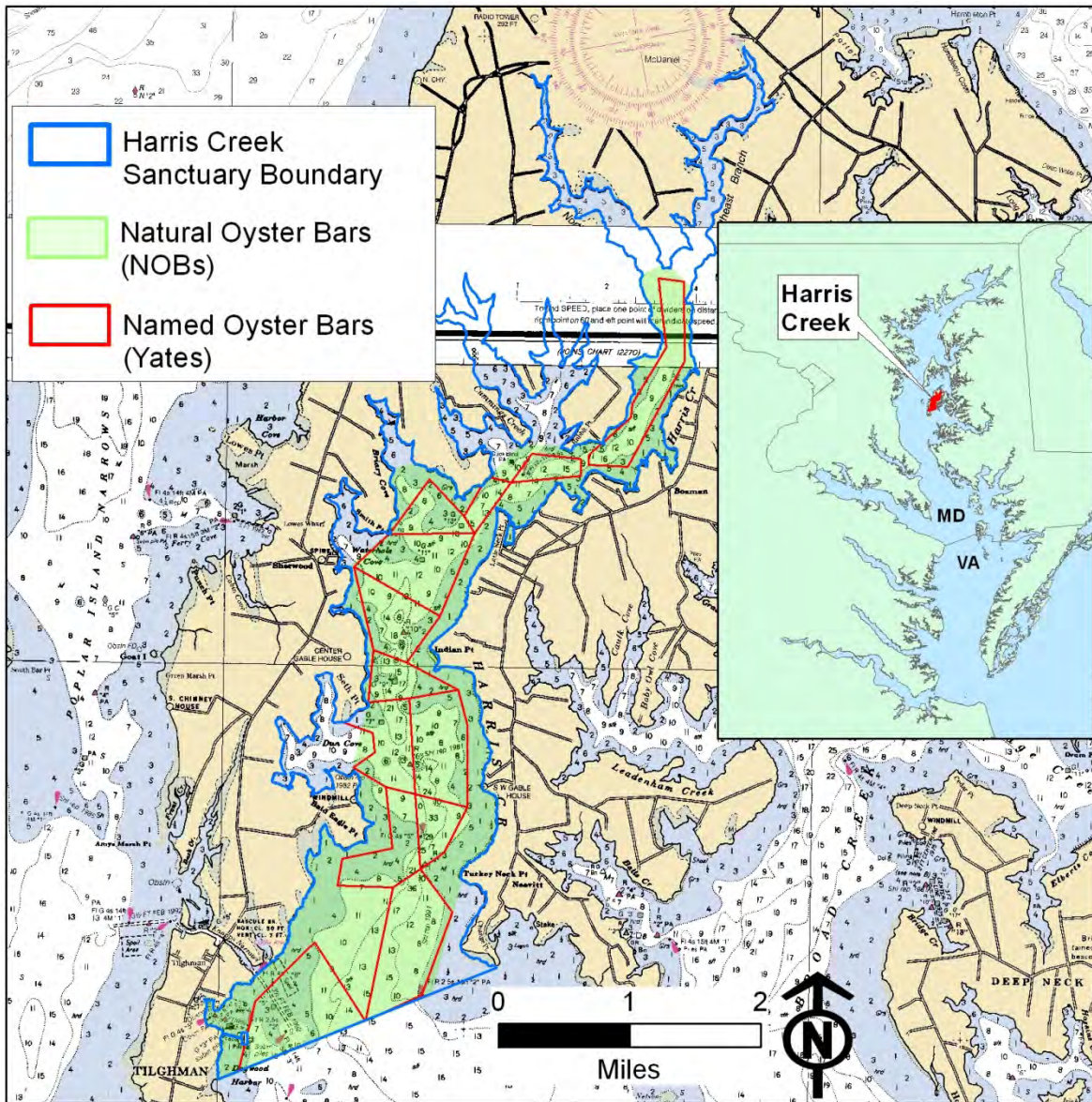


Harris Creek Oyster Restoration Tributary Plan:

A blueprint to restore the oyster population in Harris Creek, a tributary of the Choptank River on Maryland's Eastern Shore

As drafted by the
Maryland Interagency Oyster Restoration Workgroup of the
Sustainable Fisheries Goal Implementation Team
January 2013



Workgroup Participants:

Steve Allen, Oyster Recovery Partnership
Claire O'Neill, U.S. Army Corps of Engineers, Baltimore District
Angela Sowers, U.S. Army Corps of Engineers, Baltimore District
Eric Weissberger, Maryland Department of Natural Resources
Stephanie Reynolds Westby, NOAA Restoration Center (chair)

Consulting Scientists:

Stephan Abel, Oyster Recovery Partnership
Denise Breitberg, Smithsonian Environmental Research Center
David Bruce, NOAA Chesapeake Bay Office
Mark Bryer, The Nature Conservancy
Kelton Clark, Morgan State University
Bill Goldsborough, Chesapeake Bay Foundation
Chris Guy, U.S. Fish and Wildlife Service
Jay Lazar, NOAA Chesapeake Bay Office
Elizabeth North, University of Maryland
David O'Neill, National Fish and Wildlife Foundation
Kennedy Paynter, University of Maryland
Cecily Steppe, U. S. Naval Academy
Mike Wilberg, University of Maryland

Harris Creek Oyster Restoration Tributary Plan

Table of Contents

	<u>Page</u>
Executive Summary.....	1
Context and Scope	3
Harris Creek Tributary Plan Process.....	4
Data Used in the Harris Creek Tributary Plan	7
Physiochemical Criteria.....	7
Physical Criteria.....	8
Biological Criteria	9
Other Criteria	10
Spatial Analysis.....	10
Blueprint Map	11
Ground-Truthing	14
Blueprint Map Summary.....	15
Seed Needs Analysis	16
Substrate Needs Analysis.....	18
Monitoring and Research	19
Monitoring of Oyster Metrics Success Goals.....	19
Diagnostic Monitoring	20
Monitoring Protocols	23
Research.....	24
Cost Analysis for Harris Creek Tributary Plan	27
Implementation of the Harris Creek Tributary Plan	28
Adaptive Management and Project Tracking	29
References	30

List of Figures

<u>Number</u>	<u>Title</u>	<u>Page</u>
1	Harris Creek Location Map	1
2	Blueprint Map	13

List of Tables

<u>Number</u>	<u>Title</u>	<u>Page</u>
1	Criteria Considered During the Harris Creek Tributary Plan Process	7
2	Summary of Ground-Truthing Protocols	14
3	Summary of Bottom-Type Categorization	14
4	Acreage by Reef Treatment Type (with anticipated reductions)	15
5	Seed Needs and Oyster Survival Assumptions	17
6	Seed Cost Analysis.....	18
7	Substrate Needs Analysis.....	18
8	Substrate Cost Analysis.....	19
9	Suggested Restoration Success Monitoring Activities.....	21
10	Suggested Diagnostic Monitoring Activities	22
11	Summary of Monitoring Costs	23
12	Summary of Total Costs	28

List of Appendices

<u>Number</u>	<u>Title</u>
A	Harris Creek Spat Set Data
B	Restorable Bottom Analysis
C	Map of Existing Oyster Density, Shell Volume and Sedimentation
D	Interpolation Analysis for Map of Existing Oyster Density, Shell Volume and Sedimentation
E	Substrate and Seed Requirements for Each Selected Restoration Site
F	Detailed Views of Harris Creek Blueprint Map (“chartlets”)
G	Blueprint Map Geoprocessing Methods

The appendices are available on the Internet at:
<ftp://ftp.chesapeakebay.net/noaa/Harris%20Creek%20Draft%20Sep%202012/>

Executive Summary

In May 2009, President Obama issued Executive Order 13508, “Chesapeake Bay Protection and Restoration.” The oyster outcome associated with this executive order is to restore oyster populations in 20 Chesapeake Bay tributaries by 2025. The Chesapeake Bay Program’s Sustainable Fisheries Goal Implementation Team (GIT) is charged with advancing this goal. The GIT previously convened the Oyster Metrics Workgroup, which established a Bay-wide, science-based, consensus definition of a “restored tributary” per the executive order goal. The GIT has now convened interagency workgroups in Maryland and Virginia to plan restoration work in each state, in consultation with appropriate partners.

Based on consideration of salinity levels, available restorable bottom, protection from harvest, historical spat set, and other factors, the Maryland Interagency Workgroup, in consultation with Maryland oyster restoration partners, selected Harris Creek as its first tributary for large-scale oyster restoration. Harris Creek is a tributary on the north shore of the Choptank River, near the mouth, on Maryland’s Eastern Shore, as shown in Figure 1. It is an oyster sanctuary (closed to wild oyster harvest).

What follows is the Harris Creek Oyster Restoration Tributary Plan. It details the restoration site selection process, and the reef construction, seeding, and monitoring required to bring Harris Creek in line with the oyster metrics definition of a successfully-restored tributary. It calls for restoring 377 acres of oyster reefs in Harris Creek, and includes:

- a description of the process used to develop the tributary plan,
- a map showing which areas of the creek are targeted to receive plantings of substrate (reef material) and oyster seed,
- a needs analysis for oyster seed and substrate,
- a cost analysis, and
- a discussion of monitoring, implementation and progress tracking.

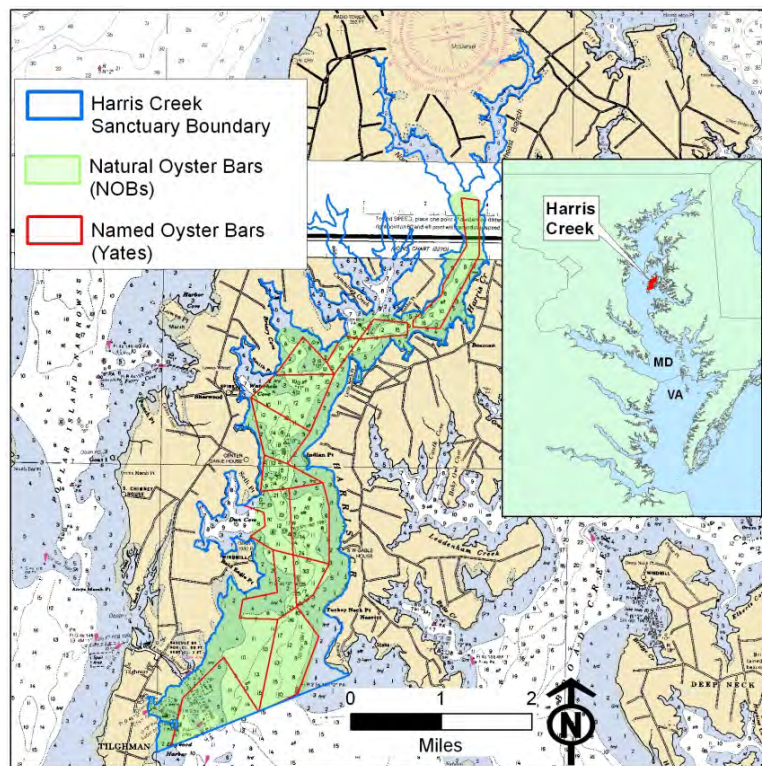


Figure 1: Harris Creek Location Map

The implementation time frame will depend primarily on availability of funding. Existing oyster seed production capacity is sufficient to allow for implementation of this plan in 3 to 5 years.

However, for planning purposes, this document assumes a worst-case scenario where Harris Creek does not receive any natural recruitment (spat set) over the course of plan implementation. Until 2000, the creek regularly received large spat sets. From 2000 through 2010, only one significant spat set occurred, and even that was lower than historic levels. Fortunately, partway through this planning process, Harris Creek received a natural spat set. This may mean some areas targeted for restoration herein, that initial surveys indicated fell short of the restoration goals per the oyster metrics report, may now already meet the restoration goals per the oyster metrics report. Thus, it is likely that the seed and cost estimates herein are high. It is also possible that the creek may receive future natural spat sets during the implementation timeframe, yielding additional boosts. Ultimately, the intent is for the added broodstock to reproduce and jumpstart spat sets in Harris Creek to levels recorded prior to 2000.

This plan represents an unprecedented scale of oyster restoration in a single tributary in Maryland. Significant data collection and analysis went into the development of the tributary plan, including benthic sonar mapping with video and patent tong ground-truthing to identify suitable bottom for restoration, water quality analysis, examination of historic oyster bars, consideration of past and current oyster recruitment, an evaluation of sediment and shell volume on existing oyster shell bottom, and two coordinated surveys to determine current oyster populations in Harris Creek. Additionally, public participation was encouraged during an open house held to hear input on the plan. It is expected that this tributary plan will serve as a model for the restoration of other tributaries in support of the Executive Order goal.

DNR, NOAA, and USACE are charged with implementation of the Harris Creek tributary plan. However, the productive collaboration of academic, non-governmental, and local groups involved in Chesapeake Bay restoration will greatly help achieve restoration success.

Summary: Harris Creek Oyster Restoration Tributary Plan

Total Acres Targeted for Restoration	377
Total Seed Required	2,093,000,000
Total Substrate Needed (cubic yards)	350,000
Total Implementation Cost (restoration and monitoring)	\$31,651,000

Harris Creek Oyster Restoration Tributary Plan

Context and Scope:

President Obama's Executive Order 13508 called for federal agencies to establish specific measurable environmental goals for restoring the Chesapeake Bay. These environmental goals were laid out in the May 2010 *Strategy for Protecting and Restoring the Chesapeake Bay Watershed*; this strategy specifically called for restored oyster populations in 20 Chesapeake Bay tributaries by 2025. In support of the executive order, the Chesapeake Bay Program's Sustainable Fisheries Goal Implementation Team (GIT) convened the Oyster Metrics Workgroup to develop a science-based, common definition of a successfully-restored tributary for the purpose of tracking progress toward the goal. The workgroup was composed of representatives from the state and federal agencies involved in Chesapeake Bay oyster restoration, as well as oyster scientists from academic institutions. The workgroup produced a report detailing these success metrics (Oyster Metrics Workgroup, 2011). These metrics serve as the basis for the Harris Creek tributary plan. The following criteria were among those set forth in the metrics report:

- A successfully-restored reef should:
 - have a minimum mean density of 50 oysters and 50 grams dry weight/square meter (m^2) covering at least 30 percent of the target restoration area at 6 years post restoration;¹
 - have two or more age classes present; and
 - exhibit stable or increasing spatial extent, reef height and shell budget.
- A successfully-restored tributary is one where 50 to 100 percent of the currently-restorable bottom has oyster reefs that meet the reef-level metrics above. Restorable bottom is defined as area that, at a minimum, has appropriate bottom quality and water quality for oyster survival).
- An ideal candidate tributary is one where 50 to 100 percent of the currently restorable bottom is equivalent to at least 8 percent, and preferably more, of its historic oyster bottom.

In 2012, USACE drafted a native oyster restoration master plan that evaluated tributaries of the Chesapeake Bay to determine those tributaries with the potential to support large-scale oyster restoration efforts. In 2012, the GIT established the Maryland Interagency Workgroup consisting of representatives from the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers' Baltimore District (USACE), and the Maryland Department of Natural Resources (DNR). The purpose of this group is to facilitate oyster restoration by coordinating efforts among the state and federal agencies, in consultation with the scientific, academic and oyster restoration communities. The workgroup utilized the

¹ In addition, a minimum threshold for restoration success was set at 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 6 years post restoration activity. Minimum threshold is defined as the lowest levels that indicate some degree of success. However, this tributary plan is focused on the 50 oysters/ m^2 target density for a successfully restored reef.

USACE Native Oyster Restoration Master Plan and the Maryland Oyster Restoration and Aquaculture Development Plan as the foundations of its work. The workgroup's specific efforts over the past year have included selecting tributaries for restoration using science-based criteria, and drafting the Harris Creek tributary plan.

The purpose of this plan is to describe the actions necessary to bring Harris Creek to the oyster metrics definition of a successfully restored tributary. It includes specific areas targeted for restoration work, and an analysis of the amount of seed and substrate required and associated estimated costs. Included too is a monitoring framework that will allow for the determination of whether or not Harris Creek can be considered "successfully restored" per the oyster metrics definition. It is recognized that this monitoring plan is not exhaustive. Many research questions may remain unanswered if only this basic level of monitoring is implemented. Thus, an additional section is included that lays out recommended research topics for which Harris Creek may be a suitable study site.

This plan estimates the funding required to restore Harris Creek per the oyster metrics definition is just over \$31.5 million. Some funds have already been identified (see implementation section); identifying the balance will need to be an ongoing effort for the oyster restoration partners. Even acquiring the large amount of required substrate (350,000 cubic yards) is a substantial challenge. The hope is that laying out this plan will clarify the needs, and allow agencies, non-profit organizations, academics and other stakeholders to collectively identify the remaining resources needed for implementation.

Harris Creek Tributary Plan Process

The Harris Creek Oyster Restoration Tributary Plan was accomplished using the following steps:

1. Identify tributary for restoration and set restoration acreage target:

Harris Creek, a tributary near the mouth of the Choptank River on Maryland's Eastern Shore, was selected as the initial candidate for restoration by the Maryland Interagency Workgroup based on the findings of the USACE master plan, DNR's fall survey data, the Maryland oyster sanctuary list, and bottom survey data from the Maryland Geological Survey and NOAA. Criteria used in the tributary selection included water quality (salinity and dissolved oxygen appropriate for survival and reproduction), availability of restorable bottom (hard bottom capable of supporting oysters and substrate), historic spat set data (Appendix A), potential for larval retention, sanctuary status, and tributary size. Harris Creek scored favorably for all criteria.

2. Define restoration goal (target acreage):

As noted earlier, the oyster metrics report defined a successfully restored tributary as one where 50 to 100 percent of currently restorable bottom, constituting at least 8 percent of historic oyster habitat, consists of restored reefs. NOAA performed a Harris Creek restorable bottom analysis (Appendix B) based on data from the USACE master plan, the oyster sanctuary boundaries, and bottom survey data from Maryland Geological Survey and NOAA. This analysis showed 600 acres of potentially restorable bottom in Harris Creek (Appendix B). Historically, there were 3,479 acres of oyster habitat identified by the Yates Survey in 1913; accordingly, 8 percent of the historic habit (3,479) is 278 acres. Hence, the restoration goal for Harris Creek was set at 300 to 600 acres to meet both of the success criteria defined by the Oyster Metrics Workgroup.

3. Conduct pre-restoration oyster population surveys:

NOAA contracted Versar, Inc., to perform a spatially-explicit population survey in Harris Creek. As part of a NOAA-funded Bay-wide project involving DNR, the Paynter Labs at the University of Maryland also conducted a Harris Creek population survey. These surveys were done in the winter of 2011-2012.

4. Develop a blueprint draft map summarizing major datasets:

The workgroup summarized the available geographic information systems (GIS) data in an initial blueprint map, showing potential locations for different reef restoration treatments. Details of the GIS analysis are described in a later section of this document. From here, the workgroup selected initial areas suitable for two types of treatment: seed only, or substrate plus seed. The workgroup also identified areas currently meeting the oyster density goal, as determined by the population surveys. General planning guidance from the U.S. Coast Guard was also considered during this process. This guidance includes setbacks of 250 feet from marinas and navigational aids and 150 feet from federally maintained channels.

5. Conduct public open house:

The initial blueprint map was presented to the public at an open house held March 21, 2012, at the Chesapeake Bay Maritime Museum in St. Michaels, Maryland. Comments received from the public were favorable, with specific recommendations to maintain access to the Indian Point Community Association dock, Dun Cove, and the Knapps Narrows channel; to avoid disturbing the Marylanders Grow Oysters Program's planting site; and to be mindful of the potential impact of illegal harvest.

6. Revise blueprint map:

Incorporating feedback from the open house, a revised map was created showing potential oyster restoration sites for each treatment type. Estimates were made for amount of seed and substrate needed; and from those, cost estimates were derived.

7. Send draft blueprint map to the Coast Guard:

The draft blueprint map was sent to the Coast Guard's waterways management section for review and advance coordination of a potential Section 10 permit and as part of ongoing NEPA (National Environmental Policy Act) coordination. In addition to a formal written review, the workgroup met informally with the Coast Guard staff to describe the tributary plan process and draft blueprint map.

8. Send draft blueprint map and tributary plan to consulting scientists for review:

In addition to input from the Coast Guard, the workgroup is coordinating the draft tributary plan, including the blueprint map, with a group of Chesapeake Bay scientists from the academic community, Federal and state resource agencies, and non-profit organizations. This review includes both a formal written review as well as an informal meeting to discuss any concerns or suggestions for improvement. It is expected that communication with the scientific community will be ongoing throughout restoration.

9. Finalize reef blueprint map and tributary plan:

Using the inputs from the consulting scientists, and the Coast Guard, the workgroup will finalize the Harris Creek tributary plan into a living document, to be updated as appropriate based on adaptive management.

10. Obtain Section 10 permit or NEPA clearance, as needed:

Restoration partners (DNR and USACE) are currently limited to placing substrate in locations where 8 feet of water depth (clearance) will remain above the reef. The current water depth requirements severely limit the spatial scale at which reefs can be constructed in Harris Creek, and would prevent achieving the restoration goal.

Depending on the implementation strategy, further regulatory actions may be required. If implementation is performed by the State of Maryland (DNR), then the existing Section 10 permit may need to be modified since it currently only allows an 8-foot depth clearance. Similarly, USACE's NEPA documentation to date has limited the federal actions to the 8-foot clearance as well. Subsequently, DNR is applying for a permit modification to allow substrate placement per this plan (allowing minimum of 5 feet of clearance). USACE is continuing its NEPA coordination to incorporate this change. Due to the target restoration acreage, shallower depths must be utilized. The process to get regulatory clearance for the shallower areas has been started.

11. Implement seeding and substrate activities:

The tributary plan is expected to be primarily implemented by the key federal and state agencies involved in oyster restoration. Specifically, USACE is expected to continue to play a large role in the placement of substrate. NOAA is planning to continue to be involved funding seeding activities, as well as mapping and survey actions. DNR is planning to contribute both to the seeding and substrate placement efforts, as well as

mapping and survey activities. All three partners plan to fund and conduct project planning and monitoring efforts.

12. Monitor project performance and adaptively manage:

Using the protocols discussed in the oyster metrics report, the workgroup will monitor the performance of the restoration sites in Harris Creek. Key parameters to be monitored include reef structure, population density, total reef population, and the number of age classes. Additionally, the workgroup will monitor water quality and other parameters that affect project success. Monitoring is planned to occur several times within 6 years of implementation. Depending on the results of the monitoring, additional seeding or other adaptive management actions will be undertaken. Details of the monitoring plan are found in the monitoring section of this document.

Data Used in the Harris Creek Tributary Plan

This section details the parameters considered in the selection of Harris Creek as the first target tributary for intensive oyster restoration, the selection of restoration sites within the creek, and the determination of location and type of reef treatment. Some of these parameters were considered in greater depth in the USACE master plan process and/or the Maryland Oyster Restoration and Aquaculture Development Plan process. They warrant mention here, though, since the Harris Creek tributary plan largely builds on these plans. Further description of each parameter is discussed in the ensuing paragraphs.

Table 1: Criteria Considered During the Harris Creek Tributary Plan Process

Physiochemical	Water quality (dissolved oxygen (DO), salinity, temperature)
Physical	Bottom quality, sedimentation, depth
Biological	Location and quantity of existing oyster population, historical spat set, larval transport
Other	Sanctuary boundaries; land use; location relative to other estuarine habitats (SAV); input from public, Coast Guard, and consulting scientists

Physiochemical Criteria

Harris Creek is classified as a mesohaline tributary. Salinity and dissolved oxygen (DO) data were compiled and screened through USACE’s master plan efforts by Versar, Inc. Point data were gathered by DNR, the Maryland Department of the Environment, the Alliance for Chesapeake Bay, and the Chesapeake Bay Program. The same salinity dataset was also used to evaluate Harris Creek for the potential risk from freshets. Temperature is not a limiting factor in Harris Creek and needed no further consideration. Details of the physiochemical selection criteria are provided in the USACE master plan.

Physical Criteria

Only areas between 4 and 20 feet in water depth were considered suitable for restoration. Deeper waters typically experience low DO conditions and higher sedimentation that are not suitable for oysters or the reef community. Shallower waters conflict with other uses of the waterway. Water depth between 4 and 6 feet deep was considered unsuitable for substrate additions due to concerns about navigational interference of placing alternate substrates. Thus, only water depths between 6 and 20 feet were considered suitable for substrate additions.

Adequate bottom must be available for oyster restoration. Hard bottom capable of supporting shell or other material likely to catch spat as well as areas that currently hold oyster shell were identified by bottom surveys using sonar in conjunction with various ground-truthing methods. Side-scan sonar surveys were conducted by the Maryland Geologic Survey (MGS) in 2010 to identify bottom type, specifically, whether the bottom surface was exposed shell habitat, buried shell, or hard bottom. Seabed-type polygons were classified by NOAA using the Coastal and Marine Ecological Classification Standard (CMECS)² surface geology component. GIS polygons were created from combining the MGS 2010 side-scan sonar mosaic; NOAA Chesapeake Bay Office's 2011 video, ponar grabs, and acoustic classification; the Paynter Labs' 2011 patent-tong survey; and Versar's 2011 patent-tong survey (Appendices C, D).

Shell sedimentation was investigated by Versar surveys in January 2012 and the Paynter Labs in January 2012. Sediment was classified as high, medium, or low on all existing oyster bars by the Versar survey. (Appendix C).

² Chesapeake Bay-CMECS is the integration of several digital maps that identify the boundaries and distribution of seabed materials and bottom habitats in the Chesapeake Bay. It is a hierarchical ecological classification system that is universally applicable for coastal and marine ecosystems. It was developed by the NOAA Coastal Services Center, in partnership with NatureServe and others, to create a standard classification system that integrates different types of data from multiple sources to fully characterize a specific area. Raw survey data were acquired by the NOAA Chesapeake Bay Office and the Maryland Geological Survey with acoustic seafloor survey systems and validated with video and sediment grab samples. Final seabed habitat polygons were classified using a variant of the CMECS. CB-CMECS places an emphasis on describing the American oyster reef community, and the sediments that encompass it. The oyster reef units described in CB-CMECS are those that can be acoustically derived and differentiated, and are classed based upon their morphological characteristics. CMECS reef attributes in addition to other spatial data sources inform the restoration potential of targeted sites. An example is the "aggregate patch reef" which describes oyster bottom that comprises shell mounds surrounded by soft sediments. Healthy oyster communities exist on this type of habitat, but in most cases restoration potential would be low. More CMECS information, including a description of the classifications, is at http://ftp.ncbo.cgclientx.com/ecoscience/Chesapeake_Bay_Benthic_Habitat_Polygons_CMECS/.

Biological Criteria

Oyster population assessments for size and density, funded by NOAA, were completed separately by Versar, Inc. and the Paynter Labs of the University of Maryland in January 2012. The Versar surveys provided spatially explicit estimates of oyster densities and population structure within the extent of restorable oyster bottom, based on a regular sampling grid. A total of 510 patent-tong samples were collected in Harris Creek. Live oyster density estimates were determined for bottom depths ranging from 4 to 20 feet. The Paynter Labs conducted a patent-tong, stratified-random sample population survey on recent Oyster Recovery Partnership (ORP) seed plantings, higher quality shell bottom determined from the CMECS seabed map, lower quality shell bottom, and non-shell bottom. Shell volume and live oyster density were recorded. Shell abundance scores documented by the Paynter Labs' surveys, were merged with the Versar sampling data to classify shell volume on existing oyster bars as low, medium, or high volume (Appendices C and D).

Larval transport modeling was conducted by Dr. Elizabeth North of the University of Maryland Center for Environmental Science (UMCES 2011). The purpose of this modeling was to investigate larval transport processes in Harris Creek and the lower Choptank River. A three-dimensional, coupled hydrodynamic and larval transport model was used to simulate oyster larval transport from a suite of proposed reef locations.

Spat set data compiled by DNR's fall survey from 1980 to 2010 were considered in an effort to understand spat set levels and patterns in Harris Creek (Appendix A). Fall survey spat set data are available for five locations in Harris Creek: Tilghman Wharf, Mill Point, Eagle Point, Wild Cherry Tree, and Little Neck. Consistent records are not available for all stations, but the complete data record for Harris Creek spans 1980 through 2010. Data from 1985-2012 was used to make the conservative assumption that there will be no natural spat set over the next 6 years (see seed needs analysis section below). This dataset is complete, and is the most recent available, thus it was assumed to be most relevant to current conditions in the creek. Historical spat set was also considered and used in selecting Harris Creek as a target tributary (Krantz and Meritt from 1939-1975; Appendix A).

The oyster diseases Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*) are more virulent in higher salinity waters, leading to higher mortality in these areas. Reproduction is also more successful in higher salinity areas. To balance reproduction and disease-related mortality, mesohaline areas were considered to be high priority for restoration.

Harmful algal blooms (HAB) resulting from *Prorocentrum minimum* and *Karlodinium veneficum* blooms have been documented in the Choptank River (Brownlee et al. 2005; Glibert et al. 2001), but Harris Creek has not been identified to have significant HAB problems or susceptibilities.

Other Criteria

The State of Maryland has designated 4,519 acres within Harris Creek as oyster sanctuary, where no commercial harvest of oysters is permitted.

Land use in the watershed draining to Harris Creek is largely agricultural with some forested and developed areas. This information was used by USACE in its oyster restoration master plan, which in turn informed the selection of Harris Creek as a site for large-scale oyster restoration under Executive Order 13508.

Four federally listed rare, threatened, or endangered species have been identified in Harris Creek watershed: Delaware fox squirrel, Eastern fox squirrel, dwarf wedge mussel, and Seth Forest water scavenger beetle (as listed by Landscape 2012 for Talbot County).

Submerged aquatic vegetation (SAV) habitat, as designated by the Chesapeake Bay Program, exists in Harris Creek. However, there were no SAV beds documented from 2006 through 2010 (VIMS 2012). In 2011, SAV beds were present, mainly in the upper creek.

Based on the National Wetlands Inventory data, there are 1,216 acres of wetlands in Harris Creek watershed.

Spatial Analysis

Initial analyses performed for the USACE master plan determined that salinity and dissolved oxygen were suitable throughout Harris Creek (USACE 2012). Spatial data were overlaid in ArcGIS to locate proposed restoration sites. This GIS analysis included the bottom classification, population survey results (Versar and Paynter), shell volume (Versar), and sedimentation characterization (Versar and Paynter) (Appendices C and D).

The workgroup used three primary data layers for the GIS analysis. Specifically, these layers were:

- A data layer identifying seabed suitable for substrate placement was defined based on areas determined to be existing mollusk (oyster) habitat with oyster densities of less than 5 oysters per square meter (population surveys), and CMECS bottom characterization of muddy sand, unclassified hard bottom, sand, and sandy mud.
- Versar and Paynter population survey data were interpolated to develop live oyster density polygons within CMECS shell bottom polygons and in depths greater than 4 feet and less than 20 feet. The interpolation method used was the Nearest Neighbor/Inverse Distance Weighted method.
- A combined data layer for shell volume and sediment was developed using the intersection of interpolated shell volume and shell sedimentation polygons within CMECS shell bottom polygons and in depths greater than 4 feet and less than 20 feet.

Shell volume and sedimentation data were interpolated. The resulting values were grouped into high, medium and low categories, relative to each other, based on summary statistics. The intersection polygons provide an estimate of the location of dense, clean surface shell.

Blueprint Map

The foundation of this tributary plan is the blueprint map (Figure 2) showing where restoration actions are targeted. Sites that met all the following criteria were considered suitable for restoration in the Harris Creek oyster sanctuary:

- Hard benthic habitat;
- Outside of a 250-foot radius around aids to navigation;
- More than 150 feet from the federally-maintained navigation channel (Knapps Narrows);
- Not on leased bottom;
- Within a legal natural oyster bar;
- More than 250 feet from a marina;
- Not identified by the general public or the Coast Guard as a concern;
- In areas with depths of 4 to 20 feet; and
- Have an existing population of fewer than 50 oysters per square meter³.

Hard benthic habitat was defined as areas that, per acoustic surveys, were found to have the CMECS classifications of artificial reef, aggregate patch reef, fringe reef, patch reef, sand and scattered oyster shell, sandy mud, sand, and muddy sand. Buffers around navigational aids and the Knapps Narrows channel were included in response to Coast Guard input. The 20-foot maximum depth cutoff was used due to concerns about potential hypoxia at greater depths. The shallow depth limit was based on the practical limit of the vessels used for restoration activities, as well as the limits of the acoustic surveys used to create the restorable bottom analysis. However, for substrate placement, a depth limit of 6 feet was used to allow for safe navigation overtop of the substrate.

As discussed earlier, the initial restorable bottom analysis identified 600 acres in Harris Creek as potentially restorable (Appendix B). However, upon more detailed analysis, it was determined that some of these sites were not suitable for restoration, so these areas were eliminated from the blueprint map. The eliminated areas consisted of: (1) sites deeper than 20 feet; (2) sites initially classified as hard-bottom but when ground-truthed for the 2012 efforts were found to be too soft to support substrate; and (3) areas that are otherwise suitable for substrate placement, but are in 4-6 feet water depth and thus pose a potential navigational concern. Also, generally very small areas (<1 acre) were excluded for practical implementation

³ Areas with more than 50 oysters per square meter currently meet the minimum density goal per the oyster metrics report, so these areas are not being targeted for initial seeding. However, they may need additional seeding in future years. This is further described in the seed needs section.

reasons. This process winnowed the initial estimate of 600 acres down to 487 acres for potential reef restoration activities.

Once the 487 acres for potential reef treatment were identified, the workgroup then determined the specific treatment (seeding versus substrate plus seeding) for each site. Adding seed only is less costly than adding both substrate and seed, and so it is the first-choice treatment. However, the seed-only option is only suitable where sufficient shell base currently exists. In the absence of existing suitable shell base, substrate must be added to create a hard reef structure. Seed oysters can then be planted on top of the new substrate base. Substrate may be any combination of oyster shell, clam shell, or alternative substrate such as crushed concrete or granite. Reef balls can be added for additional three-dimensional structure, either with or without seed oysters set onto them.

For this effort, the existing density of oysters was a key consideration in determining whether an area would be targeted for seed only, or substrate and seed. The assumption was that an area that supported existing oysters in quantity (by consensus, that amount was 5 oysters per square meter) should not be overplanted with substrate. This would risk smothering existing oysters. Also, the presence of oysters in such quantity served as an indication that existing substrate was suitable, thus the area would likely do well with the addition of seed only. Areas with fewer than 5 oysters per square meter were assumed to be in need of substrate in addition to seed. Prior to implementation, these areas will be ground-truthed before substrate or seed is placed per this plan (See description below of ground-truthing protocol to be employed). The treatment type will be adapted as needed based on the additional ground-truthing information.

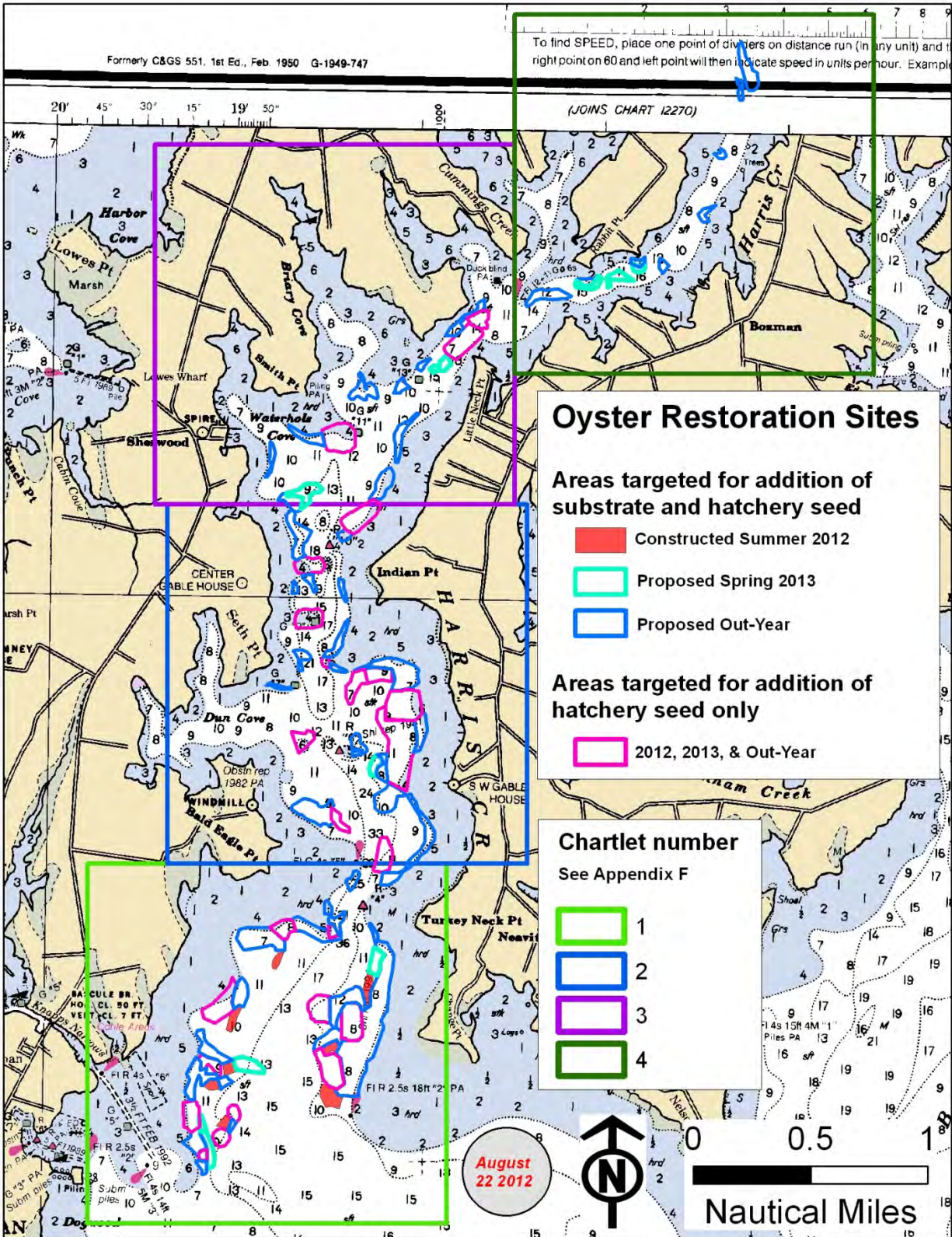
To summarize the above discussions, the criteria used for selection of the reef treatment were:

- Seeding only if existing population was equal to or greater than 5 oysters per square meter; and
- Substrate plus seeding if the existing population was less than 5 oysters per square meter.

Appendix E shows detailed information about each numbered site/GIS polygon in the tributary plan, including the acreage of each polygon, the restoration treatment it is slated to receive, volume of seed needed, and volume of substrate needed. Appendix F is a series of smaller maps (“chartlets”), which shows the sections of Harris Creek in greater visual detail. These charts use the NOAA nautical chart as a background to help the reader locate the sites. All of the restoration sites targeted for each type of reef treatment are depicted in the blueprint map in Figure 2.

Figure 2: Blueprint Map

This figure shows the center areas targeted for restoration in Harris Creek, along with the planned restoration treatment type (seed only or substrate and seed).



Ground-Truthing

Ground-truthing will be performed on all sites targeted in the tributary plan prior to restoration treatment. The purpose of the ground-truthing is to validate the acoustic surveys, and to modify the boundaries of target sites if needed to ensure the treatment proceeds on optimal benthic habitat. Ground-truthing of any given site is expected to occur within a few months prior to restoration work.

Diver ground-truthing protocol: Seed-only sites will normally undergo diver ground-truthing. Diver ground-truthing will be accomplished by running several transects within each target area. The number of transects depends on the size of the area. Typically, each transect will be 200 meters long, marked every 2 meters for reference. Transect lines will be laid out haphazardly within the target polygon; divers will then swim along the line and report the condition of the bottom every 2 meters. Parameters to characterize bottom condition will be recorded at each 2-meter interval. The parameters include: amount of exposed shell, substrate type, substrate penetration and oyster density. Divers will determine a score for each parameter. Table 2 outlines the score for each category, with increasing metric values indicating bottom-type improvement.

Table 2: Summary of Ground-Truthing Protocols

Exposed Shell	Value	Substrate Type	Value *	Penetration (cm)	Value *
Zero	0	Silt	0	70	0
Very Little / Patch	1	Mud	1	40	1
Some	2	Sandy Mud	2	20	2
Exposed	3	Sand	3	10	3
Oyster Bar	4	Rock / Bar Fill / Debris	4	5	4
		Shell Hash	5	0	5
		Loose Shell	6		
		Oyster	7		

* Increasing metric values show bottom-type improvement

The data for each transect will be recorded directly into a Microsoft Access database created specifically for the Paynter Labs. The mode value of each category will be used to determine whether each transect can be categorized as preferred, acceptable, or unacceptable bottom. The bottom-type category will be determined as the category within which two of the three data types (exposed shell, substrate type and penetration) fall. Table 3 outlines the requirements for each bottom-type categorization.

Table 3: Summary of Bottom-Type Categorization

Category	Exposed Shell Range	Substrate Type Range	Penetration Range
Preferred	3-4	4-7	5
Acceptable	2	3-4	3-4
Unacceptable	1-0	0-2	0-2

This information will be then relayed to ORP staff and the workgroup to help make decisions about which target areas may not be suitable for planting spat on shell.

Blueprint Map Summary

The polygons identified in the blueprint map (Figure 2) as areas targeted for oyster restoration activity add up to 487 acres. However, past diver ground-truthing expeditions have generally shown that initial target areas based on sonar surveys tend to overestimate suitable hard bottom; actual suitable restoration area tends to be smaller. For planning purposes, it was assumed that the actual suitable area will be reduced by 30 percent upon diver ground-truthing. This estimate is based on past diver field experience. Table 4 shows the areal reductions by the type of reef treatment (Note that areas treated in 2012 have already been ground-truthed, so the acreage is actual, not planned, and thus in the table below is not reduced by 30 percent. The same is true for areas that already meet the density goal).

In summary, the oyster metrics report defined a successfully restored tributary as one where 50 to 100 percent of the currently restorable bottom, constituting at least 8 percent of historic bottom, meets the reef-level goals. In Harris Creek, the restorable bottom analysis (Appendix B) showed 600 acres of restorable bottom, so the minimum goal is 300 acres of restored reefs. The tributary plan targets 377 acres, allowing for the possibility that some of that acreage may not respond sufficiently to the restoration activity.

Table 4: Acreage by Reef Treatment (with anticipated reductions)

Reef Treatment	Acres Identified in Blueprint Map	Suitable Acreage (Reduced by 30%, Where Appropriate)
Currently meets target density of 50+ oysters/m ²	3	3
Reef treatment: Add seed only; seeded in 2012	88	88
Reef treatment: Add seed only; not yet seeded	98	69
Reef treatment: Add substrate and seed; constructed in 2012	22	22
Reef treatment: Add substrate and seed; not yet constructed	279	195
Total Acreage Requiring Reef Treatment	487	374
Total for All Restoration Sites	490	377

Seed Needs Analysis

A projected 2.09 billion oyster seed will be required to implement this plan. This number was derived by first examining the current oyster population on each target reef site, then calculating the number of additional oysters needed on each site to reach the oyster metrics density goal of 50 oysters per square meter over 30 percent of the reef area. The oyster metrics report calls for that density to be achieved within 6 years of restoration activity, so this plan lays out oyster survival projections over 6 years. To do this, assumptions were made regarding survival rates of both planted seed and existing oysters. It is recognized that oyster survival rates are highly variable, and that the actual survival rate is unknown. However, for planning purposes it was necessary to make reasonable assumptions as to survival rates. These assumptions may be revised in future iterations of this plan if more accurate rates are determined through the recommended monitoring (see monitoring section below). Oyster survival rates were set as follows, based on Volstad et al (2008) and Oyster Recovery Partnership's field experience with hatchery-produced spat-on-shell in Maryland:

Planted spat-on-shell: first year survival rate = 15 percent;
 out-year annual survival rate = 70 percent;

Existing oysters (on the reef in January 2012): annual survival rate = 70 percent.

Approximately 3 acres of reefs in Harris Creek already meet the density goal, thus initially they would require no additional seed to meet the goal. Reefs with fewer oysters will require more seed to meet the density goal. However, the oyster metrics report also lays out a goal of having at least two year classes present on each reef. Subsequently, this plan conservatively incorporates a second seeding of all reefs to achieve the two-year class goal, including the 3 acres that currently meet the goal. For future seed planting, natural spat set may deem a second seed planting unnecessary. Population monitoring will be critical to determining the need for the additional seeding.

A key unknown is the level of natural spat sets that might occur in Harris Creek over the implementation time frame and what density of oysters might result from these spat sets. The workgroup dealt with this unknown by making a very conservative assumption that there would be no natural spat set over the course of implementation. This assumption was based on the fact that from 2000 to 2010, there was only one sizable spat set in Harris Creek. Prior to this period, there were sizable spat sets two to three times per decade. By making this assumption, the tributary plan calls for planting enough seed to reach the density goals in 6 years, even with no natural spat set in the creek. Thus, the intent is to plan for a very conservative scenario, and adapt the tributary plan as needed. The tributary plan calls for an initial large planting on most reefs, followed by monitoring 3 years later in following years, and an additional smaller planting to ensure a multi-age-class population and target density.

Appendix E identifies the specific targeted reefs by number, along with the amount of seed and substrate each reef is slated to receive. A summary of the 2.09-billion seed calculation is provided in Table 5; the seeding cost estimate is provided in Table 6.

Table 5: Seed Needs and Oyster Survival Assumptions

Type of Reef Treatment	First Planting (seed per acre)	First Planting, First Year Survival*	First Planting, Year 2-6 Annual Survival Rate*	Second Planting (seed per acre)	Second Planting, First Year Survival*	Second Planting, Year 2 Survival*	Existing Oyster Density (oysters per m ²)	Existing Oysters, Year 1-6 Annual Survival Rate*	Oyster Density After 6 Years – Surviving Oysters from Plantings and Existing Oysters (oysters per m ²)	Area Targeted for Restoration in Harris Creek (acres)	Total Amount of Seed Needed for Treatment Type
Substrate and seed	5,000,000	0.15	0.7	1,000,000	0.15	0.7	0	N/A	59	217	1,302,000,000
Seed only (current density = 5-50 oysters per m ²) **	4,000,000	0.15	0.7	1,000,000	0.15	0.7	5	0.7	53	157	785,0000
Seed only (current density = >50 oysters per m ²)	0	0	0.7	2,000,000	0.15	0.7	50	0.7	57	3	6,000,000
Total for Tributary Plan										377	2,093,000,000

* Source: Steve Allen, Oyster Recovery Partnership (personal communication, 2012), and Volstad et al (2008).

** While some sites may have greater than 5 oysters/m² density, it was assumed for planning purposes that all sites in this category had a starting density of 5 oysters/m².

Table 6: Seed Cost Analysis

Reef Treatment	Area to be Treated (acres)	Seed Required per Acre	Seed Required for Treatment Type	Seed Cost for Treatment Type (at \$7,500 per million)*
Substrate and seed	217	6,000,000	1,302,000,000	\$9,765,000
Seed only (current density = 5-50 oysters/m ²)	157	5,000,000	785,000,000	\$5,888,000
Seed only (current density >50 oysters/m ²)	3	2,000,000	6,000,000	\$45,000
Total for Tributary Plan	377		2,093,000,000	\$15,698,000

* The seed cost of \$7,500 per million was based on ORP’s experience (Allen, May 2012).

Substrate Needs Analysis

A projected 350,000 cubic yards of substrate is needed to implement the tributary plan. Substrate may be any combination of oyster shell, clam shell, or alternative substrates such as crushed concrete, granite, or reef balls. This projection of the substrate needs for Harris Creek assumes a 1-foot reef height, requiring 1,613 cubic yards of substrate per acre. The 1-foot reef height was selected to provide sufficient elevation off the bottom for the restored reefs. The computation of the substrate need is shown in Table 7, with the substrate placement cost estimated in Table 8.

Table 7: Substrate Needs Analysis

Reef Treatment	Area to be Treated (acres)	Amount Substrate Needed per Acre (cubic yards)**	Amount of Substrate Needed for Treatment Type (cubic yards)
Substrate and seed*	217	1,613	350,000
Seed only (current density = >5 oysters per m ²)	157	0	0
Seed only (current density = >50 oysters per m ²)	3	0	0
Total for Tributary Plan	377		350,000

* Includes USACE reefs constructed in 2012

** Assumes a 1-foot reef height.

Table 8: Substrate Cost Analysis

Reef Treatment	Area to be Treated (acres)	Substrate Required per Treatment Type (at 1,613 cubic yards per acre)	Substrate Cost (at \$44.63 per cubic yard)
Substrate and seed	217	350,000	\$15,620,000
Seed only (current density = 5-50 oysters/m ²)	157	0	\$ 0
Seed only (current density >50 oysters/m ²)	3	0	\$0
Total for Tributary Plan	377	350,000	\$15,620,000

* The substrate placement cost of \$44.63 per cubic yard was based on USACE experience (O’Neill, May 2012).

Monitoring and Research

The primary objective of the monitoring described herein is to determine whether or not the restoration work meets the definition of a “restored tributary” per the oyster metrics report. In addition, a set of “diagnostic” parameters are recommended. These are basic water quality and biological parameters which can help determine the cause of success or failure of the restoration work. The extent of the monitoring is consistent with the scope of this document and the oyster metrics report. A research section is included which lays out key topics that are relevant to large-scale oyster restoration, but beyond the immediate scope of this document.

Monitoring of Oyster Metrics Success Goals

The principle goal of monitoring efforts in Harris Creek is to determine if the restored reefs can be considered “successful” per the oyster metrics standards. According to the oyster metrics report, evaluation of reef-level restoration success requires the determination of four parameters:

- (1) structure of the restored reef (reef spatial extent, reef height, and shell budget),
- (2) population density (as individual abundance and biomass),
- (3) an estimate of total reef population (including biomass and number of individuals, and
- (4) the number of age classes present on the reef.

In keeping with the oyster metrics report, these parameters will be measured as the basic monitoring protocol for Harris Creek under this plan, likely in partnership with academics,

researchers, non-governmental organizations, private contractors, and other agencies. Table 9 describes in detail the recommended parameters to be monitored to evaluate progress towards the restoration goals.

Pre-restoration data on reef extent were collected by Maryland Geological Survey and NOAA using sonar, video, and grab samples. Baseline data on oyster population density were collected by Versar and Dr. Ken Paynter of the University of Maryland Paynter Labs, with NOAA funding. These data were used to estimate baseline oyster population size and densities in Harris Creek. Future monitoring results will be compared to these baseline data to determine the success of restoration efforts, and whether or not adaptive management actions are necessary. Table 9 lists estimated costs for monitoring per the oyster metrics success goals.

Diagnostic Monitoring

In addition to monitoring to evaluate the success or failure of restoration projects per the oyster metrics standards, it is wise to include further monitoring that will help determine the causes of the success or failure. These are deemed “diagnostic” monitoring parameters. These include basic water quality, disease, and physiologic factors that affect oyster health and reef structure persistence. Understanding these parameters alongside metrics of restoration success will allow practitioners to understand not only whether or not the project succeeded, but why. Table 10 lists the recommended diagnostic parameters.

Due to the large scope of monitoring, some of these factors will be measured only at “sentinel sites” within the Harris Creek tributary. Sentinel sites are fixed sites that are monitored at appropriate intervals. Collecting data on these recommended diagnostic monitoring parameters will likely require partnering with academic institutions, non-governmental organizations (NGOs), and other state and federal agencies. Table 10 shows suggested diagnostic monitoring activities and estimated costs of these activities.

Table 9: Suggested Restoration Success Monitoring Activities

Parameter	Sentinel Site Monitoring	All Site Monitoring	Method of Measurement	Units/Performance Metric	Estimated Cost
	(assumes three 3-acre sentinel sites, monitored annually)	(pre- and post-construction, years 3 and 6)			(assumes a 6-year monitoring timeline)
Population- Density	x	x	quadrat sampling or patent tong	number of oysters/m ²	These three parameters are collected simultaneously; cost to monitor sentinel sites annually for 6 years = \$18,000 (\$3,000 per year). The cost to monitor entire tributary in years 3 and 6 = \$168,000 (\$84,000 per monitoring event).
Population-Biomass	x	x	regression	g wet or dry weight/m ²	
Size-Frequency Distribution (multiple age classes)	x	x	quadrat sampling or patent tong	(length, number)	
Spatset (There are two established key bars in HarrisCreek -- Tilghman Wharf and Mill Point. These two sites can provide historical record.)	x		quadrat sampling or patent tong	(spat/m ²) Evidence of successful recruitment during at least two separate recruitment periods	No additional cost (This data is collected as part of DNR's existing annual fall oyster survey.)
Reef Height		x	sidescan or multibeam sonar/seismic profiling	(cm) Positive or neutral change in reef height from original structure	No additional cost (These three parameters are monitored as part of NOAA's existing program; the value of NOAA's data collection is \$80,000 over 6 years.)
Reef Area		x	sidescan or multibeam sonar/seismic profiling	(m ²)	
Reef Patchiness		x	sidescan or multibeam sonar/seismic profiling	Percent of reef with hard substrate and/or 15 oysters m ² ; target is >30%	
Shell Volume -- black/brown (shell budget)		x	patent tong or quadrat sampling (if possible)	increase in brown shell/black shell ratio	No additional cost
Total Additional Cost over 6 Years					\$186,000

Table 10: Suggested Diagnostic Monitoring Activities

Parameter	Priority	Frequency	Number of Sites	Method of Measurement	Units/ Performance Metric	Notes	Estimated Cost
Dissolved Oxygen	High	Every 30 minutes	3 sentinel sites	Data logger	mg/L or saturation?	DO is monitored to evaluate: (1)seasonal persistent DO (site in deepest water), and (2) diel-cycling. Locate probes as close to bottom as possible, <0.5 m. Is this covered by CBP monitoring? Is diel-cycling monitoring needed -- oysters can withstand short-term hypoxic/anoxic events? It may just be needed for deeper sites.	\$147,000 over 6 years, including equipment and labor
Temperature	High	Every 30 minutes	3 sentinel sites	Data logger	°C		
Salinity (Conductivity)	High	Every 30 minutes	3 sentinel sites	Data logger	PSU	A conductivity probe can be sited in shallower water in upriver area to monitor for freshet. Freshet monitoring would require only twice daily measurements. Monitoring of ambient salinity in tributary for oyster biology would require probes to be cited in upstream and downstream regions.	
pH	Medium	Every 30 minutes	3 sentinel sites	Data logger	-log[H ⁺]		
Total Algae (Chlorophyll a)	Medium	Every 30 minutes	3 sentinel sites	Data logger	µg/l	For chlorophyll a and turbidity, suggest also having one site located away from reef to act as control.	
Turbidity	Medium	Every 30 minutes	3 sentinel sites	Data logger	NTU		
Alkalinity	Medium	Monthly	3 sentinel sites	Titration	mg/L of CaCO ₃	Alkalinity needed to calculate carbonate saturation which could impact juvenile growth and larvae at modest pH changes; collect samples at depth of sensors.	\$100 for test kits; data can be collected when sensors are changed
Disease (Dermo, MSX)	High	Annually in fall	2	Histology	Prevalance, intensity	There are two established key bars in Harris Creek -- Tilghman Wharf and Mill Point -- so we may not need to do anything else in Harris Creek, but nothing is covered in upstream portion.	No additional cost (included with DNR's fall survey unless additional sites are added)
Predation	Low	Annually in fall	Signs of predation will be assessed during populations surveys. No specifically targeted monitoring for predation.	Shell examination	N/A	In Harris Creek, predation exclusion devices are not viewed to be warranted.	No additional cost
Poaching	High	Constant	All	MLEIN	N/A	Harris Creek will be a target area for the MLEIN (MD Law Enforcement Network) radar and camera system	No additional cost (part of DNR's existing MLEIN program)

Table 11 summarizes the costs of the suggested restoration success and diagnostic monitoring activities for the Harris Creek restoration sites.

Table 11: Summary of Monitoring Costs

Monitoring per Oyster Metrics Success Standards*	\$186,000
Diagnostic Monitoring*	\$147,000
Total Cost	\$333,000

* This reflects the cost to monitor beyond what is already funded as part of ongoing federal, state and NGO programs.

Monitoring Protocols

More information is provided below for some of the monitoring identified in the restoration success monitoring table. Note that these are parameters already collected by agencies and or partners.

Post-Planting Monitoring – Spat Growth and Mortality

Growth and mortality of seed plantings are monitored 4 to 8 weeks after planting by collecting spat on shell. Spat on shell planted 4 to 8 weeks earlier are collected to assess growth and mortality. The 44- to 88-week window has been found to be the most effective in assessing these parameters. Focusing on a narrower window in time has proven difficult with weather and other variables affecting the opportunities to sample. Using the planting vessel’s track lines as a target, divers collect hatchery shells from each survey location. Divers place a 0.3-meter x 0.3-meter quadrat on the bottom and collect all shells contained within the quadrat. Divers attempt to collect at least six quadrat samples at each site. When shell densities are too low for quadrat sampling, such that the diver could not find shell in areas with few track lines, the diver will instead haphazardly collect 50 to 100 shells from throughout the bar.

Each shell is examined for live spat, boxes, scars, and gapers. Additionally, the first 50 live spat observed in each sample are measured for shell height and, each shell is inspected for the presence of *Stylochus*. All shells are returned to the bar when sampling is complete. The number of spat per shell is multiplied by the total amount of shell planted on each bar to calculate the amount of spat detected on the bar by the post-planting monitoring survey. Spat survival is then calculated as the percentage of spat planted that was detected by the survey.

Environmental and biological factors such as dissolved oxygen, bottom quality, and salinity, are collected to investigate their relationship to growth; survival analyses are conducted to correlate various environmental and biological factors with growth and survival.

Oyster Population Surveys

Patent tong surveys are conducted on target reefs to assess restored oyster population dynamics including reef-level population estimates, oyster size frequency and disease dynamics, as well as spatial patterns of oyster and shell densities across a given reef.

A grid of 25-meter x 25-meter cells is overlaid onto the planted area using spatial tools in ArcGIS and each grid cell is sampled with hydraulic patent tongs. Number and size (mm) of live and dead (box) oysters are recorded at each grab. In addition, shell score (the amount of shell substrate collected in each tong grab) is quantified on a scale of 0 to 5⁴. The density of oysters at each point is calculated based on the grab area of the tongs (between 1 and 2 square meters depending on the vessel used) and a population estimate is generated using this density data. The total biomass of oysters at each reef is estimated according to Liddell (2007). The density of oysters and shell score at each patent tong survey point is spatially referenced using GIS. These spatial data allow for shell score and density plots to be generated to illustrate the spatial distribution of shell and oysters at each site. All oysters and shells, except those collected for disease sampling, are returned to the reef.

Reefs targeted for patent tong surveys are all reefs planted 3 and 6 years prior, in order to facilitate the consistent sampling of each reef. Sentinel reefs are targeted to act as long-term monitoring sites. These reefs are sampled every year (rather than every 3 years). This allows for the analysis of temporal trends in oyster population and disease levels, as well as how the spatial distribution of oyster density and shell base changes with time.

The dynamic nature of the conditions in the Chesapeake Bay and the ever-changing body of information on oysters and restoration in general require a flexible monitoring plan paired with controlled experiments to maximize restoration success and efficiency. Additionally, the productive collaboration of all agencies involved in Chesapeake Bay restoration has greatly helped with the success of restoration. The coordination of the efforts of the Maryland Geological Survey, NOAA Chesapeake Bay Office, ORP, and the Paynter Labs has allowed for the implementation of the most up-to-date data on the suitability of areas for planting. This coordination is critical to the success of oyster restoration.

Research

As previously stated, the purpose of this plan is to lay out the reef construction and seed plantings needed for Harris Creek to meet the definition of a restored tributary under the

⁴ Oyster Recovery Partnership's tong fullness scale: 0=no shell in the tongs; 1= 1/5 full; 2= 2/5 full; 3= 3/5 full; 4= 4/5 full, 5= totally full. These values are for total volume of shell within the patent tongs.

implementation strategy for Executive Order 13508. The monitoring section describes the monitoring needed to determine whether the reefs in Harris Creek are, in fact, successfully restored per the goals defined in the oyster metrics report, and potential causes of success and/or failure.

Large-scale restoration provides a great opportunity for research beyond the scope of the monitoring plan. For example, none of the work laid out thus far, addresses ecosystem services. Increasing the ecosystem services is a major motivation behind the oyster restoration effort. Are the reefs constructed in Harris Creek actually providing increased services? One could assume they are, if functioning reefs are present in significantly increased numbers; but is that assumption correct, and can we quantify these services? Are we using restoration approaches that maximize those services? These types of questions are beyond the immediate scope of determining success or failure per the oyster metrics definition (and this document), but answering them is important.

The purpose of this section is to lay out these types of research needs. Harris Creek can serve as an excellent research platform for pursuing some of these studies. Others, though, might be better studied in tributaries where extensive restoration work has not yet begun, if true baseline information is required. Harris Creek received extensive seed plantings in 2011 and 2012, and 22 acres of newly-constructed reefs in 2012. Thus, depending on the study needs, the opportunity to collect baseline information may have passed. Other studies may require data from multiple tributaries with different ecological conditions (e.g., different salinity and temperature regimes) for comparative analysis.

The hope is that having the restoration plan herein outlined, and laying out some research needs (albeit not necessarily an exhaustive list), will allow researchers, agencies and funders to understand the intended restoration work slated for Harris Creek, and to determine if it may constitute a suitable study site for research. In fact, it may be possible to actually design reefs to facilitate certain studies by having agencies and researchers work collaboratively. The ideal approach to large-scale, tributary-based restoration is to maximize the gain in both restored reefs as well as knowledge about successful restoration strategies. The interest in optimizing learning from the effort may need to be tempered, though, with the realities of limited resources in a difficult economic climate.

From discussions with regional scientists, the following priority research needs were identified:

- Determination of the ideal substrate/s from which to construct oyster reefs – Shell is traditionally used to reconstruct oyster reefs, but the supply is limited. Alternatives such as granite, crushed concrete and reef balls have been used, but identification of the optimal substrate under various conditions remains unknown. Questions remain unanswered as to whether some types of substrate might impede poaching or interfere with legal fishing gear such as trotlines.

- Determination of the ideal height/s to which reefs should be constructed – The cost of constructing reefs is high, often made more so by material transport costs. Constructing higher reefs requires more material and is thus more expensive. Additionally, higher reefs may present additional permitting obstacles. The increased cost may be justified, though, if higher reef elevation increases oyster survival or provides other benefits. Permitting agencies may be swayed if ecological justification can be shown for the higher relief.
- Efficiency of oyster restoration practices generally – There are a number of topics that could be better understood to improve the efficiency of oyster restoration practices. Some of the above studies on reef substrate and height may be appropriate to include in this category. However, there are additional topics such as increasing survival of planted spat, increasing hatchery efficiency, reducing predation and poaching, optimizing the location where reefs are constructed to serve as larval sources or sinks, and increasing production at lower cost.
- Quantification of ecosystem services provided by oyster reefs – Implicit in the goal of restoring oyster reefs is the idea that the reefs will provide increased ecosystem services (e.g., denitrification and nitrogen sequestration; provision of habitat for finfish, invertebrates and sessile organisms; enhanced forage for waterbirds; enhancement of adjacent habitats such as SAV beds; water filtration; enhanced shoreline protection). The increase in these services following restoration has not been fully quantified. Such information could help assign an accurate value (dollar or otherwise) to rebuilding these reefs. Currently, it is comparatively easy to quantify the costs of oyster restoration, but difficult to accurately enumerate the benefits. A clear understanding of the benefits of a restored tributary would help funders and managers weigh the costs and benefits to further justify the investments. It does need to be recognized that it can be difficult to separate the impacts of an oyster reef from confounding factors (e.g., increased development in the watershed or extreme weather events may increase water turbidity, even if a new oyster reef is providing increased water filtration). As a result, careful study design is required to measure actual ecosystem services.
- Understanding disease dynamics – Disease continues to be a major source of mortality throughout much of the oyster's range in the Chesapeake Bay. Understanding how various restoration techniques influence disease rates (and associated mortality) could be significant in terms of improving restoration efficiency, increasing oyster survival, and reducing costs.
- Understanding predation dynamics – Spat are particularly susceptible to predation. Understanding how various reef construction and seed planting methods influence predation and survival could be significant in terms of improving restoration efficiency, increasing oyster survival, and reducing costs.
- Efficacy of restoration work in shallow water – Reefs naturally existed in shallow waters of the Chesapeake Bay. However, due to concerns about interference with navigation, the restoration effort has been largely pushed into deeper waters. Information

documenting the resilience and productivity of shallow-water reefs would build a stronger case towards permitting of this type of restoration.

- Investigation of other restoration techniques – Currently, the tributary plan calls for just two basic restoration techniques: adding seed, or adding seed on top of new substrate. Other types of restoration techniques should be explored, such as placing biofilm on planted material to attract larval settlement. Testing and refining of existing techniques should be ongoing.
- Determination of sex ratio – It is assumed that as restoration sites age, an appropriate balance of male to females is achieved. If a balance is not achieved, reproduction from restored populations may be limited or compromised. Investigations into the sex ratio of restored reefs will confirm that there is a sufficient balance of male and female oysters and provide insight into reproductive process occurring on restored reefs.
- Relation of slope of oyster reefs within the seascape to water flow and design of oyster reefs – 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. Limited quantitative guidance is available in the scientific literature (Smith et al., 2003; Woods et al., 2004; Stanley and Sellers, 1986; Lenihan, 1999; and Seliger and Boggs, 1988).
- Understanding the role of currents in restoration success and larval transport – The concept of “source” and “sink” reefs has long been discussed, but determining current dynamics in Harris Creek and exactly how they influence this process remain unknown. Understanding these dynamics might help improve the efficiency of restoration work by maximizing natural spat set and reducing the amount of hatchery seed required. Additionally, currents may influence sedimentation rates and dissolved oxygen levels, two important factors in restoration success.

Cost Analysis for Harris Creek Tributary Plan

The total estimated cost for implementing this plan is \$31,651,000. Of that, \$31,318,000 is for substrate (including material purchase and substrate placement) and hatchery-produced seed (including planting). The remaining \$333,000 is for monitoring. Table 12 summarizes the plan implementation cost (details of the seed costs are in Table 6; details of substrate costs are in Table 8; and details of monitoring costs are in Table 11).

This estimate assumes a cost of \$7,500 per million planted oyster seed (ORP, May 2012), and \$72,000 to purchase and place substrate 1 foot high over 1 acre (\$44.63 per cubic yard, USACE, Baltimore District, May 2012). This cost is for clam shell or granite, which are the substrate materials currently available in large quantities. The cost could be different for other materials, such as fossilized oyster shell, reclaimed oyster shell or other substrates, should they become available.

Table 12: Summary of Total Costs

Two Billion Seed	\$15,698,000
350,000 Cubic Yards Substrate	\$15,620,000
Monitoring	\$333,000
Total Cost	\$31,651,000

Implementation of the Harris Creek Tributary Plan

The time frame for implementation of the Harris Creek tributary plan depends primarily on funding. The estimated cost for implementation is \$31.7 million. Approximately \$13 million of this has already been identified. Governor O’Malley has slated \$7 million to the project in Fiscal Year (FY) 2013. NOAA contributed \$1 million in FY11, and is contributing an additional \$1 million in FY12. USACE’s Baltimore District contributed \$2 million in both FY11 and FY12. An additional \$2-4 million is in the USACE FY13 budget, which is currently under consideration by Congress. Additional funds for hatchery operations and mapping is provided by DNR. Construction and seeding of Harris Creek oyster projects to support this tributary plan started in May 2012.

Project completion is also dependent upon oyster seed production and performance of the restoration actions. Current and anticipated seed production capacity from the University of Maryland’s Horn Point facility is likely sufficient to supply the project over several years. The Horn Point hatchery currently produces, and ORP plants, about 500 million spat-on-shell annually; the hatchery has plans to expand to 1 billion annually over the next 3 years. The 2.1-billion seed demand for Harris Creek could be met within 3 to 5 years at current capacity, and sooner if capacity increases. However, other restoration projects, oyster gardening programs, aquaculture, and public re-seeding of the wild fishery grounds require seed from this partnership as well, so presumably not all of the Horn Point hatchery’s annual production would go to the Harris Creek initiative. A natural spat set on the creek could significantly reduce anticipated costs, seed needs, and the timeframe in which restoration can be achieved.

Substrate for new reef construction may be a limiting factor. The amount of substrate needed to restore Harris Creek is estimated at 350,000 cubic yards. This could be any combination of oyster shell, clam shell, or alternative substrates such as crushed concrete, or granite. Reef balls can also be used for additional three-dimensionality. Oyster shell is a natural material, and relatively inexpensive if it can be found locally. However, it is currently in extremely short supply, and demand is high from both the restoration and aquaculture sectors. Further, oyster shell provides no protection from illegal harvesting/poaching. It may be possible to reclaim old shell from past unsuccessful restoration efforts, but it remains unclear how much of this shell is potentially recoverable and at what expense. Granite and concrete are readily available, and may help deter poaching. However, these materials are costly, and concerns exist about possible interference with other fisheries (e.g., trotlines (for crab harvest).

Reef balls are a good citizen outreach activity, and may help deter poaching. However, reef balls are costly as well, and concerns exist about possible interference with trotlines as well.

Another key component for implementation is permits. Currently, Section 10 permit restrictions limit placement of substrate in water depths that maintain a clearance of 8 feet of water depth above the planting. Assuming 1 foot of substrate is placed, 9 feet of water depth or greater is needed to maintain the 8-foot clearance. The analyses performed for the tributary plan show that in order to meet the restoration target, shallower areas need to be restored. Subsequently, DNR is applying for a permit modification and USACE is updating its NEPA coordination to allow substrate placement in depths as shallow as 6 feet.

Adaptive Management and Project Tracking

The Harris Creek Oyster Restoration Tributary Plan is meant to be an adaptive, living document. The expectation is that there will be many lessons learned, and that the plan will be adapted to reflect changing conditions and new information. The original document will be posted on the websites of the NOAA Chesapeake Bay Office and DNR. As the document is adapted, newer versions will be posted to ensure transparency.

NOAA, USACE-Baltimore District and DNR will produce annual reports describing progress that has been made on restoring the oyster population in Harris Creek. These reports will be produced annually by February for the previous calendar year. The reports will include: an accounting of the seed and substrate planted, a map showing the location of the seed and substrate plantings for the year, a summary of any major issues encountered by the project, and, a discussion of any adaptations made to the original plan, and planned work for the next year. These annual reports will be posted on the websites of the NOAA Chesapeake Bay Office and DNR.

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