc.	MDNR, VMRC, academia
Existing harvesting closures/sanctuaries	MDNR, VMRC
Watershed Suitability- sustainable land use/planning	Local governments, States
Bottom Condition Surveys	MD- NOAA, MGS/MDNR; VA- NOAA, USACE
Population Surveys	NOAA, USACE, VMRC, MDNR
Hydrodynamic and Larval Transport Modeling	academia
Bathymetric Surveys	NOAA
Recruitment Surveys including historic records	MDNR, VMRC, USACE, NGOs
Restoration- construction	
Site Selection	USACE, NOAA, MDNR, VMRC, ORP
Construct hard habitat	USACE, MDNR, VMRC, NGOs, watermen, private contractors
Groundtruth	academia, ORP, NOAA
Produce spat-on-shell or seed	MD-State*; VA- commercial aquaculture, watermen
Plant spat-on-shell	MD- MDNR, ORP; VA- Private leaseholders, Watermen
Provide broodstock for restoration	Commercial aquaculture, Watermen, MDNR, VMRC
Fishery Management	
Sustainable management of oyster fishery;	MDNR, VMRC
Enforcement of harvest regulations	NRP, MDNR, VMRC
Designate sanctuaries	MDNR, VMRC
Regulatory Issues	
Permits/Regulations	USACE, VMRC, MDNR, MDE
Monitoring	
Post-construction bottom surveys	MD- NOAA, MGS; VA- NOAA, USACE
Monitor to determine ecosystem benefits	USACE, academia
Monitor spatsets/reproduction	USACE,MDNR, VMRC, academia
Monitor disease	MDNR, VMRC, academia
Monitor mortality	USACE, MDNR, VMRC, academia
Monitor regional WQ (salinity [includes freshets], DO, T, phytoplankton)	CBP, NGOs, local watershed organizations
Monitor salinity, DO, (and temperature) of restoration sites	USACE, MDNR, VMRC, academia
Adaptive Management	
Re-seed with spat-on-shell	MD- MDNR, ORP; VA- Private leaseholders, Watermen
Provide additional substrate	USACE
Research Gaps	
Biological and benefit modeling	USACE, academia
Disease; Larval Transport	academia
Performance of alternate substrates; site selection	USACE, academia, MDNR
Shell reclamation	USACE, MDNR

note: academia can include independent grants and research as well as investigations funded by USACE, NOAA, or the States

* "State" refers to MDNR, UMCES, ORP, and the hatchery operations

Figures 6-2 and 6-3 USACE has been involved in bottom surveys in Virginia, but not in Maryland. NOAA and MGS have performed all past bottom surveys in Maryland. It can be expected that NOAA (and possibly MGS in MD) will fulfill this role for both States going forward. USACE will be involved with identifying areas for bottom surveys, but there will likely not be a need for USACE funding in this area. Another area where USACE involvement has differed is in producing and planting oysters. The State of Maryland operates two hatcheries and provides spat-on-shell as an in-kind service to cover matching funds. However, in Virginia, spat-on-shell is generated primarily from private leaseholders and watermen. The Commonwealth of Virginia does not operate a hatchery.

6.6 RESEARCH NEEDS

There are many oyster restoration topics that require further investigation. These are listed below in no particular order:

- Quantification of oyster benefits,
- Larval transport,
- Development of disease resistance and transmission,
- Site selection with respect to water currents and bottom topography,
- Performance of alternate substrates, and
- Shell reclamation (of shallowly buried shell plantings) and potential impacts.

Efforts are currently underway to investigate oyster benefits generated by recent restoration projects in Virginia as discussed in Section 5.7.1. USACE-Norfolk District and ERDC are working to determine the environmental benefits of oyster reefs in the Great Wicomico and Rappahannock Rivers. This study will particularly focus on how sanctuary reef benefits compare to the benefits of reefs that are under rotational harvest management regimes. A coupled hydrodynamic-ecological modeling approach is being used that will integrate the Adaptive Hydraulics (ADH) model with the Comprehensive Aquatic System Model (CASM), and a custom-developed stage structure population dynamics model.

As described in the "Strategy for Protecting and Restoring the Chesapeake Bay Watershed (EPA 2010)":

"Oysters are a keystone species in Chesapeake Bay. They grow naturally in reefs that create and provide habitat not just for themselves and additional generations of oysters, but for many species of commercially and recreationally important finfish and shellfish. Oyster reefs were once the dominant hard-bottom habitat in the Chesapeake Bay, and it is thought that the ability to restore the overall water quality, habitat and fisheries in the Bay is likely closely linked to our ability to restore oyster populations."

As discussed in the next section, adaptive management and monitoring will play a significant role in large-scale oyster restoration. Oyster restoration will be most successful if research and technological advancements are incorporated into restoration techniques as they are achieved.

7.0 ADAPTIVE MANAGEMENT AND MONITORING

7.1 THE NEED FOR ADAPTIVE MANAGEMENT

The implementation of large-scale oyster restoration is new to the Chesapeake Bay, and the science and engineering behind it is still being developed. Details on how high to build reefs, where to place them in tributaries for maximum recruitment (either providing or receiving), how to positively influence the stock/recruit relationship, metrics for long-term sustainability, and the use of alternative materials are still being researched.

Due to the inherent uncertainty present in science-based oyster restoration, USACE has designed an adaptive management framework to ensure the proposed oyster restoration program provides the desired benefits over the predicted project life. This includes a series of potential actions to reverse downward trends in reef substrate and the oyster population upon it. A monitoring program of sufficient precision will be necessary to determine when adaptive management measures need to be considered and when and where to initiate these measures.

Some of the uncertainty is introduced by factors outside the control of USACE such as, cataclysmic weather events, such as hurricanes and freshets, both of which can eliminate all oyster larvae in a wide area, as well as red tides, which can kill oyster larvae (and even adults) if severe enough. Dead zones caused by anoxia can impact reefs by killing adult oysters if they persist longer than a week and kill oyster larvae or newly settled spat in a day, as they are much less tolerant of low DO than adults. A strong storm could potentially flush the oyster larvae out of a tributary into the main stem of the Chesapeake Bay, greatly decreasing recruitment on a given restoration project or cause a high sedimentation event that inhibits settlement on restoration project(s).

Predators, such as blue crabs, mud crabs, and cownose rays, could take a heavier than expected toll on the stocked oysters on a restoration site. Restoration sites could be poached, which has happened on sanctuary sites, in both Maryland and Virginia. The oyster diseases MSX and Dermo will still cause oyster mortality, at times extensive, though as reported recently (see section on disease) some resistance, particularly in high salinity stocks in the lower Chesapeake Bay, to both diseases is developing and it appears to be increasing over time due to natural selection. Climate change, in particular increases in salinity and acidity of Bay waters, could have negative impacts on various oyster populations. The framework outlined here has taken into account these possibilities to the extent such things can be predicted.

The recognition of the value of and need for monitoring and adaptive management extends outside USACE to the Bay-wide oyster restoration community. The Chesapeake Bay Program's Sustainable Fisheries GIT convened an Oyster Metrics Workgroup (OMW) charged with developing common, bay-wide restoration goals, success metrics, and monitoring and assessment protocols for oyster restoration. The OMW Report was completed in December 2011 (OMW 2011). The goals are specific, compatible and quantitative and focused on ecological function and ecosystem services. As a member of the oyster metrics team, USACE adopted the recommendations of the OMW report, though such recommendations may need to be modified as additional research clarifies what is needed to restore self-sustaining oyster metapopulations to entire tributaries. Because there are no long-term (multi-decadal re-established reefs) successes due to the infancy of the efforts, we expect that adaptive management will be a key component to ensure that long-term success of individual tributary restoration efforts is achieved. The monitoring and adaptive management framework laid out in the following pages are consistent with the OMW recommendations, though more in-depth monitoring and research may be needed in some cases to ensure long-term sustainability and proper adaptive management on the tributary-wide scales proposed. As restoration progresses to larger tributaries and/or sub-estuaries with less retentive hydrodynamics, the risk and uncertainty will increase and along with them, adaptive management and monitoring needs.

The monitoring and adaptive management framework laid out in the following pages is consistent with the Oyster Metric Workgroup Report (OMW 2011) developed for the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program.

7.2 MONITORING

Monitoring will be performed to determine if oyster restoration projects are performing as desired. Biomass and density targets will be established for a project to evaluate performance on the most basic level. Additional specific monitoring objectives will be customized for each restoration project. Standard monitoring parameters such as salinity, temperature, DO, and shell volume provide data on restoration projects, but can also provide insight on the impacts of climate and sea level change to restoration projects.

To determine if success criteria are being achieved, including biomass and density, a monitoring program will be required. The monitoring program should accomplish the following:

- Provide support for adaptive management decisions by providing data on critical stages in the development of the reefs that can guide the next steps in the restoration process. This monitoring should answer crucial questions that affect implementation decisions. For example: Did sufficient numbers of transplanted broodstock survive and spawn to support continued reef development? Is cultch quality sufficient to support a second year's recruitment? What is the recruitment upon the restored reef? Is recruitment increasing or decreasing over time? What are the biomass and shell accretion rates on the restored reef?

- Evaluate intermediate conditions that help to track progress toward the final goals. For instance, are enhanced abundances of oyster larvae and new recruits observed in a tributary following seeding with broodstock oysters? What is the disease status of oysters on sanctuary reefs? Is oyster biomass increasing over time? Is heavy sedimentation occurring on the reef? Such a monitoring objective permits setting intermediate goals and evaluating success in reaching those goals.

- Measure specific elements necessary to evaluate success criteria established for the project. For instance, numbers and sizes of oysters are needed to evaluate the filtration capacity of an oyster reef. Monitoring to track progress toward a biodiversity goal is more difficult because there is no quantitative relationship between oyster density and the habitat value of a reef, however, this work should be considered. Secondary production, chlorophyll a and TSS reduction rates can be measured on reefs. Shell accretion and deposition rates should also be measured.

- Aid in identifying unexpected stresses, environmental conditions, and/or ecological interactions that can affect the overall success of the project including water quality, disease, impacts from extreme weather events such as increased sedimentation, poaching, and predation. Oxygen levels, TSS, and chlorophyll a are several parameters that should be recorded over restored oyster reefs.

- Monitoring on sanctuaries should also be used to determine long-term trends in disease status. It is hoped that sanctuaries will accelerate disease resistance development in the Bay, a development that, despite ongoing fishing pressure that selectively removes large adults that often exhibit some tolerance to disease especially if found in salinity Zones 2 and 3 (Cranfield et al., 2005, Carnegie and Burreson 2011), is occurring. If the biomass (and presence of large, adult oysters who have exhibited measureable disease resistance versus the smaller individuals on fished areas) is large enough on the sanctuaries relative to fished areas to exert a positive influence on selection this should happen.

- Consider impact of climate and sea level change to restoration projects.

While each of these are important objectives for a comprehensive monitoring strategy, and their proper implementation will be crucial to the overall success of USACE efforts, it is unlikely that every individual restoration project will be able to incorporate all of these monitoring objectives. For instance, water quality can be affected by a very wide range of factors, measuring all of which would be impractical. Having a monitoring program in place that identifies when water quality problems affected the success of a project would be invaluable. Allocation of the limited resources available for monitoring should be guided by the strategic needs for ensuring success. Incubator systems, which many other stocking efforts will depend upon, will require more extensive monitoring of sites than sites where the goal is simply to establish a stable population of oysters. It is essential that broodstock enhancement at these sites be closely monitored.

Additionally, the use of shell-string and bottom surveys in areas where recruits should settle is important. Shell-string surveys have value in that they measure initial recruitment and remove the quality of the present substrate and post-settlement mortality as factors. Since substrate quality can greatly influence recruitment, poor substrate could show little if any recruitment despite high recruitment potential.

Due to the wide variety of monitoring currently being conducted Bay-wide, basic monitoring protocols are provided in Table 7-1. The first two data elements, the reef presence and the oyster demographics and density, are so crucial that they require additional explanation.

Table 7-1. Monitoring Protocols

Monitoring Element	Data Recorded	Methods	Monitoring Objective
Presence of reef	Bottom conditions	Patent tong or diver survey	Substrate quality/unit area.
Oyster demographics/ density	Oyster numbers	Patent tong or diver survey	Numbers and age/size classes of oysters/unit restored reef area
Oyster biomass	Ash-free dry weight	Sub-sampling of oysters from all size classes on restored reefs	Determine oyster biomass/unit reef area
Secondary production	Ash-free dry weight	From oyster biomass and sampling associated reef fauna	Determine total productivity of restored oyster reefs
Chlorophyll a	Concentrations of chlorophyll a	Water sampling	Chlorophyll a levels in water to estimate water quality improvements from oyster reef
TSS (total suspended solids)	Concentration of TSS in water column	Water sampling	Determine potential TSS reductions provided by restored oyster reefs
Shell accretion and condition	Shell volume per reef area	Sub-sampling of reef complex	Proxy for shell accretion rate

7.2.1 SURVEY DESIGN FOR MONITORING

The Great Wicomico reef in Figure 7-1 was built entirely from dredged shells placed from a barge using a water cannon, typical of many restoration efforts in the Bay. A detailed hydro-acoustic survey was done pre- and post-construction, in order to identify where shells were to be placed, and then where they actually landed. From the post-construction map, it is evident that, while it was intended that shells were to be placed in a uniform layer within the Baylor polygon, this clearly did not occur. As shown, some shell was placed outside the Baylor polygon on river bottom of unknown quality. Such restored areas, unless on private leases or on soft bottom (in which cases the shells should be moved accordingly) will be considered part of the restoration and monitored as such. The high quality reef (high relief) is clearly patchy in extent, which is a natural feature of historic oyster reefs. It also illustrates the limitations of placing shells from a barge using a water cannon.

In order to properly evaluate restoration reef performance, substrate placement location and its relief must be known and taken into account in the monitoring protocols. Assuming patch locations are known, the reef sampling program must properly stratify in order to assess reef performance due to the clear differences between unrestored bottom, and low and higher relief reefs (Schulte et al. 2009a). If this is not done, estimates of reef performance will be severely compromised. It is recommended that for all restoration projects, pre and post-construction surveys be done so a stratified random sampling designed survey, the preferred survey design,

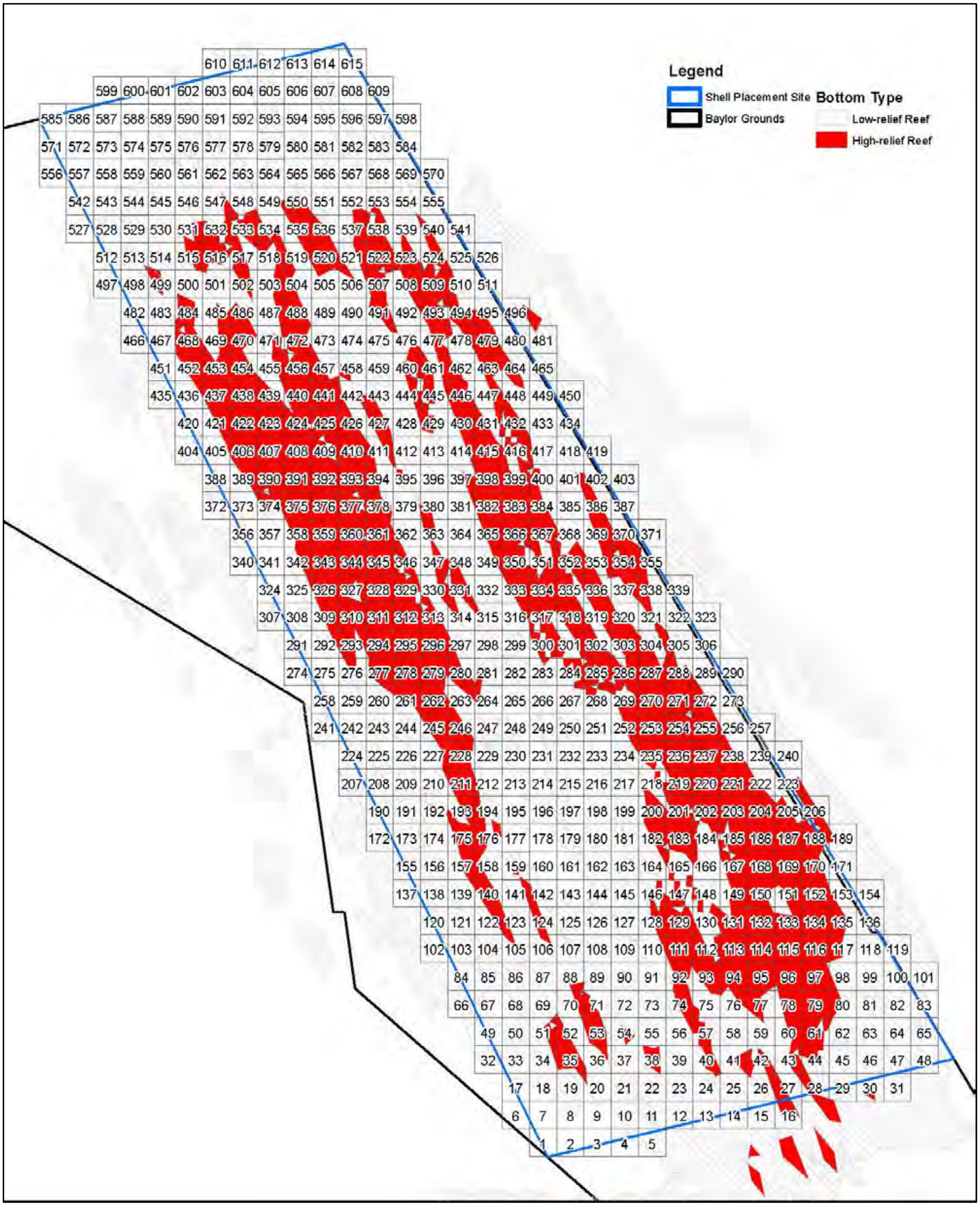


Figure 7-1. Great Wicomico Reef Construction with Strata Identified.

can be used. Only in the rare case where strata are not present (such as a restoration site composed entirely of uniform reef balls) could simple random survey design be used.

It is equally important to quantify the patchiness of the reef. This can be addressed if pre and post-construction surveys are done to determine where and how construction materials were placed. Then, using a stratified random sampling regime, patchiness of the reef, as well as an accurate estimate of oyster density/strata, biomass, and overall abundance for the restored site can be developed. It is recommended that the SE (standard error) be no more than 15 percent of the mean, 10 percent or less being preferred. This will influence the number of samples needed, as the greater the patchiness and number of strata, the more samples will be needed to keep the SE within the recommended limits. This level of SE should ensure a reasonable CI (confidence interval) around the population estimate parameters. Sampling must be done quantitatively. Patent tongs and divers are the preferred methods for obtaining a discrete bottom sample of known area, though other methods could be considered if they do likewise. This topic is further addressed by the OMW report (OMW 2011).

While overall estimates could be developed for a river, it is crucial to keep differing restoration strata separate within the monitoring program. Adaptive management may only be necessary on degrading portions of a particular reef, not the entire reef. Care will be needed when placing additional shell in order to leave high performing reef habitat (≥200 oysters/m2 with multiple age classes present) alone and this is feasible with good monitoring and post-construction survey data. Typically, low resolution surveys, such as non-properly stratified patent tong surveys or dredge surveys, do not provide this level of detail and should not be used to evaluate sanctuary reefs in the restoration program or to develop any estimates or metrics to determine the success of the restoration program. It should be noted that such approaches have been abandoned for other fisheries in the Bay, notably for blue crabs, which for some time has utilized a stratified random sampling design to improve the accuracy of the annual bi-state stock assessment of the crabs.

7.3 ADAPTIVE MANAGEMENT

Monitoring will provide data that will be used to employ the principles of adaptive management to the proposed project. Table 7-2 provides a brief summary of how the monitoring program relates to adaptive management and outlines various adaptive management measures. Possible adaptive management measures include, but are not limited to a number of potential actions:

- Additional stocking of selected strains of disease-resistant native oysters upon restored habitat, in source areas to provide recruits or in sink areas to prevent reef degradation;
- Moving of disease-resistant spat-on-shell (seed) to other sites to promote the development of disease resistance;
- The addition of fresh shell or alternate substrate;
- Measures to reduce or prevent predation;
- Relocation of construction material erroneously placed outside target areas if such area is unsuitable; and
- The addition of more habitat to address the issue of scale.

Table 7-2. Monitoring Program with Adaptive Management

Monitoring Element	Adaptive Management Application
1. Early survival rate of oysters after transplanting.	Supports decisions related to handling and planting protocols. Such decisions are related to age of oysters at planting – the longer the time in the hatchery the larger the oyster and more expensive, but also increased survival from handling and planting. Planting densities also influence survival rates of young oysters, and planting methodology to maximize survival and growth are still being developed. Monitoring will refine these methods which will be adaptively applied as the data is gathered.
2. Abundance, density and fecundity of transplanted broodstock oysters.	a. Evaluates need for additional stocking. b. Facilitates comparison with predicted values for density and biomass. c. Allows for estimation of % larval abundance resulting from the restoration.
3. Abundance of oyster larvae.	Supports comparisons with historical data (density) and biomass goal comparisons. Biomass goal tracking is a key element on which adaptive management decisions are made.
4. Abundance and densities of new recruits to restoration sites. *Evaluation of spatset density over time.*	Evaluation of sufficient stocking density. *Track progress* toward the *intermediate goal* of observing increased recruitment from the transplanted stocks and toward the final *success criteria* of altering the regional population within the reef's area of hydrodynamic influence as well as recruitment trends over time, which may trigger adaptive management actions if they fall below desired values.
5. Substrate quality.	Assess the need for additional cultch planting. Assess the placement of the reefs within target areas, with the intent of modifying placement methods and designs to better place reef construction materials in from shoreline intertidal to open Bay mainstem reefs. Assess impacts from storm events and large inputs of fresh water, which can deposit large amounts of sediment over a reef in a very short period of time, potentially burying a restoration reef, with the intent of studying the reef response to the event – if oyster densities are high enough the reef may self-clean, natural processes may move the sediment off of the reef in time to prevent mortality. If not, intervention may be needed.
6. Growth and survival of oysters at restoration sites.	Evaluate progress of the primary success criteria for the project.
7. Shell accretion and condition.	Determine the volume of oxic shell on reef. Evaluate the degree of shell degradation due to physical (predation and burial) and chemical (ocean acidification) processes.
8. Disease status of: a. oysters before transplanting. b. on sanctuary reefs.	a. Evaluation of seed oyster source. It is currently debated in the Bay scientific and management community what stocks are best to use for seed in different tributaries and salinity regimes. Data collected on seed source, coupled with data on their subsequent performance, will be used to refine seed source choices for restoration stocking efforts. b. May suggest the need for further seeding or indicate a cause for observed mortality.
9. Ancillary water quality data.	a. Aids in identifying non-disease-related mortality sources. b. Could also demonstrate improvements to water quality due to oyster filtration c. Identify non-stock related influences on recruitment, which will help guide adaptive management decisions such as when to re-shell habitat as well as additional stocking needs in order to maintain desired levels of recruitment. d. Look at interactions with other marine life, such as macroalgae and SAV. This may influence reef siting decisions, in order to enhance their abundance or inhibit macroalgae growth on restored reefs. e. Monitor salinity, temperature, and DO for potential climate-change related impacts.

The last measure of additional habitat may be appropriate, if recruitment enhancement is not evident despite a stock of oysters restored and remnant habitat that met expectations over multiple years. It is likely that the reef network is still too small to enhance recruitment in the region.

A selected strain refers to a primarily field-selected oyster strain with demonstrated disease resistance. Disease-naïve stocks should not be used in hatchery-based stocking programs. Because oyster diseases remain a serious impediment to restoration, actively breeding and stocking disease-naïve stocks will perpetuate the problem by increasing such stocks' contribution to recruitment wherever they are stocked. Stocking of oysters within source areas may require much higher densities than currently found on all wild reefs, including those in the lower James River. Only a precise and accurate monitoring program, coupled with high-resolution hydrodynamic modeling, can resolve this issue successfully in a fashion to minimize cost and maximize benefits. Less precise surveys may result in excessive stocking in some areas where not needed or understocking in areas where it is.

The next key adaptive management measure is the application of additional fresh oyster shell or other hard materials, such as recycled concrete, limestone, or granite to restored habitat sites to enhance recruitment and rehabilitate reefs that are demonstrated by monitoring to be on a negative trajectory towards unrestored bottom, a fate common to prior (Smith et al. 2005) and present (Powell et al. 2006) efforts to repair and maintain degrading oyster habitat. Such decisions, again, depend on having monitoring data of sufficient precision to inform decision makers on when, where and how much material to deploy. Further, alternate materials, more costly than shell, will increasingly be used due to the shortage of shell resources, especially in Maryland. In Virginia, where dredging for buried shells has been much less extensive, this is less of a problem. However, fossil shells should be used wisely as they are a non-replaceable resource and dredging has negative environmental impacts.

To protect stocked oysters from predation, measures could include use of nets, fencing, biodegradable mesh bags, light-shelling, and/or cage and racks to protect broodstock oysters (either cultchless or spat-on-shell, neither of which are immune to predation). This risk is more frequent in high salinity waters, where large-scale mass predation events due to cow-nose rays are more commonplace. Identification of predators impacting reefs will also help determine whether the predatory species assemblage is changing, possibly from climate change.

7.3.1 ADAPTIVE MANAGEMENT FRAMEWORK

The desired outcome is that the reefs, once built, achieve the metrics established by the OMW, especially the metric for oyster biomass, as biomass drives other reef processes, such as recruitment and shell accretion rates. The goals, success metrics, assessment protocols, and assessment frequency established by the OMW are summarized in Table 1 of its December 2011 report to the Sustainable Fisheries GIT (Appendix E). The main target is:

> "An oyster population with a minimum mean density of 50 oysters and 50 grams dry wt/m^2 covering at least 30 percent of the target restoration area at 3 years post restoration activity. Evaluation at 6 years and beyond should be used to judge ongoing success and guide adaptive management. The minimum threshold is an oyster population with a

mean density of 15 oysters and 15 grams dry weight biomass/m^2 covering at least 30 percent of the target restoration area at 3 years post restoration activity. Minimum threshold is defined as the lowest levels that indicate some degree of success."

Achieving these goals and metrics may take time, until greater disease resistance develops than currently exists in the native stocks in most areas, coupled with lower TSS levels and reduced anoxic "dead zones" in the Bay. The latter two are beyond the scope of the present study. Proposed actions are discussed in the following text. More specific adaptive management plans, particular to each tributary, will be developed in the site-specific tributary plans as the program progresses, and these plans may differ in some details than the actions discussed here, which serve as guidelines for the overall effort.

7.3.1.1 Recruitment

In the event of recruitment failure, which is defined as a spatset of less than 50/m^2 in Zone 2 or 3 waters and 25 in Zone 1 waters of a reef in any given year, no action is recommended. If recruitment failure occurs for a second year in a row, reefs on which this occurs in Zone 2 or 3 will be re-shelled with the equivalent of 1 cm of fresh, clean oyster shell over the reef surface. This equates to approximately 40 cubic meters of shell over an acre of reef. This is to be done prior to spatset the third year (winter or spring timeframe, no later than 1 June). For Zone 1 reefs, this shelling will be done if it is determined that poor substrate is the cause of recruitment failure, which can be accomplished via monitoring. If not, it is likely that recruitment failure is due to low-salinity conditions (freshets) or inadequate spawning stock in the metapopulation. Adaptive management in this case will be addressed by additional spat-on-shell plantings as described below.

If recruitment failure occurs for more than two years in a row, and oyster biomass on the reef is less than 25 g DW/m^2 (50 percent of the long-term goal biomass), additional spat-on-shell is recommended over the reef surface at a rate of 250 spat/m^{2}over the shell portions of the reef surface. This equates to a re-seeding of spat-on-shell of slightly over 1 million spat per acre of reef. Only those reefs that experience this will be re-seeded with spat, others that are meeting the goal metric will be left alone, unless recruitment failure in Zone 1 waters is the case. In this event, the spat-on-shell stocking will proceed as described, in order to encourage multiple year classes on the restored reefs.

Relying on rare (less than once per decade), intermittent recruitment in low salinity waters is not likely to produce satisfactory results. Recruitment was likely steadier and higher in such waters prior to the massive overfishing that occurred in the late 1800's and it represents a degraded, less stable ecological state for the oyster. If it does represent the original condition of recruitment in low-salinity regions, the stability of these populations relied on the "storage effect" (Warner and Chesson 1985). The "storage effect" occurs because large adult oysters experience lower mortality rates in these low salinity environments, which do not support many typical predators and space competitors of oysters found in higher salinities, such as oyster drills, boring sponges, most barnacle species, mud crabs, and cow-nose rays, among others, but experience low and intermittent recruitment. Unfortunately, this situation was altered in the 1980's during a series of drought years, which allowed Dermo to spread throughout all extant oyster populations. As a result, Dermo now causes mass mortalities (>75 percent) in these low salinity populations, which had been refuges from disease. Mortality in these disease-naïve populations is very high during a spring/summer drought, much higher since the drought years of the 1980s, which has increased the costs of ecologically unfavorable periods and thereby reduced the resilience of low salinity refuge populations such that the occasional strong recruitment event no longer compensates for disease mortality.

Additional monitoring will be required in the event of a multi-year recruitment failure. After two years of low recruitment, the shell-string survey (or comparable survey) will be performed for at least two years or until recruitment on the shell-string is seen to meet the long-term average of the final 3 years of the initial 6-year shell string survey. This is done to determine that sufficient recruits exist to set on the reefs. If this is the case and recruitment on the reefs remain poor, re-shelling as per the 2-year recruitment failure is recommended to be done again if it is determined that shell condition on the reefs is poor.

7.3.1.2 Shell Condition

Shell condition on the reefs will be evaluated in the monitoring plan. This will be done as part of the sampling. If shell condition is such that there is less than 10 liters of oxic or "brown" shell per square meter of reef the reef will be defined to be in "poor" condition. Oxic shell includes live oysters, recently dead oysters or "boxes" as well as any shell that is not covered by sediment and/or black in color due to embedding in the reef below where oxygenated waters are present. Grey color shells on the surface not covered with sediment shall be counted as "oxic." For reefs restored with dredged shell, it is likely that the reef base will be constructed out of shell mined from deposits long buried beneath the sediment surface. Shells from such deposits are grey in color. Also, this shell material must consist primarily of whole shells at least 2 inches in size. Shell hash (small pieces) does provide substrate, but oysters that settle on it experience very high rates of predation as they are essentially "cultchless" and not embedded in the reef matrix.

Poor shell condition can reduce spatset. If shell condition is defined as "poor" but the shell-string data shows normal levels of recruitment, then the reefs should be re-shelled at 80 cubic meters of shell per acre of reef. Due to much higher sedimentation rates in the modern day Bay, such reshelling may be needed even on projects with adequate recruitment, as it is unknown if oyster reefs can persist over multiple decades under current conditions.

7.3.1.3 Additional Considerations

If shell condition is not poor and recruitment on the shell-strings is average or better, additional consideration must be given to the cause of recruitment failure. Red tides can be one cause. Anoxia or high runoff via freshets could be another cause. Water quality monitoring data that includes DO readings can be used to determine if anoxia is present. Using the recommended data which includes a detailed post construction survey that has depth information and the oyster population monitoring data with DO, it could be determined if anoxia is negatively impacting the reefs. Overgrowth with algae during high eutrophic conditions could be another. Water quality and/or weather data could be consulted to reveal these causes. These events do not automatically trigger re-stocking or shelling, unless the reef is damaged by, for example, a hurricane. However, such actions should be considered especially if biomass drops below 25 g DW/m^2.

Poaching of restored oyster reefs and habitat has been a significant problem in Maryland waters of the Bay, and is increasing in Virginia waters. USACE projects in both states have been poached in the past. To deter poaching, alternative reef materials can be placed on shell reefs. Such materials need to be large enough (~300 lbs) in order to be a deterrent. Reef ball structures, as well as granite and/or recycled concrete, among other materials, could be used to do this. While effective patrolling of sanctuary areas as well as use of GPS technology on watermen's boats would be preferred to physical deterrents, physical protections are necessary at this time. In Maryland, enforcement has improved due to the use of GPS technology, but this has not been adopted in Virginia and, despite the (as yet limited) use of GPS tracking, poaching remains a problem.

7.4 SUCCESS CRITERIA AND METRICS

In addition to the interim metrics outlined above, which are used to make decisions on how to manage restored reefs, USACE needs more specific metrics to measure goals. USACE has adopted the additional success criteria and metrics outlined by OMW and will develop additional criteria and metrics if needed internally to meet USACE's goals for long-term sustainability, accountability, and ultimately self-sustaining populations. The end goal – large-scale restoration of habitat and self-sustaining populations in sub-estuaries of the Chesapeake Bay- will take time, and has not been done to date. Reversing population declines that have gone on unabated since the 1800's will be challenging. There are three metrics that have been discussed widely in the Bay scientific community and these are oyster biomass per unit area of restored habitat, live shell volume (often concomitant with accretion rates of shell), and oyster densities on restored habitat. All three require metrics and will be important in both defining goals and adaptive management. They, along with basic monitoring and recommended adaptive management measures related to these three metrics, are discussed below.

7.4.1 BIOMASS

Current information allows a projection of biomass for the restored oyster habitat as shown in Table 7-3. Note that this reflects similar trajectories for unseeded habitat in high-recruitment regions or areas seeded with spat-on-shell in low-recruitment regions. It is anticipated that these numbers would be refined if better information is gained as restoration techniques progress.

Another important aspect to note is that biomass accumulates over time and may continue to increase past year 6. Mature, historic oyster reefs may have had oyster biomass on them much

Table 7-3. Projected Oyster Biomass Accumulation

Year	Biomass (dry weight in grams per square meter of oyster reef)
1	0
2	17.05
3	39.21
4	48.30
6	50

higher than these goals. If the overall trend by year 6 does not show an increase in biomass, corrective actions will be required. It is important to note that all adaptive management measures are designed to help ensure this biomass is achieved. This goal is adopted from the OMW report (OMW 2011). These biomass goals are quite modest, and successful reefs can have much higher biomass/unit reef area. The most robust examples of modern-day reefs lie on remnant reefs in the lower James River and Lynnhaven Rivers in Virginia waters of the Bay. For restoration reefs, those in the Great Wicomico River, Lynnhaven River, and several low-salinity refuge reefs in Maryland waters currently hold the highest biomass.

These reefs have been subject to fishing for roughly two centuries, and in large part are in poor condition. Additionally, they have been subject to repletion, which for the James River reefs, consisted mostly of shells added to the reef structure, beginning in 1931 and continuing today. As can be seen in Figure 7-2, the great majority of the reef acreage has very little oyster biomass, with only a few small reefs having greater than 50 g DW/m². These smaller reefs are in much better overall condition than the large majority, and represent a more natural condition than current depleted stocks, which can be observed on most of the Bay bottom.

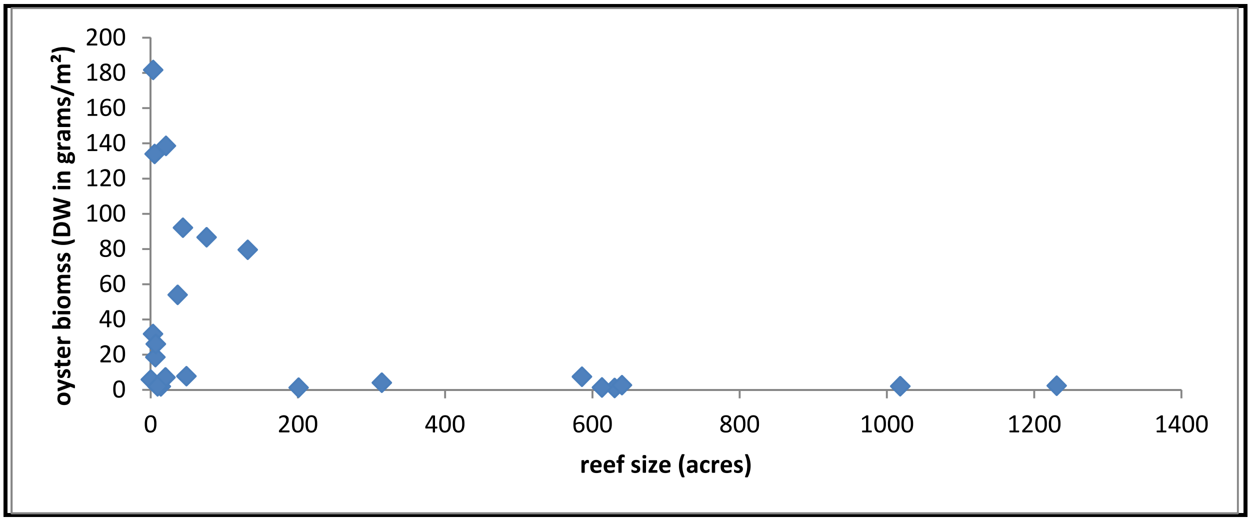


Figure 7-2 Oyster Biomass in the Lower James River, Virginia in 2006

A similar situation can be observed on restoration reefs in the Lynnhaven River. The Hume's Marsh high-density oyster reef sample had an oyster biomass of 232.22 g AFDW (ash free dry weight)/m^2. The Keeling's Drain high-density oyster reef sample also had a high oyster biomass of 251.54 g AFDW/m^2. At the same time, most of the reef acreage held a significantly smaller biomass than the high-density patches. Lower density portions of these reefs, which consisted of most of the restored acreage, held a biomass of ~ 25-30 g AFDW/m² (For oysters, AFDW is typically 10-20 percent less than DW) (Burke 2010).

In the Great Wicomico River, the high relief reef (HRR) habitat has held over 100 g DW/m² over the time period 2007-2010 (Schulte, unpublished data). Reefs that hold significantly greater than 50 g DW/m² are highly exceptional, and half that is a reasonable goal that will, if achieved, allow restored reefs to accumulate additional biomass and shell over time, becoming self-sustaining.

7.4.2 Density

The next aspect to consider is the oyster densities needed to achieve the goal of 50 g DW/m² biomass. Three systems where appropriate data have been obtained were considered. In the James River, the following relationship between oyster biomass and density can be seen in Figure 7-3.

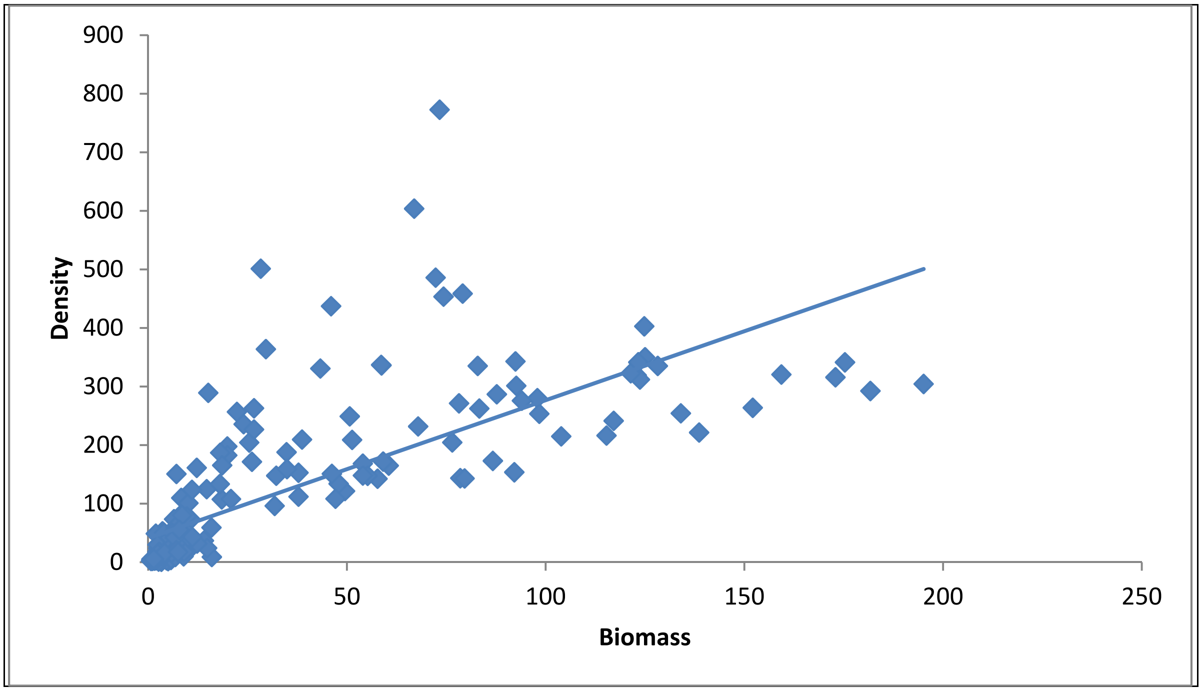


Figure 7-3. Relationship Between Oyster Biomass (in g DW/m²) vs. Oyster Density/m² from the Lower James River, Virginia. The Regression equation is density=2.35514697(biomass) + 41.23049041, $r^2 = 0.554$.

Due to the variation in oyster demographics resulting from strong or weak year classes of recruits, these numbers can vary more widely than biomass, though this metric is still fairly reliable when the goal is multiple age classes of oysters (at least 2 according to the GIT recommendations) which would include significant numbers of adults. Additionally, oyster spat add very little biomass so the biomass metric is primarily driven by the presence of large adults (≥ 60 mm).

Figure 7-3 reveals that in order to achieve the OMW goal of 50 g DW/m², an oyster density of 159 oysters/m² that includes 3-4 year classes is needed according to this sub-estuary data set for oyster habitat in salinity Zones 2-3. Considering the high-density restored reefs in the Lynnhaven mentioned earlier, the Hume's Marsh reef and Keeling's Drain reef would require an oyster density of 206 and 154 oysters/m², respectively (average of 180 oysters). In the Great Wicomico River, the restored HRR reefs required, on average, 162 adults/m² through the time period 2008-2010, with 226 needed in the winter 2007-08 survey data set (this contained many more small oysters proportionally than later years).

What is striking is the similarity between the densities needed to achieve the OMW recommended goal of 50 g DW/m² between the three distinct sub-estuaries (159,162 and 180, mean of 157). In order to achieve the OMW goal for oyster biomass, which USACE is adopting as a reasonable metric indicative of a reef that could become self-sustaining with time, equates to a density of 150 oysters of at least 3 age classes per square meter of restored reef surface by year 6 (for Zone 2-3), concomitant with the biomass goal over time described in Table 7-3. In early years, newly built reefs will be dominated by oyster spat, but by year 4 it is expected that spat, year 1, 2, and 3 oysters should be present in a typical year from then on. As the reef ages, older oysters should be found, with more documented over time as disease resistance continues to develop on the protected sanctuaries even in Zone 3 high salinity, high disease waters. Figures 7-4 and 7-5 demonstrate this.

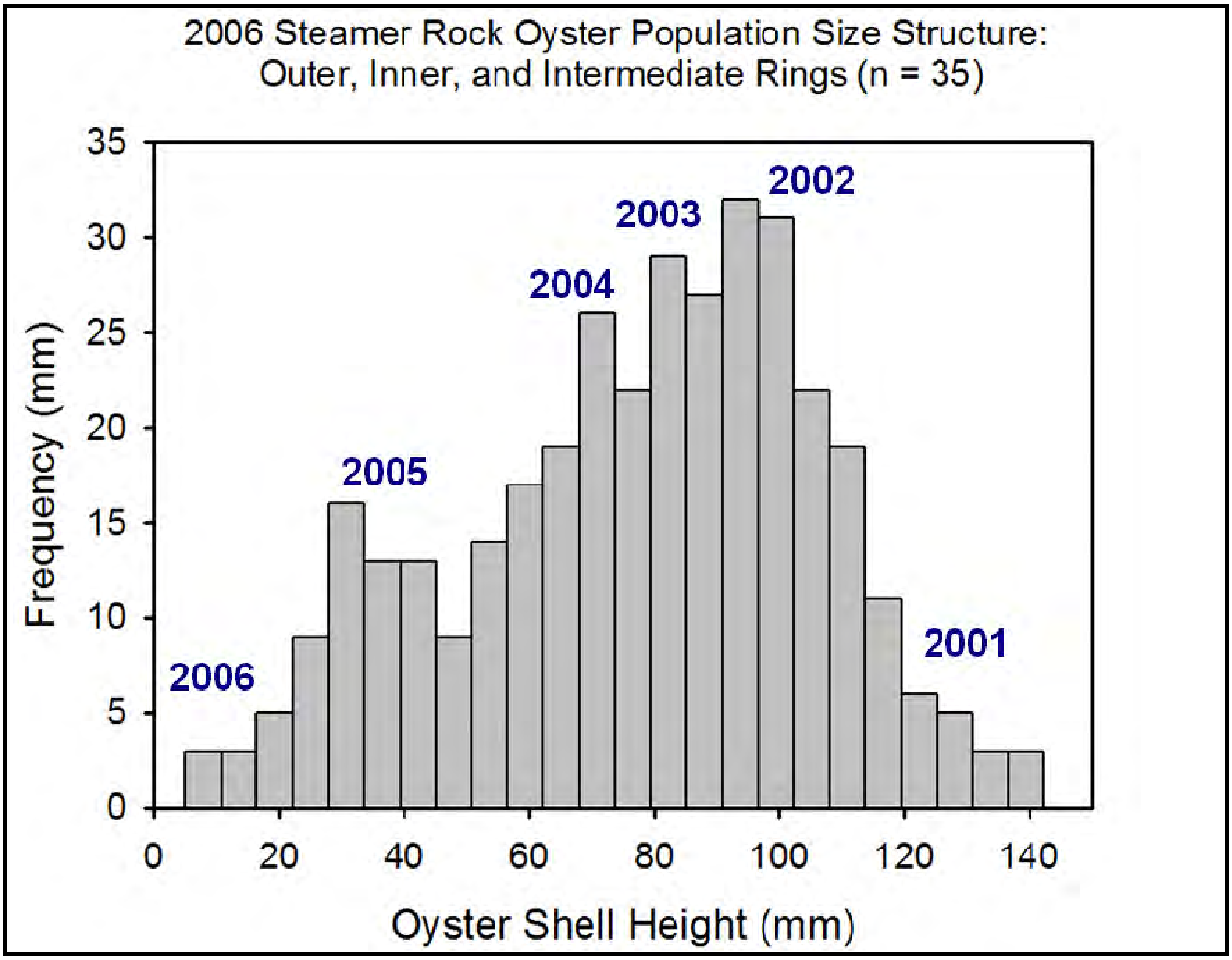


Figure 7-4. Oyster Demographics from a Concrete Reef (Steamer Rock) in the Lower Rappahannock River (Zone 3 Salinity Waters), Virginia. Six year classes are evident.

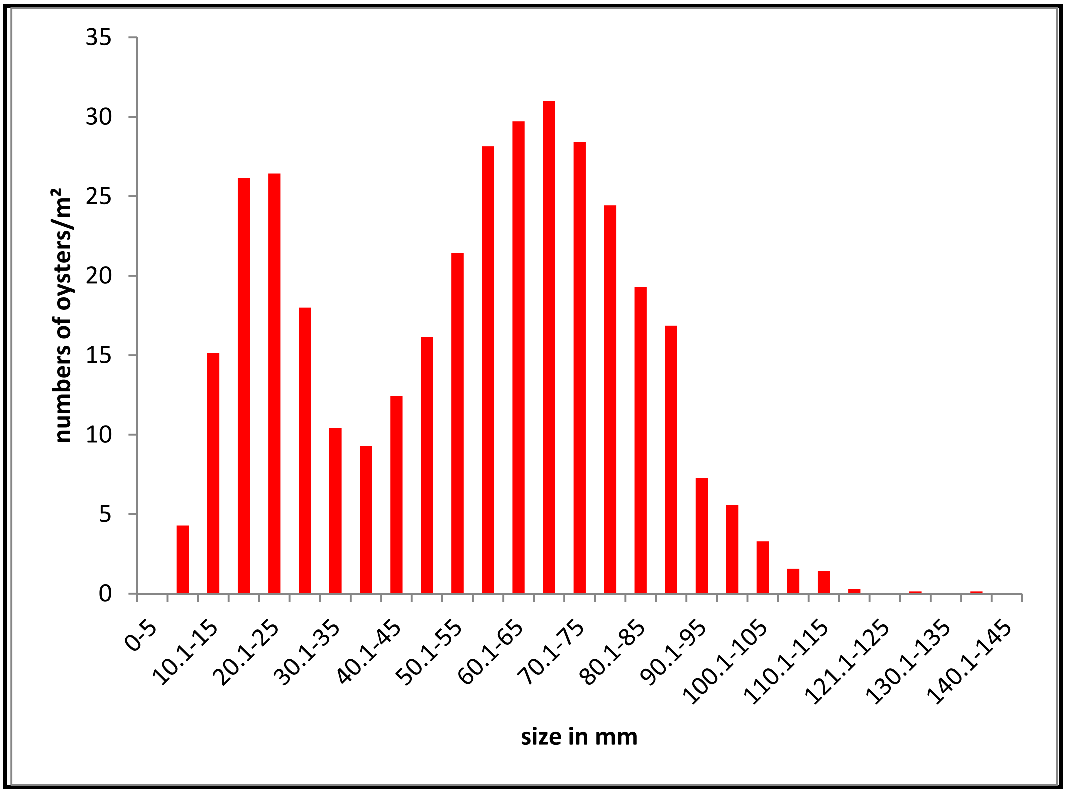


Figure 7-5. Size-Frequency Distribution in 2010 on HRR in the Great Wicomico River.

7.4.3 SHELL ACCRETION

The last metric to consider is shell accretion rates. What should such a rate be and how can it be measured? To begin with, as a reef grows, oysters in the bottom layer die due to smothering and add their shell to the reef matrix. This process can continue under good conditions for thousands of years, resulting in large reefs with several meters of shell above the Bay bottom, structurally analogous to coral reefs in more tropical climes. To be effective as attachment substrate, shells or other materials need to be free of heavy sediment coatings or biofouling from competitor species such as tunicates, barnacles, and sponges. Accretion rates are difficult to precisely measure on an annual basis, and the measure of oxic or "brown" shell, sometimes called "live" shell can be used as a proxy.

USACE recommends that a minimum of 10 liters or more of oxic or "brown" shell be present per square meter of shell reef. Less than 10 L/m^2 require attention and possibly adaptive management measures to improve it. While it may seem that a biogenic reef would have far more than 10 L/m^2 after several years of positive growth, the monitoring data suggests that for subtidal reefs in Chesapeake Bay, it is quite rare to see more than 15 L/m^2 of reef. For comparison, 30 L/m^2 of reef equates to 1.3 inches of clean shell substrate over a square yard of reef while 15 L/m^2 equates to 0.65 inches of clean shell over a square yard of reef. Most remnant habitat in the public oyster fishery in the Chesapeake Bay (as well as Delaware Bay) has less, often approximately 5 L/m^2, which is essentially a thin crust perhaps a single oyster shell or two in thickness. The 10 liters corresponds closely with the 50 g DW/m^2 and 150 $oysters/m^2$ goals as well. Figure 7-6 illustrates the relationship between oyster biomass and shell volume.

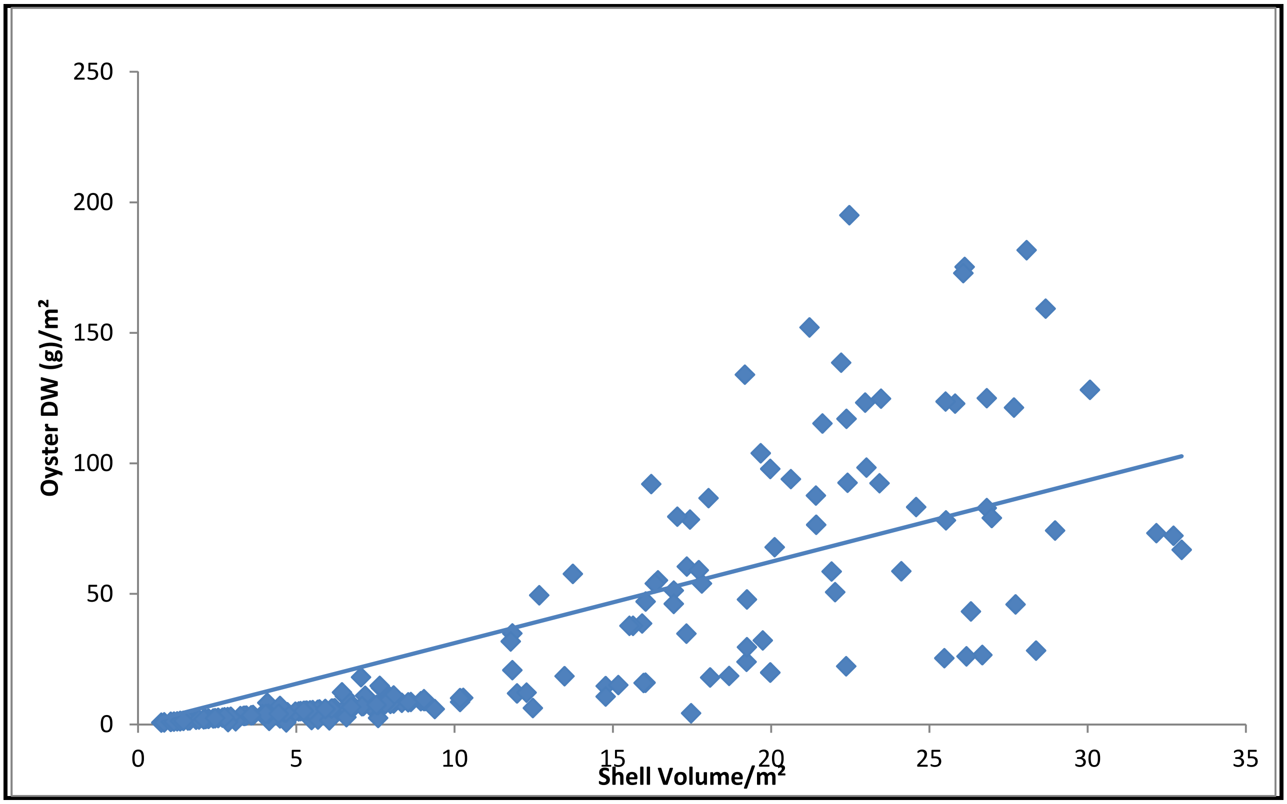


Figure 7-6. Relationship of Oyster Biomass to Oxic Shell Volume. The regression equation is biomass = 3.85 (shell vol.) – 13.28, $r^2 = 0.622$.

In order to obtain the OMW goal, using this equation there would be 9.54 liters of oxic shell required. The data for the Lynnhaven and Great Wicomico Rivers produce similar results, indicating a close relationship between the OMW goal of biomass to a specific oyster density and live shell volume. All three are important monitoring parameters to be used in adaptive management.

Mussels and mud crabs (top), and juvenile naked gobies (left) in sampling trays from restoration reefs in the Severn River, MD.

8.0 AGENCY AND PUBLIC COORDINATION

The goal of public involvement and coordination is to create, facilitate, and maintain open channels of communication with the public to allow for full consideration of public views and information in the decision-making process. Public and agency coordination activities were established to accomplish the following:

1. Provide information about proposed USACE activities
2. Make the public's wishes, needs, and concerns known to decision-makers
3. Provide for consultation with the public before decisions are reached
4. Allow for the consideration of the public's views in decision making

8.1 OVERVIEW AND BACKGROUND

Development of the master plan began in earnest after the June 2009 publication of the record of decision for the PEIS. The PEIS comprehensively addressed the environmental effects of oyster restoration in the Chesapeake Bay. USACE, MDNR, and VMRC were the lead agencies for the PEIS and EPA, NOAA, and USFWS were cooperating agencies (as defined by 40 C.F.R. § 1501.6 for NEPA). Public outreach for the PEIS set the stage for the approach to public outreach in the master plan. The PEIS underwent an extensive peer review process that included reviews by the Scientific Advisory Committee, the Ecological Risk Assessment Advisory Group, the Oyster Advisory Panel, the ASMFC- Interstate Shellfish Transport Committee (ISTC), and additional designated Peer Review Goups (PRG). Each PRG was composed of two to five nationally recognized members of the scientific community. These groups and the peer review process are discussed in detail in Appendix B-2.

After the publication of the PEIS in September 2009, USACE issued a notice of intent on September 18, 2009 to prepare a *Programmatic Environmental Impact Statement for the Chesapeake Bay Oyster Recovery Project, Maryland and Virginia*, along with a master plan. The project sponsors for the oyster restoration program are MDNR and VMRC. NOAA, USFWS, and EPA agreed to be cooperating agencies. PRFC, TNC, and CBF were also identified as potential project sponsors and participated in collaborating agency meetings and review of master plan documents. In December 2010, USACE re-examined the need to include NEPA at this stage of the planning process. USACE determined that NEPA was not necessary given the PEIS recommendations and the fact that it is more appropriate to complete NEPA, if it has not already been assessed, on a smaller-scale during the development of specific tributary plans. The “cooperating agency” designation was no longer appropriate, and that designation was changed to “collaborating agency”. Although, collaborating agencies have no specified responsibilities in the sense that cooperating agencies do within the NEPA process, the collaborating agencies participated closely in development of this master plan, by providing technical guidance, participating in meetings, and providing a review of technical white papers and the draft master plan. All of the above mentioned agencies were viewed as collaborating agencies.

8.2 COLLABORATING AGENCY MEETINGS

USACE, the project sponsors, and the collaborating agencies met in May 2006, March and December 2009, and May and June 2010 to discuss the native oyster restoration master plan. Minutes from each of these meetings are presented in Appendix F. These meetings helped to verify the scope and technical approach for the master plan. Although USACE will not prepare an EIS for the master plan, appropriate NEPA documentation will be prepared for each individual tributary plan accomplished under the umbrella of the master plan. Additional agency meetings will be held as needed.

8.3 PLAN FORMULATION WHITE PAPERS

The USACE team and the collaborating agencies used a series of white papers to develop consensus concerning the strategies to be used in the master plan. Various oyster restoration strategies and restoration concepts were formulated by developing white papers that:

- Discussed the significance of the paper's topic to oyster restoration and USACE's master plan,
- Summarized the current state of knowledge, and
- Described the application to the master plan.

These white papers were provided to the two state sponsors as well as the collaborating agencies for review and comment. Comments were addressed by USACE. Ultimately, the formulation white papers were used to obtain consensus among USACE, the sponsors, and the collaborating agencies on USACE's proposed strategies. The final formulation white papers and a table summarizing the findings of each paper are available in Appendix C-1. Significant comments and responses are described throughout Section 5.2. The following white papers were developed:

- Physical Characteristics- Physiochemistry,
- Physical Characteristics- Individual Reefs,
- Physical Characteristics- Population,
- Physical Characteristics- Hydrodynamics,
- Disease,
- Reproduction,
- Scaling Oyster Restoration, and
- Predation

8.4 PUBLIC OUTREACH

During the development of the master plan, the project team used several communication methods to distribute information to the public, including electronic mail, press releases, and a project website. Public presentations of the project findings were advertised with electronic mail lists, press releases and websites.

NAO and NAB worked jointly to write two news releases to be sent to local media outlets. Press releases were distributed via e-mail contact lists, as well as through MyMediaInfo, an online database of media outlets. Media advisories were then sent the day before each public meeting.

Additionally, a publically accessible website was created and linked to via both NAO’s and NAB’s website. The website allowed users to download copies of the draft master plan, submit comments on the master plan, and view presentations from the public meetings.

Overall information-sharing was geared toward electronic and Internet submissions due to its potential for immediate mass distribution, high accessibility, low cost, and low environmental impact.

USACE hosted a series of public meetings once the draft master plan was released for review. The meetings were held in an open-house style format. A formal presentation was made at a designated time. Posters presenting the content of the presentation plus some additional information were stationed around the room for attendees to view. Staff was available for open discussion throughout the meetings. Public meetings were held:

Tuesday, April 10, 2012, 3 − 8 p.m. – Chesapeake Bay Foundation (Annapolis, MD)
Tuesday, April 17, 2012, 5:30 − 9 p.m. – Thomas Nelson Community College (Hampton, VA)
Thursday, April 19, 2012, 3 − 8 p.m. – Chesapeake College (Queenstown, MD)

The April 10, 2012 meeting had 17 individuals officially sign-in. Eight individuals noted their affiliation with environmental groups or agencies (NOAA, MDNR, Severn River Association, Chesapeake Bay Foundation, and Chesapeake Bay Savers).

The April 17, 2012 meeting had 32 individuals officially sign-in. Many agencies and organizations were represented, including: Chesapeake Bay Foundation, Lynnhaven River NOW, The Nature Conservancy, Virginia Marine Resource Commission, and Virginia Institute of Marine Science.

The April 19, 2012 meeting had 25 individuals officially sign-in. The groups came from both the private (watermen, Harris Oyster Company, Argo Systems) and public sectors (MDNR, Talbot County DPW, UMCES). Two Congressional representatives (Congressman Andy Harris [MD-01] and Senator Barbara Mikulski) had staff attending. One reporter from the Record Observer-Star Democrat also attended.

Attendance records and all public meeting materials are in Appendix H.

8.5 FOLLOW-ON DESIGN AND SUPPLEMENTAL DOCUMENTS

Individual design documents for recommended sites will follow the master plan and provide detailed plans for tributaries. USACE will prepare appropriate documentation for each of these sites as required by NEPA. The NEPA documents will address any site-specific details, such as final decisions on the precise location and configuration of oyster reef structures. Companion studies and NEPA documents would include appropriate public involvement.

8.6 PUBLIC COMMENTS RECEIVED

During the 30-day comment period, a total of 29 comments were received on the draft document. A variety of concerned residents and representatives of watermen's associations, local governments, and other non-profit organizations provided comments. All public comments to the draft document were collected, reviewed, and discussed within the master plan team. In general, comments pertained to the effects of sedimentation on oysters, whether funding would be available for such large-scale oyster restoration, concern for recommending permanent sanctuaries versus harvest reserves and how poaching would be handled. All comments received during the public comment period were considered, and copies of all letters and emails received prior to the closing date of May 19, 2012 are included in Appendix H as well as formal responses to comments.

9.0 CONCLUSION

USACE supports large-scale tributary-based oyster restoration in the Chesapeake Bay. This master plan is a strategy for coordinated USACE involvement in future oyster restoration efforts based on USACE's authority to construct oyster habitat. The master plan outlines various strategies for addressing salinity-driven differences, disease, reproduction, scale, reef construction, and adaptive management. USACE restoration will be constructed within sanctuaries, but it is anticipated that these restored areas (if completed at a sufficient scale) will contribute larvae to help develop habitat/restore populations in areas outside sanctuaries.

This master plan recommends that 24 (Tier 1) tributaries of the Chesapeake Bay are currently suitable for large-scale oyster restoration. These sites are distributed throughout the Bay with 14 sites in Maryland and 10 sites in Virginia (Table 9-1). Tier 2 tributaries either do not have enough suitable area to meet restoration targets and/or do not have suitable hydrodynamic properties. Tier 2 locations are recommended for consideration following the completion of Tier 1 projects or improvements in existing conditions.

Table 9-1. Tiered List of Tributaries by State

Tier 1	Tier 2	
Maryland		
· Severn R (S) · South R (S) · Chester R (lower) (S) · Eastern Bay (lower, upper) (S) · Choptank R (lower, upper) (S) · Harris Creek (S) · Broad Creek · Little Choptank (S) · St. Mary's R (S) · Tangier Sound (lower, upper) · Manokin R (S)	· Magothy R (S) · Rhode R · West R · Chester River (upper) (S) · Corsica R (S) · Honga R · Potomac R · Fishing Bay · Nanticoke R (S) · Monie Bay	· Big Annemessex R · Little Annemessex R · Patuxent R (S) · All MD Mainstem Segments (S)
Virginia		
· Great Wicomico R (S) · Rappahannock R (lower) · Piankatank R · Mobjack Bay · York R (lower) · Pocomoke/Tangier Sound · James R (lower, upper) · Elizabeth R · Lynnhaven R	· VA Mainstem · Little Wicomico R · Cockrell Creek · Corrotoman R · Rappahannock R (middle, upper) · Severn R · York R (upper)	· Back R · Poquoson R · Onancock Creek · Nassawaddox Creek · Hungars Creek · Cherrystone Inlet · Old Plantation Creek · Nansemond R

(Tributaries with large sanctuaries are designated with an 'S'.)

Estimated costs vary widely per tributary. Cost estimates project that investments ranging from $3.8 million to $46.2 million for the smallest Tier 1 tributary (Lynnhaven River, 40 to 150 ac) to $287.5 million to $1.07 billion for the largest Tier 1 tributary (Tangier/Pocomoke Sound ac, 3,000 to 5,900) are needed to achieve restoration targets. These estimates include habitat construction, seeding, and monitoring. The cost range within an individual tributary reflects the low and high acreage target as well as the lowest and highest priced alternate substrates. These estimates are conservatively high as existing habitat is not included in most estimates. Once quantified, existing habitat would reduce the effort needed to reach restoration targets. In many tributaries, restoration efforts will need to be carried out over a number of years to construct the targeted acreage.

Table 9-2 provides a summary of the restoration targets and costs for all the Tier 1 sites in Maryland and Virginia as well as projected costs for three implementation scenarios.

Table 9-2. Summary of Restoration Targets and Estimated Costs

	Number of Tier 1 Tributaries	Oyster Reef Restoration Target (acres)	Total Estimated Low Range Cost	Total Estimated High Range Cost
Maryland Tier 1	14	7,300-14,600	$0.87 billion	$2.85 billion
Virginia Tier 1	10	10,100-20,400	$0.97 billion	$3.63 billion
Scenario 1- All Tier 1 Tributaries	24	17,400-35,000	$ 1.85 billion	$ 6.50 billion
Scenario 2- Salinity-based restoration	24	18,200	$ 1.99 billion	$ 3.42 billion
Scenario 3- E.O. Implementation	20	14,400–28,400	$ 1.56 billion	$ 5.38 billion

USACE envisions restoration to be concentrated in one to two tributaries at a time in each state until the targeted scale and success metrics are achieved in those tributaries; then significant restoration operations would be transitioned to the next selected tributary. USACE recommends that the next step is for oyster restoration partners to select an initial Tier 1 tributary to focus restoration efforts within each state and develop a tributary plan that considers the factors outlined in Sections 5.5.4 and 6.2. A tributary approach to restoration is recommended to build a critical mass of oysters and habitat that will have an impact on depleted oyster populations in the targeted tributary.

A concentration of resources and funding is necessary to establish self-sustaining populations. Past restoration efforts have been too small and too widespread to broadly impact population levels in the Bay. USACE envisions construction of significant acreage (e.g. 25 to 100 acres) per year in a small number of tributaries until their restoration targets are reached for those tributaries. This would require a staggered approach where habitat is constructed and monitored in alternating years between the tributaries. Construction efforts would continue in a specific tributary until metrics of success are achieved or the partners determine that resources should no longer be committed to a non-performing tributary. The speed of recovery will be tied closely to favorable climatic conditions (precipitation and temperature), but also to the level of resources devoted to restoration.

Large-scale, tributary-based oyster restoration is in its infancy. Techniques and methods are only beginning to be identified and are largely untested at this scale. With this in mind, as well as recognized funding and resource limitations, it is recommended that small tributaries (creeks and small rivers) receive initial focus, rather than large tributaries. Based on the findings of Carnegie and Burreson (2011), initial efforts should be focused in mesohaline-polyhaline (higher) salinities with particular attention given to mid-river reefs.

There are many oyster restoration topics that would benefit from further scientific investigation. Future research is needed to quantify the diverse benefits provided by oyster restoration, understand larval transport, advance the development of disease resistance, and understand disease transmission. Research is needed to identify the role water currents and bottom topography play in site selection. The performance of alternate substrates needs to be better documented. Investigations are also needed to determine how and where shell reclamation can be incorporated into restoration plans. This is not an exhaustive list, but it highlights some of the prime areas for additional research. Oyster restoration will be most successful if research and technological advancements are incorporated into restoration efforts.

The goal and objectives, and the adaptive management and monitoring plans proposed in the master plan are consistent with the recommendations of the Chesapeake Bay Program's Fisheries GIT's multi-agency Oyster Metrics Workgroup. Further, USACE restoration projects will follow the metrics outlined by the report of the Oyster Metrics Workgroup (OMW 2011), which includes USACE master plan team members. Tributary-based oyster restoration, as laid out in the master plan, will additionally contribute towards achieving a number of strategy goals of other Chesapeake Bay Program GITs including those of the Protect and Restore Vital Habitat GIT, Protect and Restore Water Quality GIT, and Maintain Healthy Watersheds GIT.

USACE will look to partner with other interested agencies and partners to coordinate and accomplish science-based, cost-effective, large-scale oyster restoration. The greatest achievements will be made by joining the capabilities of each agency in a collaborative manner to pursue restoration activities. Large-scale oyster restoration in the Chesapeake Bay will only succeed with the cooperation of all agencies and organizations involved. Resources and skills must be leveraged to achieve the most from restoration dollars.

Reversing population declines that have gone on unabated since the 1800's will be challenging. Large-scale restoration of habitat and self-sustaining populations in sub-estuaries of the Chesapeake Bay will take time, and has not been done to date.

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