Virginia Oyster Restoration Review Workshop Summary

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College of William & Mary
Williamsburg, VA

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Preface

Chesapeake Research Consortium's (CRC) Kevin Sellner was asked to attend a NOAA-sponsored Virginia Oyster Restoration Review workshop, assist Mr. Bill Goldsborough (Chesapeake Bay Foundation) in meeting facilitation, record comments, and derive a summary of the workshop's presentations and open discussions. Ms. Paula Jasinski, NOAA Chesapeake Bay Office-VIMS, organized the workshop, identifying key Virginia participants from those restoring, monitoring, and managing the native oysters of Virginia. The workshop was convened at the Alumni House, William & Mary College, on March 31, 2010. The summary reflects the author's recorded comments and presentation highlights, expanded in some cases from monitoring details received prior to the workshop. This workshop was an important initial step in developing a coordinated, consensus-derived Virginia restoration and monitoring strategy now moving forward through the U.S. Army Corps of Engineers' development of a Native Oyster Restoration Plan, a NOAA-led Federal agency response to the Presidential Executive Order of 2009, Virginia's Marine Resource Commission 2010 harvest area restoration strategy, NOAA Chesapeake Bay Office Benthic Assessment Program, and the individual efforts of several organizations including Virginia's Chesapeake Bay Foundation office, The Nature Conservancy, and VIMS' Mann research laboratory, Lipcius laboratory, and Wachapreague Laboratory.

The author has taken the liberty of editing text received and now in the Appendices. For Appendix 1, format changes were made to make the text consistent throughout. For Appendix 4, figures presented by S. Giordano in his presentation at the March 31 meeting were inserted into the text of the Benthic Assessment Protocol received prior to the meeting, to reflect last minute data analyses and graphics generated by Giordano et al. that would otherwise not be included in the method description.

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Executive Summary

Native oyster restoration in Virginia has been a multi-institution effort for the past two decades, supported by early geographic delineations of oyster grounds in the state's tidal waters (Baylor survey, circa 1896; Haven et al. surveys of the 1970's). In recent years, there has been considerable Federal, state, academic institution, and non-governmental organization effort to restore native oyster bars for two principle reasons, for maintenance of a native oyster fishery, and for ecosystem benefits such as habitat, nutrient cycling, and return of 'healthy' food webs for the estuary. Most recently, U.S. Army Corps of Engineer estimates of native oyster restoration success have far surpassed estimates obtained through routine, long-term monitoring conducted by the state Virginia Marine Resources Commission and its partner, the Mann Laboratory at the Virginia Institute of Marine Science. These differences, in turn, have led to internal and extramural organization discussions to define "success" in native oyster restoration and basic monitoring protocols, with little resolution of the noted differences.

The workshop began with presentations encouraging specific restoration goals for oyster restoration projects , open communication regarding the selection and monitoring plans of sites to be restored (by whom, when, and how), use of rigorous pre- and post monitoring protocols, and creation and distribution of geo-referenced site data. These were followed by several presentations highlighting near-term schedules for oyster restoration by those agencies most active in Virginia. Both the Norfolk and Baltimore Districts of the U.S. Army Corps of Engineers summarized current and near future steps to develop a Master Plan for Native Oyster Restoration in the Chesapeake that includes participation from other agencies and states and a discussion on the production and distribution of collected monitoring data. Participants encouraged extramural review of the Plan, perhaps by the Chesapeake Bay Program Scientific and Technical Advisory Committee (STAC). NOAA's Chesapeake Bay office has taken the Federal lead on oyster restoration under the 2009 President's Executive Order 13508 on Chesapeake Bay Protection and Restoration. The final strategy establishes the goal of restoring native oysters in 20 Chesapeake Bay tributaries by 2025. The workshop participants encouraged refraining from a fixed number of 'successful' tributary restorations and substituting considerations of native oyster function as a possible metric. Further, immediate and active discussions between the U.S. Army Corps and NOAA on a common policy, or complementary strategies, were suggested, for deriving a Master Plan and EO response consistent with each other as well as the individual efforts of each state; this appears to be underway in bilateral agency discussions and wider adoption and possible modification insured through activities within the multiple partner Chesapeake Bay Program Protect and Restore Fisheries Goal Implementation Team. Virginia's Marine Resources Commission (VMRC) relayed 2010 fiscal constraints recently derived from legislative mandates, and indicated it would focus on restoring native oysters for its harvest program as its priority. VMRC's 2010 funding ($600,000) is dramatically short of the 2007 Virginia Blue Ribbon Oyster Panel's recommendations for supporting restoration ($2.5 M annually).

A series of presentations followed outlining on-going monitoring associated with native oyster restoration in VA's tidal waters. Mann provided a lengthy overview of oyster sampling, stock assessment, shell requirements, and the VIMS-VMRC monitoring program (including repeated hydraulic patent tong sampling at a site to minimize mean density variability), leading to better comprehension of future needs for restoring a viable, sustainable native oyster population. Lipcius followed with a description of the VIMS-U.S. Army Corps restoration and monitoring program in the Great Wicomico River, and the extensive use of geo-referenced bottom mapping and videography for characterizing initial reef areas, identifying high, low, and base relief oyster areas in Baylor polygons, subsequent distribution of spat-on-shell using stratified random selection of these 3 geo-referenced areas, and subsequent monitoring and analysis in these strata. Giordano followed with an overview of bottom mapping the NOAA Chesapeake Bay Office completed in late 2009 as part of its Benthic Assessment Program, with specific web-based access to data collected in its geo-referenced bottom mapping and videography program. Giordano offered to provide pre- and post-restoration monitoring of the bottom for future oyster restoration projects in VA (and MD) waters. Finally, in the final presentation of this section, Leggett provided a short summary of the VA Chesapeake Bay Foundation restoration and monitoring program that focuses on sanctuary creation and sub-sampling with patent tongs for estimating short- and several year restoration success.

After an expansive summary of the MD Native Oyster Restoration Program by MD Department of Natural Resources M. Naylor over lunch, an open discussion by meeting participants ensued, with the following basic conclusions reached:

1) Vertical relief in oyster bar restoration appears to yield high oyster densities through growth and recruitment, relative to oyster densities recorded for sites with low or no relief.
2) Differences in oyster densities and derived acres of increasing oyster populations from oyster restoration projects conducted through VMRC and those of the U.S. Army Corps of Engineers appear to be a result of data aggregation. Post-workshop sampling of previously collected data in both monitoring programs will be done, sampling within similar strata of high, low, and base relief.
3) The differences reported in the two programs largely fall into characterization of oyster densities in high relief restored sites, a specific design of the U.S. ACE program, versus lower mean densities obtained by averaging multiple samples from a diverse relief spectrum, the latter the goal of the VMRC monitoring program to assess oyster restoration in originally identified planting polygons.
4) Geo-referencing bottom substrate types and mapping bathymetry should become standard practice for oyster restoration projects prior to site selection for restoration to increase likely probabilities for successful oyster growth and recruitment in Virginia's waters. Further characterization of surficial sediments on these substrates, using videography for example, would also enable site considerations for low-to-high sedimentation areas. The addition of hydrodynamic modeling for selected areas, possibly with particle tracking algorithms, would additionally advance possibilities for selecting appropriate oyster restoration sites to those areas where sediments remain in suspension rather than depositional locales.
5) Lipcius is convening a small group of regional scientists to identify goals for native oyster restoration and the appropriate techniques for monitoring that should be implemented

to assess whether the restoration effort proposed or undertaken can meet the goal. The product, due by late summer 2010, will be goal-specific recommendations of monitoring protocols.

6) Greater communication, and collaboration, is needed immediately for the on-going development of the U.S. Army Corps of Engineers Native Oyster Restoration Master Plan and the NOAA-led Federal agencies' strategy for oyster restoration in the bay's tidal waters that is being drafted in response to the 2009 President's Executive Order. This communication should include dialogue with state agency staff in Virginia and Maryland to ensure complementary programs, specific recognition of fishery- or ecosystem service-focused restoration, and non-redundant manipulation of the same sites [a bilateral agreement is now in place and participation by other potential Federal and state partners is envisioned in activities of the Chesapeake Bay Program's Protect and Restore Fisheries Goal Implementation Team].
7) As funding and scheduling permits, NOAA's Chesapeake Bay Office offered to provide a benthic assessment program for the tidal states, to provide needed geo-referenced bottom substrate conditions prior to and after restoration, the former for siting restoration in near optimal bottom sites for oyster growth and recruitment and the latter for quantifying efficacy of the restoration practice.

Because reconciliation of oyster abundances for specific sites will likely be obtained through the re-assessment outlined in (1) above, it is immediately obvious that communication between restorers and monitors must become standard procedure, siting of restoration projects for increasing likely growth and recruitment is critical, data collection using common practices must occur, and that data access is a huge necessity for future successful restoration. The workshop is a first step for assuring this transition in VA native oyster restoration.

Introduction

The decline in oyster populations and harvests in tidal Chesapeake Bay waters is well documented. Because of this identified loss in a valued commercial product as well as the ecologically important role that the eastern oyster *Crassostrea virginica* plays in the bay, numerous organizations, Federal agencies, and state fisheries departments in Virginia and Maryland have conducted active restoration projects over the last 30 years. These efforts have largely been unsuccessful, or at least success or failure has been difficult to assess due to inadequate monitoring (ORET 2009).

A recent publication (Schulte et al. 2009) and several presentations by those authors have indicated possible large increases in native oyster populations resulting from an experiment in the Great Wicomico River, a small Virginia trap estuary. This is in contrast to reported poor success for those same areas assessed through routine monitoring by the state and its long term science advisor at VIMS. This debate has led to uncertainty in restoration plans for the future, as investing in restoration should be based on broadly accepted population dynamics for the same areas for best use of limited Federal and state resources.

In an attempt to resolve these identified differences in restored oyster populations, foster collaborative restoration and monitoring approaches, and ideally develop standard monitoring procedures for assessing future restoration efficacy, NOAA's Chesapeake Bay Office at the Virginia Institute of Marine Science (NCBO-VIMS) convened a regional meeting, "Virginia Oyster Restoration Review Workshop", on March 31, 2010 at the College of William & Mary in Williamsburg, VA. Attendees included representatives from the active restoration agencies, departments, institutions, and non-governmental organizations (NGOs) in the state to openly discuss recently collected data in tidal Virginia waters. Of critical importance was the resolution of the population densities in restored areas reported by the various organizations, in order to assist immediate restoration activities in state waters as well as inform long-term planning strategies by the two most active Federal partners, the U.S. Army Corps of Engineers (ACE) and NCBO so that these efforts could complement those of the Virginia Marine Resources Commission (VMRC) and to a lesser extent the NGOs active in the region (e.g., Chesapeake Bay Foundation, The Nature Conservancy).

Meeting Details

Background

A recent compilation of restoration data from tidal bay waters for the period 1990-2007 (ORET, 2009) indicated that little could be concluded from Virginia's multi-institution and multi-organization restoration activities for the 18 year period. Although 275 bars were 'restored', largely through placement of shell (Fig. 1), few data were available from any monitoring program so success/failure of the restoration activity could not be assessed. Although substantial monitoring appears to have been conducted, the data were not available either due to an absence of an electronic database and insufficient time, resources, or staffing to transfer hard-copy data to an electronic format, preventing detailed analyses. Specific recommendations, however, were offered including: all groups should clarify restoration intent (is restoration for fisheries or ecological services?); science-based designs and quantitative monitoring should be the only practices used in state waters by all restoration groups; coordination across groups and adoption of common protocols should be standard practices (restorers and monitors communicate, conduct only a single activity per site); oyster stock assessments should be done and use one protocol; and data must be collected, entered, and shared.

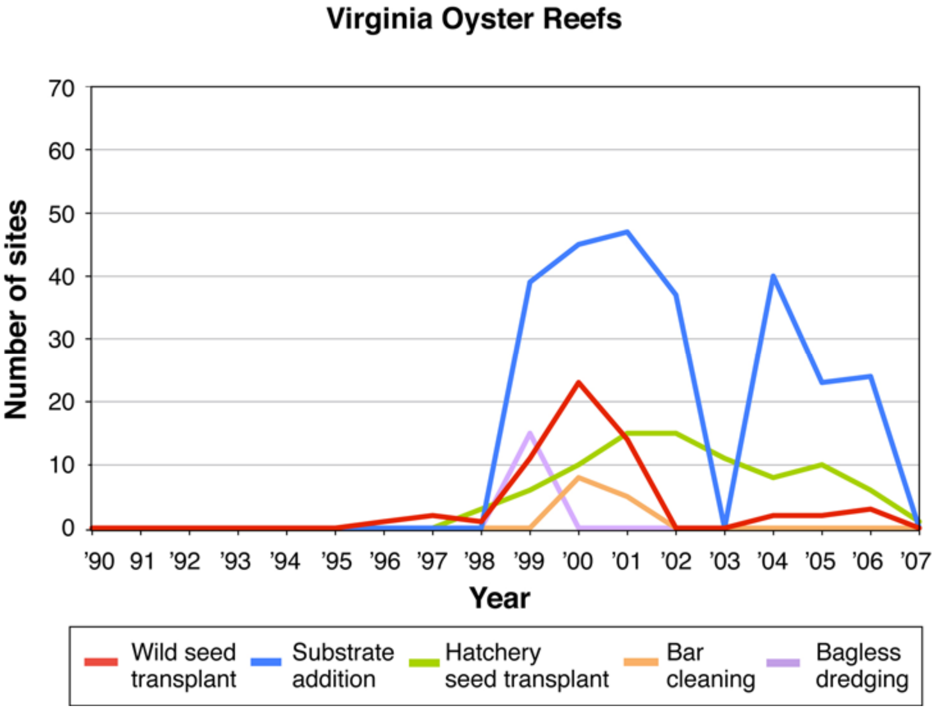

Figure 1. A summary of oyster restoration activities in Virginia, 1990-2007 (ORET 2009).

U.S. Army Corps of Engineers Master Plan

The Baltimore and Norfolk District Offices of the U.S. Army Corps of Engineers will be drafting a native oyster restoration Master Plan over the next few months, outlining an ACE approach to restoring sanctuaries in the tidal Chesapeake Bay. The specific goal of the ACE is ecosystem restoration. The Corps will develop restoration criteria and seek to prioritize restoration sites. Critical to this commitment is assessing changes in populations through time in restored areas. The current strategy uses a geo-referenced stratified random sampling procedure, structured around geo-referenced hard substrates in Virginia's waters (Lipcius et al., Appendix 2, see below). All data collected will be made available to the larger community.

The ACE Master Plan will outline the Corps' multi-year strategy for restoring native oyster populations in the tidal Chesapeake. Following internal discussions and writing, the plan will be distributed for public comment and possible independent scientific review, e.g., using the Chesapeake Bay Program (CBP) Scientific and Technical Advisory Committee (STAC). Of obvious importance is the Corps' concern for wisest use of any appropriated funds, i.e., producing a sustainable native oyster population, insuring an expanded role of the oyster in habitat, filtering capacity, and nutrient cycling, critical to functioning of a healthier tidal ecosystem and thereby likely fostering continued Federal support for restoring the bay through this critical resource.

Workshop comments were largely supportive of the ACE goal, with encouragement for discussion with other agencies (NOAA, see below) and a possible Master Plan derived from Corps, NOAA, and VMRC considerations for VA waters.

Multi-Federal Agency Native Oyster Restoration Strategy

NOAA's Chesapeake Bay Office and Federal Response to the President's Executive Order

The recent Executive Order 13508 required restoring fish and wildlife in the Chesapeake Bay. In consultation with ACE, VMRC, MD Department of Natural Resources (MD DNR), Potomac River Fisheries Commission (PRFC), and the Chesapeake Bay Program's Protect and Restore Fisheries Goal Implementation Team, NCBO has drafted a Federal response to the requirement in the 203 strategy. The strategy has proposed an outcome to "Restore native oyster habitat and populations in 20 tributaries out of 35 to 40 candidate tributaries by 2025." The selection of the tributaries for restoration would be informed by an examination of existing data or application of a quantitative model, with details outlined in a NCBO-ACE joint letter seeking input from the respective organizations as well as meeting participants. Each restoration project would include a monitoring and research component, with monitoring informing adaptive management of the restoration for that tributary. The process would be led by the newly formed CBP Protect and Restore Fisheries Goal Implementation Team, which now includes the state fisheries managers from Virginia and Maryland, DC, and Potomac River Fisheries Commission as well as the Atlantic State Marine Fisheries Commission (ASMFC).

Workshop participants raised a few issues for consideration. First, NCBO was encouraged to begin discussions with the ACE for collaborative efforts in the 203 strategy and the ACE Master Plan, making sure both reflected unique activities of each agency but a partnership that would indicate collaboration and non-redundancy. These discussions are underway, resulting in a joint letter between NOAA-ACE towards maintaining discussions and complementary programs. Second, because tributary commitments, including fisheries management, are state responsibilities, it is extremely important that each state agrees with and can assist in meeting the interagency outcome; this potentially can be addressed in the Protect and Restore Fisheries Goal Implementation Team of the CBP. Third, and possibly more important, was the recommendation that the goal be changed to reflect ecosystem/functional benefits rather than an arbitrarily selected number of tributaries restored successfully. The concern over a fixed number of tributaries with a restored and sustaining population is that not reaching the number but coming close could be viewed as 'failure' and further, what is the metric for restoration 'success'? Re-establishing habitat, filtering capacity, nutrient flux (denitrification particularly) as well as a recruiting oyster population would all be excellent metrics.

Virginia's Marine Resources Commission Native Oyster Restoration Program

VMRC's Wesson summarized past and current native oyster restoration by the state. Critical to potential state activities, the 2006-2007 Virginia Blue Ribbon Panel was convened to guide future state native oyster restoration, with a strong recommendation for an annual state appropriation for $2.5M solely for restoring the resource for harvest and ecological benefits. Unfortunately, state funding for native oyster restoration is much lower, $600,000 in the current fiscal year, leading to an internal decision for committing these resources to harvest areas. Additionally, an immediate issue for the state is access to shell, now a scarce commodity after transport to other states and regions.

A general reference for state oyster habitats is the Virginia Oyster Atlas from 2003-2004, listing 'good' and 'poor' bottom; it is available through the VIMS website (http://web.vims.edu/mollusc/oyrestatlas/?svr=www). The development of this atlas was funded through the Army Corps of Engineers to guide future restoration siting.

VIMS and VMRC Oyster Monitoring

Mann provided an overview of immediate needs for the state in its commitment to oyster restoration and harvest. He made a strong plea for implementation of stock assessments for this resource, as routinely done in other fisheries. Through estimates of oyster numbers, age structure, and demographic information for specific areas (e.g., Dexter Haven locations), Virginia could derive reasonable estimates of the existing population.

Mann also reviewed monitoring procedures, eliminating dredges from a list of quantitative methods due to variable penetration depths, clogging, durations, etc. He also concluded that patent tongs are of limited value due to variable penetration in multi-layered reefs; hydraulic patent tongs would be preferred, through deep penetration assured with the method.

Sampling should be conducted using geo-referencing and grids, producing multiple samples and some estimate of patchiness (variability). Age structure of collected samples should be determined, enabling matching cohorts to individual and multiple spawning events in a year, and identifiable length-to-age relationships that can be used for year-to-year assessments of population size. To insure collection of those data, all monitoring strategies, samples/replicates, etc. must be documented in each project, with monitoring implemented where the restoration has occurred. A description of these monitoring limitations is provided in Appendix 1.

Mirroring comments from VMRC's Wesson (above), Mann suggests that Virginia oyster populations are shell-limited. This is reflected in a need for managing the population through estimating costs for acquiring shell in any proposed fiscal commitment to restoration as well as routinely estimating the quantity of shell accreting or disappearing (live/total, L m^{-2} y^{-1}) for a given bar or Baylor polygon. If shell is not accreting above an estimated sea level rise of 4.55 mm y^{-1}, natural processes will ensure restoration failure in the long term, and a non-sustainable oyster population at a given site. Mann argues convincingly for estimates of shell availability and accretion as a justification for future restoration at any locale, with the possibility of considering alternative substrates to meet shortfalls in shell availability.

In a summary of the monitoring protocol for VIMS and VMRC, Mann stated that the program uses multiple samples collected in each restoration area, ranging from 7-20 per polygon. The number of samples to analyze at a site is determined by the number of replicates needed to minimize the standard error (s.e.) of the mean for the site (Bros and Cowell 1987) to a nearly constant low value (Fig. 2). In the example provided, note that the s.e. approaches 20% of the mean at approximately 8-20 samples for the 5 sites represented.

Sampling specifics are as follows (Mann et al. 2009): A hydraulic patent tong with an open dimension of 1 m^2 is employed. Upon retrieval of each grab, oysters are counted and measured (mm), and the volume of shell material (L) recorded. The recorded dimension on each oyster is determined (shell height). A count of the number of oysters per tong has been made in all years sampled. Prior to 1998 a representative sub-sample (n > 100) of oysters was pooled across individual samples for a given reef, measured, and classified into 5 mm size bins. From 1998 to 2003, for each sample, all oysters have been measured and classified into 5 mm size bins. Beginning in 2003, for each sample, individual oyster lengths have been recorded to the nearest mm. Since 1998, samples with >20 L of shell have been halved to facilitate processing, with resulting counts and length frequency distributions for each sub-sample doubled to estimate density and size distribution on a per m^2 basis when sub-sampling was necessary. All articulated valves of dead oysters, boxes, are also counted and measured. Mean oyster density (number m^{-2}) is calculated for each oyster reef by averaging the number of oysters collected from all samples on a reef within a year and on a reef-specific basis for the years 1993–2006. Shell volume (L m^{-2}) is reported coincident with the measurement of all boxes. For the period 2002 to 2006, shell was additionally categorized as brown shell, shell that lies above the sediment-water interface, and black shell that was exhumed during the collection process.

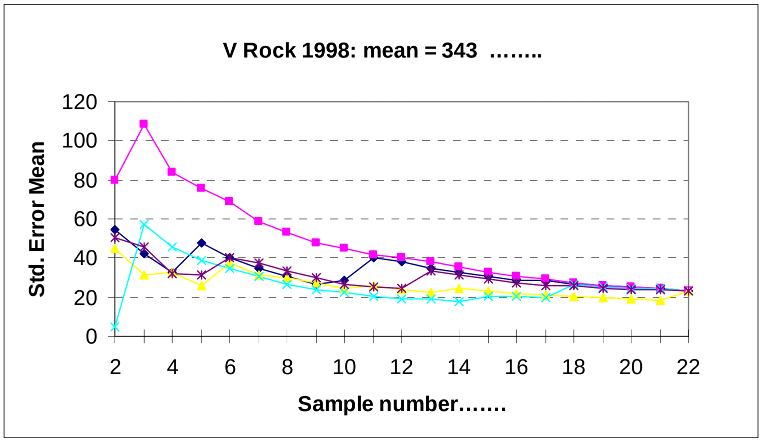

Figure 2. Standard error of the mean oyster density at 5 locations in a VIMS sampling area (R. Mann, pers. comm.).

Analysis of the VIMS/VMRC data indicates that few of the Baylor polygon areas have seen substantial population increases through time, in contrast to reports from Schulte et al. (2009). This likely reflects the goal of the sampling program, to characterize the status of oyster populations across a restored Baylor polygon, and hence sampling <u>all</u> areas of the polygon that includes high and low relief areas as well as a large area with diffuse or a single layer of shell and viable oysters.

U.S. Army Corps and VIMS Partnership: Schulte et al. Monitoring

Lipcius provided the overview of his monitoring program of Army Corps restored reefs in the Great Wicomico River. As reported in Schulte et al. (2009), his group documented unprecedented oyster growth in restored sanctuaries in tributaries of the southern bay, indicating very high oyster densities in high relief areas, lesser but still high densities in low relief areas, and typical minimal growth in open, flat bottom habitat (Fig. 3). The

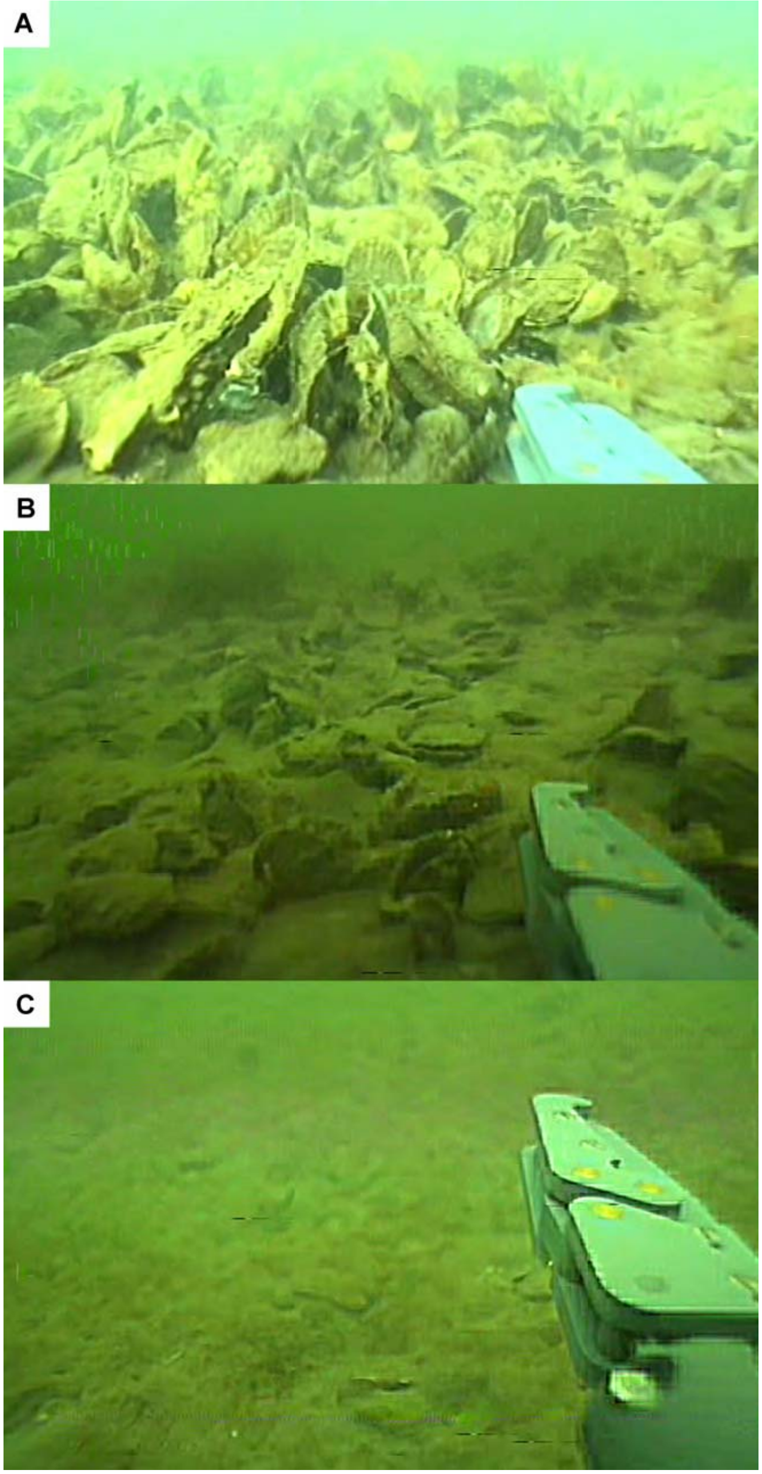

Figure 3. ROV photos of (A) high-relief reef, (B) low-relief reef, and (C) unrestored bottom (from Lipcius et al., see Appendix 2).

densities reported exceeded those noted by Mann and Wesson for similar areas, leading to uncertainty in oyster restoration success in Virginia's tidal water native oyster restoration programs run by VMRC and the ACE.

Sampling details likely explain the reported differences in the two estimates. Schulte et al. collected site- and relief-specific data to inform the ACE Master Plan (see above), collecting samples at specific sites where shell was known to have been added, thereby providing estimates of restoration 'success' at those sites for invested Federal funds. The strategy can be summarized as follows: In Baylor polygon regions of the Great Wicomico, the protocol uses extensive pre-site ROV bottom mapping for geo-referencing hard substrate areas followed by shell dispersal at two densities in the hard substrate areas (High Relief or >1' of shell application, Low Relief or ~0.5' of shell application); other hard substrate areas within the polygons, those containing thin veneers of shell, are geo-referenced but receive no added shell. Stratified random sampling of oyster densities is conducted in these 3 strata, with the number of samples (replicates) collected in the 3 strata proportional to bottom area of the stratum and accompanying population variance identified in the stratum (justification for this approach is presented in Appendix 3). Samples were collected via 1 m^2 patent tong retrievals, with repeated collections at the same site to retrieve all oysters for estimating single patent tong collection efficiencies (~70%). Estimates of total shell (L m^{-2}), live and box oysters, gray and black shell, shell height and weights, and numbers and taxonomic composition of the associated fauna collected in each habitat is determined (Appendix 2).

Analysis of collected samples using these protocols suggests that oyster densities (spat + adults) were proportional to relief. For example, shell accretion was estimated at >6 L m^{-2} y^{-1} in the High Relief strata versus 0.05-0.06 L m^{-2} y^{-1} in Low Relief strata. Considering Mann's (see above, Appendix 1) suggestion that successful restoration requires at least accretion rates of 4.5 L m^{-2} y^{-1}, the High Relief strata would be highly successful yielding sustaining populations, while the Low Relief and no relief areas would be unsuitable regions or approaches to restoring a viable, sustainable native oyster population. Additionally, spat recruitment noted in the High Relief strata was comparable to sets observed in shell string surveys conducted in the same area.

Lipcius indicated that shell relief configuration is important to oyster restoration success. In deployments of shell from 0 – 1.3 m height, a plateau shape was necessary for successful oyster restoration. Low Relief strata (0-0.1 m) were often typified by high sediment accumulation rates, likely a partial explanation for the low shell accretion rates noted (see above), while reefs exceeding 0.15 m height proved sufficiently high for maintaining a vigorously growing oyster population and little sediment accumulation. Pre-restoration knowledge of site-specific sediment accumulation rates would therefore be extremely important in determining site locations and shell relief needed to ensure successful restoration.

Lipcius indicated that siting of sanctuary restoration should also be aided by strong linkages with local hydrodynamics, thereby assuring local seed availability for recruitment, versus larval washout in non-retaining estuaries. Wang (VIMS) has provided highly-resolved transport patterns in several small southern bay embayments, invaluable for explaining source vs. sink reefs/populations for seed production and delivery. This approach is consistent with the collaboration of MD DNR, Oyster Recovery Partnership, and University of Maryland Center for Environmental Sciences on applying an oyster transport model in MD's waters.

MD Native Oyster Restoration Program

Naylor summarized MD's native oyster restoration program, indicating Governor M. O'Malley's commitment to substantial sanctuary acreage increases across state waters. The progressive restoration program adopted in MD should inform the ACE Master Plan and the NCBO-led EO Oyster Strategy that will be compiled and further defined over the next several months.

Benthic Habitat Assessment by NOAA's Chesapeake Bay Office

Giordano et al. have been conducting bottom surveys throughout the bay and its tributaries for the last couple of years, with one goal of identifying hard bottom substrate as potential oyster restoration sites in tidal waters. In 2009, the NCBO team scanned 7.1 km^2 (~1800 acres) using their acoustic techniques (see Appendix 4) and found 530 acres appropriate as possible oyster substrate. All observations were geo-referenced, permitting site-specificity and location for shell additions. Further, the techniques were complemented by video observations for characterizing mud/shell in the hard substrate areas. All data are analyzed and bottom maps prepared and posted on the web (Fig. 4). The web mapping tool permits examination of specific site characteristics, as well as video footage for clarifying surficial sediment qualities and associated macrobiota of the area.

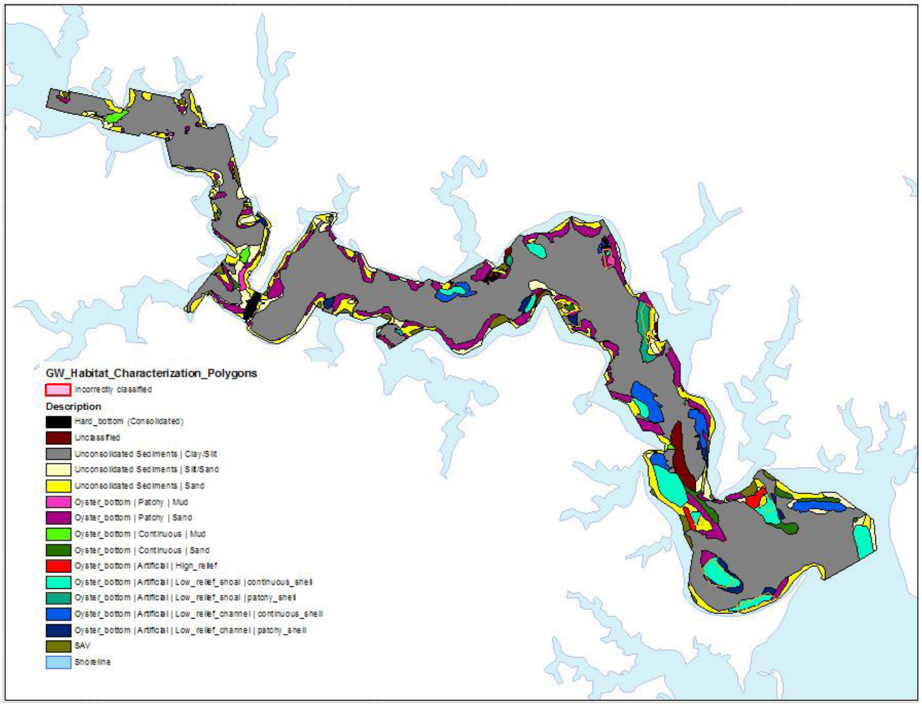

Figure 4. Digitized habitat polygons for the Great Wicomico, determined from backscatter, bathymetry and video, in the NCBO Benthic Assessment program (from S. Giordano presentation, see Appendix 4).

The technique appears to mimic the bottom characterization capacities of the Schulte et al. monitoring protocol. A comparison is planned for the two bottom mapping approaches, including estimates of oyster densities at High Relief, Low Relief, and no relief sites of Baylor polygons within the Great Wicomico estuary. Further, Giordano offered the services of the Benthic Habitat Assessment team as one pre-siting technology for general use in VA and MD as the individual state as well as multi-Federal agency oyster restoration programs move forward. The technique is sufficiently robust to also provide post-restoration assessments, as a complementary assay for other monitoring efforts by an agency, department, or NGO.

Virginia Chesapeake Bay Foundation

The Chesapeake Bay Foundation has been active in native oyster restoration in VA tidal waters for more than 15 years. Prior to 1996, sanctuary oyster reefs and harvest bars were monitored using VMRC dive, dredge, and patent tong surveys, respectively, with most restoration 'success' limited due to ray predation and disease (T. Leggett, pers. comm.). From 1998 through 2006, cultchless hatchery-produced oysters were used to stock 3-dimensional sanctuary reefs, a few small shoreline reefs, as well as used in some limited aquaculture. Since 2006, CBF has deployed spat on shell on sanctuary reefs in the Piankatank and Lynnhaven Rivers, monitoring reefs over time using 0.33 m^2 hand tongs. A pre-plant survey is conducted to determine an estimate of standing stock on the reef where spat-on-shell will be planted. Three samples are taken on the reef and spat, small, and market size oysters and boxes are enumerated. After spat-on-shell has been planted, a post-plant survey is conducted to determine handling mortality and then several samples are taken over the next year to determine growth and survival of the planted spat-on-shell. At some point, the planted oysters blend in with the wild oysters and planted spat become difficult to distinguish from wild spat. For shoreline reefs, 4-5 quadrats are employed (see Luckenbach procedures below). Data are maintained in a CBF database.

As noted by Mann (above, Appendix 1) in a summary of appropriate gear for quantitative sampling, densities obtained with hand tongs and VMRC dive densities did not compare favorably. Monitoring in the pending restoration project in the Lafayette River estuary will use the procedures developed by Luckenbach (Luckenbach and Ross 2009, Paige and Luckenbach 2009), with pre- and post-restoration sampling.

Luckenbach Oyster Monitoring Design

The Luckenbach monitoring approach is as follows (M. Luckenbach, pers. comm.): Most of his group's oyster monitoring done has been on intertidal or very shallow subtidal reefs (including the Shell Bar Reef in the Great Wicomico River) sampled with quadrats (25 cm x 25cm x 10 cm deep). On reefs with significant vertical relief, quadrats are placed every 2 – 3 m along randomly-selected transects from the crest of the reef to the seabed (see p. 32, Luckenbach and Ross 2009).

For estimating entire oyster populations over larger areas that include many types of oyster habitat, particularly intertidal oyster-rich areas where oysters are distributed in many small patch and fringing areas, found in clumps in the marshes, or on man-made shoreline structures, mapping of all locations of oyster accumulations is done using aerial and ground-based surveys, followed by qualitative oyster density estimates. Thereafter, working with GIS tools, this dataset is stratified by region (individual coastal bay or tributary region), habitat type (e.g., patch reef, fringing reef, marsh, bulkhead, etc.), and qualitative oyster density estimate followed by random allocation of replicate samples within each of these strata, with the numbers of replicates proportional to the area and/or estimated density range. This probabilistic approach yields not only good mean density estimates, but meaningful variance estimates and the ability to make statistically-valid inferences.

Workshop Discussion

Prior to the meeting, the dramatically higher oyster densities noted for high relief sites in the Great Wicomico (Schulte et al. 2009) were not consistent with densities noted for the same oyster reefs, reported by Mann and Wesson, leading to obvious differences in estimates of restoration efficacy in these few Virginia tributaries. However, the detailed description of the site-selection procedures, shell deployment strategy, and geo-referenced estimates of oyster densities in high, low, and no relief sites by Lipcius provided the meeting participants with sufficient geo-spatial resolution of restored areas that the differences between the two monitoring approaches could be understood. The method used by Schulte et al. (Lipcius et al., Appendix 2) provides quantitative estimates of oyster densities, shell accretion, live and box counts, brown and black shell, and strata-associated macrobenthic communities for specific reliefs within each restored area. It can resolve all parameters for high relief, low relief, and no relief areas within a geographic region, such as a Baylor polygon. It quantifies oyster densities in each of these strata, with confidence intervals specific to each, enabling geo-spatially explicit population estimates and therefore restoration success in each. In contrast, the Mann-Wesson protocol collects (for the same reef parameters) 7-20 samples across the entire geographic area (i.e., Baylor polygon) without regard to relief. Replicates per polygon are determined from estimates of variation about the mean, with the number of replicates fixed to minimize standard error of the mean polygon population (see Fig. 2).

These two methods will derive different mean estimates (see explanation in Appendix 3), as the goals of the two monitoring strategies differ. Schulte et al., for the use of ACE funds, hope to identify reef conditions most favorable to restoring a viable, long-lived, self-sustaining population and hence, through the collected results, they can document that high relief bottom substrate systems support the greatest populations, leading to the conclusion that 3-dimensional structure matters to successful restoration. Mann and Wesson on the other hand wish to compute restoration success across the entire reef originally delimited through the Baylor polygons. Their mean reflects their goal of oyster population success across no-to-high relief areas within the entire polygon.

To explore whether the two methods actually generate the same relief-specific densities, Mann will re-sample his replicates within each polygon using coordinates specific to Schulte et al. samples in the 3 strata. It is anticipated that Mann and Wesson sampled some of each strata in their replicates in each polygon and by re-stratifying polygon-specific replicates into high, low, and no relief areas identified by Schulte et al., mean densities for the 3 strata will be derived, yielding in all likelihood similar mean densities. Lipcius, in turn, could obtain an estimate of strata-independent mean densities as well, then comparing those densities to the Mann-Wesson mean polygon densities, further indicating that the two methods could yield similar results, IF the goals of the two programs were reversed. If the Shell Bar Reef has been sampled by these two groups, then data from Luckenbach might also be explored in this comparison.

Lipcius volunteered to convene a small group of active oyster researchers to discuss current and feasible monitoring techniques and derive recommendations of appropriate monitoring procedures for specific restoration goals common to Virginia's multi-agency, department, and organization effort (Appendix 5). A summary will be derived, providing consensus recommendations for monitoring techniques that should be employed to assess efficacy of the restoration practice(s) implemented for each goal.

Considerable interest was shown for routine inclusion of geo-referenced bottom mapping for pre- and post-restoration projects, potentially provided through the Benthic Assessment Program of NOAA's Chesapeake Bay Office. Characterizing bottom substrates with acoustic and video mapping capabilities should be undertaken prior to any restoration project, to increase probabilities for restoration success by focused restoration in hard substrate or vertically elevated hard substrate locations. Videography will further elucidate surface conditions, e.g., whether sediments overlie desired hard substrate, indicating sedimentation conditions that might remove some hard substrate areas as likely restoration sites. Use of hydrodynamic models and particle tracking to identify high sedimentation areas versus current-winnowed and therefore likely hard substrate-desirable locations could also be used more frequently in site selection. Post-shell placement benthic mapping should also be routine, enabling large area estimates of high, low, and no relief as well as quantitative sampling of oyster abundances in each of these substrata for determining 'success'.

Group discussion encouraged immediate open dialog between the organizations with substantial near-term resources committed to native oyster restoration. Strong encouragement was expressed for continuing and expanding active dialog between the U.S. ACE and NOAA's Chesapeake Bay Office in designs of their respective Master Plan for Native Oyster Restoration and the Federal commitment to restoring a substantial number of oyster populations in the tributaries. Additionally, expert opinion/review should be considered prior to publication and distribution of any strategy, to insure science-based restoration is assured.

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Appendix 1. Quantitative Oyster Monitoring and the VIMS-VMRC Monitoring Protocol

Quantitative Sampling of Oyster Populations and Habitat for Fishery Stock Assessment and Ecological Restoration.

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Authors note: This document is offered as a stimulus to discussion to improve both broad scale stock assessment and restoration needs, understanding that these may not be the same. Constructive commentary is welcome.

Definitions (modified from Mann and Powell, 2007).

Fishery Stock Assessment is quantitative estimation of abundance and certain life history parameters of an exploited resource, in this case oysters. The assessment supports a fishery management process to sustain the target species and the economic entities that rely upon it. Fishery management does not require ecological restoration although it may contribute to it. A stock can thus be viewed as an economic resource. It is possible to sustain this economic resource at less than maximum sustainable yield through careful management based on an understanding of recruitment and mortality rates in combination with other life history parameters - this is routinely accomplished with finfish during rebuilding plans. Both recruitment and mortality rates are difficult to estimate in oysters, rarely examined with adequacy in extant exploited populations, and afforded inadequate attention in current “restoration” plans. Fishery restoration can be supported in its entirety on direct stock enhancement procedures such as hatchery seed production and deployment, and shell planting and transplant of seed. Such exploited stocks are ephemeral and may not by themselves supply desirable long-term ecological services because, by definition, they are destroyed at harvest. The more effective the harvest, the more complete the destruction. There are disease related reasons why complete harvest of an oyster population may be desired under some management scenarios and as this extreme is reached, the dual option of exploitation and ecological restoration becomes less and less tenable. Rather, the dual role model is inconsistent with high fishery yield. The objective of fishery stock assessment is to collect quantitative information to support the management process.

Ecological restoration of oysters is the provision of ecological services by a self-sustaining population within a defined footprint. Ecological services comprise benthic-pelagic coupling, the physical provision of complex, three-dimensional habitat structure, and the supply of biogenic carbonate to the benthos. Ecological restoration includes as well the increase in habitat complexity and resultant enhanced species richness (e.g., Nocker et al. 2004, Tolley and Volety 2005) and providing opportunity for higher-level predators (Harding and Mann 2001a,b). Oysters have pelagic larvae with the capability of lateral dispersal. Thus apparently isolated populations, extant as reefs or the contiguous footprints of former reefs separated by regions devoid of either live oysters or characterized by sedimentary habitat unsuitable for oysters, can be connected as subunits of a larger population (metapopulation). Larval dispersal in the Chesapeake Bay is limited on a per generation time frame. Thus the metapopulation comprises exporting source populations and importing sink populations, likely differentially distributed from year to year imposing complex structural requirements for stability even in the short term. Oyster distribution in the Chesapeake Bay is severely spatially limited at this time by the end products of past harvest practices and the current disease pressure on unselected stocks.

Data requirements: Introductory comments

The data requirements to support fishery management and restoration are different with needs for the latter being greater in complexity. Quantitative stock assessment for oysters is now in place and forms a basis for discussion of surplus production, harvest quotas, and optimal harvest scenarios. These approaches can be improved. By contrast, I argue that there is not a single restoration effort that, at this time, addresses the evaluation of restoration success with complete adequacy.

Data needs for stock assessment and fishery management

The management of single species relies on a suite of data including growth, age at maturity, fecundity, sex ratio, frequency of recruitment to the spawning stock, life expectancy, mortality rate, and abundance. Stock assessment attempts to address these through fishery independent approaches. In addition information may be garnered from fishery dependent data, examples including catch and effort, these have been minimally examined for the Virginia oyster fishery but the historical data have some limitations that cannot be corrected (for example, effort estimation when “two piling” market and seed oysters before this practice ceased). All approaches have inherent bias based on gear selectivity, time and location of sampling, and catch sorting (culling). There is currently a responsible movement towards multi-species management, especially so in finfish. The “state of the art” with oysters is not yet at that point of sophistication. Note that the typical suite of fishery-oriented data essentially ignores the suite of habitat roles that are central to oyster and estuarine ecology. I will address the habitat issue later in this text. At this juncture the focus is on sampling for fishery-related data.

Sampling gear: Options and limitations.

Four types of sampling gear will be examined for their strengths and weaknesses. These are dredges, mechanical patent tongs, hydraulic patent tongs, and video records.

Dredges

The base requirement for a dredge to be used in quantitative surveys is that it can be assumed to cover a defined swept area with known capture efficiency on a consistent basis. If these requirements can be met than a simple division of the number captured by the area covered gives density. Multiply density by the spatial footprint of the habitat and a total stock is estimated. Over the past decade the science supporting swept area approaches has been intensively examined and refined by the National Marine Fisheries Service (NMFS) in support of the surf clam, ocean quahog, and sea scallop fisheries. These studies also highlight the limitations of gear that was designed as qualitative rather than quantitative sampling tools. The oyster dredge is such a piece of gear. It will not sample consistently over non-uniform bottom because:

1. The dredge is towed by a flexible line of ill-defined length with ill-defined scope and “hinge points” at either the winch or the passage of the towline over the stern of the vessel. An additional hinge point is the attachment of the line to the dredge. The cumulative design in tow mode functions by alternately digging and releasing, hence the action of a towline over the stern of the vessel during dredging. As such, the dredge scoops but does not plane, so it does not sample representatively over the course of a tow, especially when the tow path moves over varying bottom type as would be found on a reef.
2. The dredge fills over the course of the tow to become a plough, after which it does not sample at all. Even when the dredge does not fill, the probability exits that it fills gradually and thus its efficiency changes over the course of the tow. Thus, the only conditions under which a dredge can be used quantitatively are for very short tows (see Powell et al. 2002).
3. A dredge is size-selective because it samples the surface more so than the underlying reef. If the YOY (spat) are near the surface then the sampling is not representative. Bias in favor of live animals over shell has been noted by both Powell at al. (2002) and Mann et al. (2004).
4. A single dredge will vary in efficiency depending on scope, speed of towing, size of vessel, and even vessel operator, in addition to state of and direction of the tide. With this combination of variables it is unwise to attempt to transfer calculated efficiencies from one dredge/vessel/operator/location to another. In fact these variables dictate that any attempt to use a dredge as a quantitative tool require that it be calibrated for every use (time of deployment), vessel, bottom type, tidal stage, and more. This is simply impractical.
5. There are, to the best of my knowledge, no published depletion-based efficiency estimates for oyster dredges. There are for surf clam and ocean quahog dredges, but the latter operate in uniform substrates and do not sample in an oscillatory manner when towed - they slide and exhume that target species with hydraulic jets.

The “bottom line” is that oyster dredges cannot be supported as area-specific sampling devices for stock assessment. The history of their use in the Chesapeake Bay has always been in a semi-quantitative mode at best in that the long term dredge surveys have not been used to support standing stock estimates in either Maryland or Virginia.

Mechanical patent tongs.

Mechanical patent tongs, like classic grabs or cores, sample from a known area, so the swept area concerns associated with dredges are eliminated. The challenge is to assess the efficiency of sampling in the area enclosed by the tong opening as it sits on the bottom. This is influenced by tong weight, length of tong teeth, bottom type, deployment protocol (that collectively determine how far the teeth initially penetrates the bottom), and by retrieval protocol. A typical mechanical patent tong is designed to close as it is recovered – both actions simultaneously. Herein lies its weakness as a sampling tool in that a well-operated patent tong in fishing mode both sorts and retrieves in one action. It is selective, especially so when penetration is limited. This is particularly problematic where natural reefs retain their base structural integrity, such as in the James River where exploitation has been limited to hand tongs with their limited bottom penetration ability. Thus patent tongs sample the surface layer with greater consistency than underlying layers; the latter are poorly sampled if at all: they are surface scrapes. As will be addressed in later discussion related to restoration sampling, the inability to simultaneously sample the underlying shell habitat limits the use of patent tongs in restoration studies. Finally, most mechanical tongs have limited covers and are thus susceptible to spillage of material during retrieval – mostly small material that is of limited interest in fisheries with minimum size limits. This material is, however, often critical in stock assessment.

Hydraulic patent tongs

Hydraulic patent tongs separate the actions of closing from retrieval. Thus each can be optimized in design rather than compromised. The tong may be heavier allowing both deeper initial penetration of the bottom, and insuring that the tong continues to "dig" during the closing action. The same arguments apply in the design of certain grabs that also separate closing from retrieval. The result is a deeper sampling. Once closed the hydraulic patent tong is then retrieved. The tong used in Virginia studies has the optional cover to retain surface material and the integrity of the surface in the retained sample. Total volume retained in a single sample can regularly exceed 50 L with an intact surface layer.

Video records.

Video recording offers attractive features such as records of mobile species that escape the three previously described gear types, images of actual spatial structure of the oyster community, and the ability to survey large areas in continuous swaths. Laser-based measuring accessories offer the option to retrieve linear measurements from video records. The major challenges with oyster reef video is that of visibility, although this can be to some extent accommodated by careful operation, and incomplete exposure of individual oysters in either settled aggregations or in sediments. The latter in particular will result in underestimation of one or both of numbers and dimensions. The ideal approach for video-based assessment is the use of stereo records. Such an approach is being examined for scallop surveys (Hab-Cam, Scott Gallager, Woods Hole Oceanographic Institution). This is impractical in the Chesapeake Bay, as the Hab Cam is a very sophisticated tool but it is the size of a small car.

Previous attempts to compare sampling gear - a commentary.

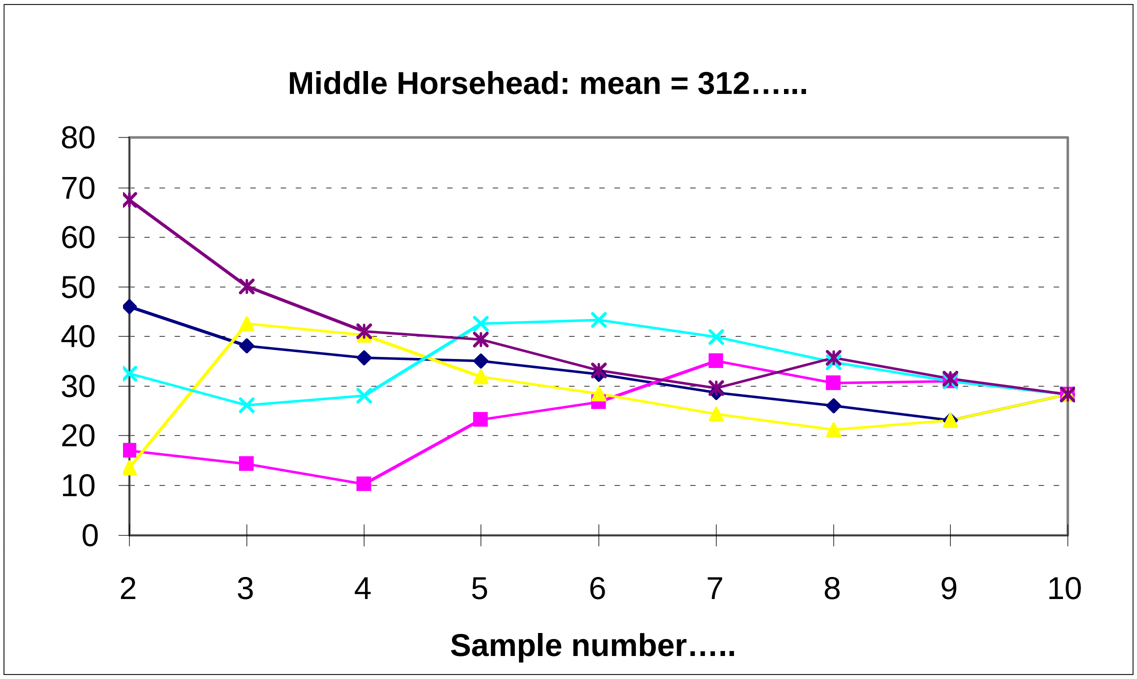
There are published studies that attempt to compare the data obtained from dredges and tongs (Chai et al. 1992, Mann et al. 2004 as examples). They are not in uniform agreement as to the possibility of developing correction functions that allow estimation of density estimates (tong data) from dredge qualitative data. This is unsurprising given the previously described limitations in dredge design for quantitative sampling.

Sampling design for oyster stock assessment

The challenge is quantitatively sample an organism that displays aggregation at scales from meters to kilometers.

Stratified random surveys have long been used by NMFS in fishery management and elsewhere in ecology to estimate population size in a defined area. Such designs are appropriate for oysters given the presence of reefs that form defined strata in a broader landscape. The following discussion is based on the use of hydraulic patent tongs for collection of individual samples within a defined reef (=stratum, singular) area. Within a reef the distribution of oysters is not uniform, as demonstrated by variance:mean ratios in Mann et al. (2009a) for long term James River data. Adequacy of sampling can be assessed in the field in real time by application of the methods of Bros and Cowell (1987), a plot of the standard error of the mean (s.e.m.) versus the number of samples collected (n). As the s.e.m. continues to decrease as n increases, the question posed by Bros and Cowell (1987) is, to summarize: "at what point in the progression of sampling does the continuance of effort produce proportionally less and less useful information?" The answer is when the slope of the relationship between s.e.m. and sample number lessens and approaches zero. Note the term *approaches*: as mentioned above in a perfect sampling this will continually decrease. Examples of data from the 1998 James River survey are given in Figure 1. These are taken from a study, effected during early NOAA CBSAC-funded efforts (Chesapeake Bay Stock Assessment Committee), to determine sample numbers for future surveys where funds and vessel time were limited. Plots are available for every reef system surveyed in the James River in 1998 and all show the same trends. With sample numbers from 25-30, the s.e.m. is approximately 13% of the mean with a range from 6-17% for the higher density (>100 oyster m^{-2}) reefs. In typical survey mode a lower sample number is used, 7-20, depending on the size of the reef and historical records, to be time efficient in sampling. We continue such analysis on a regular basis. These plots can be made in the field in real time, so they are practical in use. The end point for sampling any one stratum in a large-scale survey is a compromise between time invested/available and data product.

Figure 1. Example plot, standard error of the mean (s.e.m.) versus the number of samples collected (n). Data from Middle Horsehead reef, James River stock assessment 1998.



A note is appropriate here concerning inclusion of zero values in the data set. Zeros can result from either making the boundaries of the stratum larger than the actual reef footprint, then sampling the peripheral band between the reef and stratum boundary, or by sampling areas within the reef boundary that are devoid of oysters simply because of the patchy nature of the habitat within the reef. Such patches may occur naturally or may be transient features, especially where reefs have been fished, replenished, or constructed simply because of the non-uniform products of each of these activities. Zeros should be included in the s.e.m. plots when the desire is to estimate total population size for whole stratum. Tong sampling seeks a mean value per unit area. This mean value will be lowered by inclusion of the peripheral band, but the included area in the final calculation (total = mean x area) will be the same. If the desire is to explore spatial structure within the individual stratum then the data can be further stratified and re-examined, often eliminating the zero values; however, where the stratum boundaries are fixed from year to year and the intent is to generate a single mean value then zeros should be included.

Protocols for Fishery Stock Assessment as Employed in Virginia

The following is based on a now standard (since 1998) protocol reviewed by CBSAC in the early years of the survey, in later years with renewal proposals and in formal presentations, and in peer review publications (Mann and Evans 1998; Mann et al. 2009a; Southworth et al. in press).

Oysters are collected during the fall (October through November) from natural oyster reefs. This time period is chosen because it is after the annual reproductive period and resultant YOY (spat) are large enough to see by eye in field collection and survey mode. The YOY numbers are not representative of total recruitment to the substrate in that mortality will have occurred prior to the sampling. The values represent survival to the YOY size at time of survey. Given the period of recruitment, as estimated from both shellstring surveys and subsequent growth analysis, the fall survey YOY is generally considered to have a mean age of 3-4 months.

A quantitative sampling program is employed at all reefs using a stratified random grid with documented oyster reefs (bars) forming the individual strata. A list of reefs sampled in the respective rivers is typically based on historical designations – an example is that for the James given in Mann and Evans (1998) and Mann et al. (2009a). These historical designations are generally based on prior surveys by Dexter Haven and collaborators (work in the mid to late 1970s, published in Haven et al. 1981) who resurveyed the historical Baylor (1896) surveys post the epizootics of MSX and Dermo. Once adopted, strata are generally maintained as long term units. For example, the nineteen reefs sampled in Fall 1993 in the James River remain intact in current surveys. Four more were added in 1995, and also remain intact through 2010. It has been tempting to examine a re-stratification option where long term (>10 y) sampling exists with very large cumulative n values (literally thousands in the James for example), but this has not been pursued.

Field collections

Surveys use the 43-ft VMRC vessel *J.B. Baylor* with a hydraulic patent tong. The open dimensions of the tong are such that it sampled one square meter of bottom. Upon retrieval of each sample (= patent tong grab), oysters are counted and measured (mm), and the volume of shell material (L) recorded. The recorded dimension is the longest from the hinge to the shell margin. This is correctly termed shell height, although commonly described as shell length in most literature. I adopt the common convention and refer to shell length (SL) in subsequent text. A count of the number of oysters per tong is made in all years sampled. Prior to 1998 a representative sub-sample (n > 100) of oysters was pooled across individual samples for a given reef and measured and classified into 5 mm size bins. From 1998 to 2003, for each sample, all oysters were measured and classified into 5 mm size bins. Beginning in 2004, for each sample, individual lengths were recorded to the nearest mm. Since 1998, samples with > 20 L of shell have been halved to facilitate processing. The resulting counts and length frequency distributions for the sub-sample are doubled to estimate density and size distribution on a per m^{-2} basis when sub-sampling is necessary. The procedures of Bros and Cowell (1987), as discussed earlier, are employed to assure adequacy of sampling within each strata. All articulated valves of dead oysters, commonly termed boxes, are similarly counted and measured. The utility of box counts as a quantitative measure of mortality is questionable given recent analysis in Mann et al. (2009a). Box counts underestimate mortality, often by quite large margins.

Mean oyster density (number m^{-2}) is calculated for each oyster reef by averaging the number of oysters collected from all samples on a reef within a year.

Shell volume (L m^{-2}) is recorded. Since 2002, shell has additionally been categorized as brown shell that was been exposed to oxic water above the sediment water interface and black shell that was exhumed during the collection process.

Biomass estimation

A subsample of oysters covering the entire demographic is chosen for estimation of the relationship between oyster shell length (mm) and biomass or dry tissue weight (g). Typical n values for this exercise are >100 with a premium placed on representation from every 10 mm size class. After the oysters are measured to the nearest mm, the tissue is removed and dried to constant weight (DW, g) at 80°C (72 h). Wet shell weights (WSW, g) are collected from the same oysters used in biomass determinations after the tissue had been removed and before the shells had air-dried. The relationship between SL and WSW is described.

Biomass calculations are routinely made for each 5 mm size class for each reef using the mid-point of each reef specific, 5 mm size class as SL in the fitted SL-DW equation.

Age structure and mortality

Demographic plots are prepared for each year for each reef for both live oysters and boxes using 5 mm bins. Distinct year classes of live oysters that can be followed for a minimum of three years are rare in Virginia rivers. The period of recruitment to the benthos (also commonly termed spatfall) in the Virginia sub-estuaries results in a broad size range within each year class such that inter-annual junctions are not distinct with a 5 mm size bin. Where 1 mm bin data is available, post 2004, cohorts are discernable with very large n values (thousands of individual oysters). The individual cohorts (not year classes, there being one or more cohorts in a single year class) are identified by the method of Bhattacharya (1967). There are other discriminatory methods, but this one is simple to use. Cohort identification in the demographic plot is assisted by the availability of shellstring studies that identify the number and temporal spacing of recruitment events in targeted summer(s) represented by the collected sample (see http://web.vims.edu/mollusc/publications/mepubamr.htm for shellstring data). The range and modal length of each cohort can be identified. The cohorts are thus assigned to years and an age at length relationship explored. Unpublished data using isotope ratios have confirmed that this age at length estimates are reasonable.

What length at age relationship should be used? Harding et al. (2008) and Mann et al. (2009a) argue that a linear fit ($y = mx + c$) is appropriate for early years given the life expectancy of an oyster (10-15 years in undisturbed populations, Cummings and Powell 1985), their plastic form, and lack of adherence to isodiametric form. More recently Southworth et al. (in press), and Harding et al. (in review) have examined both linear and quadratic fits for the available data for the Great Wicomico and Piankatank Rivers and found that the quadratic fits are slightly better. The standard adoption of an age-at-length plot using the von Bertalanffy (1938) model is not considered essential for extant Virginia oyster populations given their truncated age distribution.

Using the linear or quadratic age-at-length estimator (whichever gives the best fit), the demographic plots are recast as graphs of year classes for each year and reef surveyed. Where live cohorts can be followed for more than two successive years, the number of individuals per m^2 is recorded in successive year classes. Survivorship and mortality can thus be estimated by the following relationships as a proportion with values ranging from 0 – 1.0:

(1) Survivorship $= \#Live\ (t+1)/\#Live(t)$
(2) Mortality $= \#Live(t) - \#Live\ (t+1)/\#Live\ (t)$

where #Live(t) equals the number of live oysters at time t (t, units of 1 yr). A possible error inherent to this approach is assignment of the animals to the wrong year class (too old or too young) from the age-at-length estimator. The manner in which this is currently used is a knife-edge at a chosen length, where in fact there is overlap, especially when there is a late recruitment in year t_o and an early recruitment in year $(t+1)$. The error cascades through the demographic, and in some instances where #Live(t+1)>#Live(t), gives nonsense negative mortality values in the simple proportion estimator; however, the incorrect assignment to year class may not be the only challenge in the proportion estimator. Under counting of small size, and thus age classes, can give similar errors. The possibility exists that both spat and spat boxes are underestimated by this sampling method, the latter being physically separated during collection. One of the challenges in the James River in particular, where recruitment can occur as late as September (Southworth et al. 2002, Southworth & Mann 2004, Southworth et al. 2006), is to count spat in October-November patent tong surveys. Underestimation of spat in patent tong surveys is cause for concern.

On the utility of box counts in mortality estimation

Using the above described approach box-length demographics can converted to age demographics employing the assumption that all boxes are $\leq$1 year old in order to categorize the boxes into the same age classes as the live animals. Thus live oysters with lengths x through y and boxes with lengths x through y are assumed to represent the same year class and are only counted once. If December is the end of the growing season and the surveys are in the preceding October-November, then all boxes represent mortality in that calendar year with the bulk of mortality being in the warmer months (predation, especially on the smaller individuals) and in the late summer (disease). This assumption is central to the approach that all boxes can be used in mortality estimation, although the longevity of undisturbed hinges in articulated valves has not been described adequately in the literature (it has been critically examined by Harding, Southworth, and Mann in experiments at VIMS over a multi-year period but the study is still in progress), and there is no requirement to estimate the "age" of new boxes as proposed by Volstad et al. (2006). It is important to respect the fact that spat box densities may underestimate mortality in that size range because of both the fragility of the articulated box (it disarticulates quickly) and that predation-related mortality does not leave an intact box in very small oysters.

If boxes are assigned to year classes and only counted once, then mortality can be estimated by a second relationship as follows, again expressed as a proportion with values ranging from 0 – 1.0:

$$\text{(3)} \qquad \text{Mortality} = \#\text{Box}(t) / [\#\text{Box}(t) + \#\text{Live}(t)]$$

The two mortality estimators are related by use of the #Live(t) value. A comparison of data from both estimators is presented in Figure 9 of Mann et al. (2009a) and presented below as Figure 2 for the present text. The box count method substantially underestimates mortality. It should be viewed as a qualitative estimator at best.

Disease status

The prevalence and intensity of *Perkinsus marinus* (Dermo) and *Haplosporidium nelsoni* (MSX) at selected locations in selected target regions is reported in annual reports from the Shellfish Pathology staff at VIMS (http://www.vims.edu/research/departments/eaah/programs/shellpath/publications/index.php). Wherever possible the sampling is coordinated with the pathology surveys to allow comparison of disease-weighted prevalence (WP) with mortality data. Weighted prevalence is calculated based on the following formula:

$$WP = (0.5xR) + (1xL) + (3xM) + (5xH) / n \ \ldots\ldots\ldots \ (4)$$

Where R, L, M, and H are Rare, Light, Medium, and Heavy infection intensity respectively.

General guidelines for data analyses

For a general descriptive approach, a typical examination includes:

- The relationship between the presence of live oysters (# tongs with live oyster density m^{-2}

Figure 2. On the utility of box counts in mortality estimation.

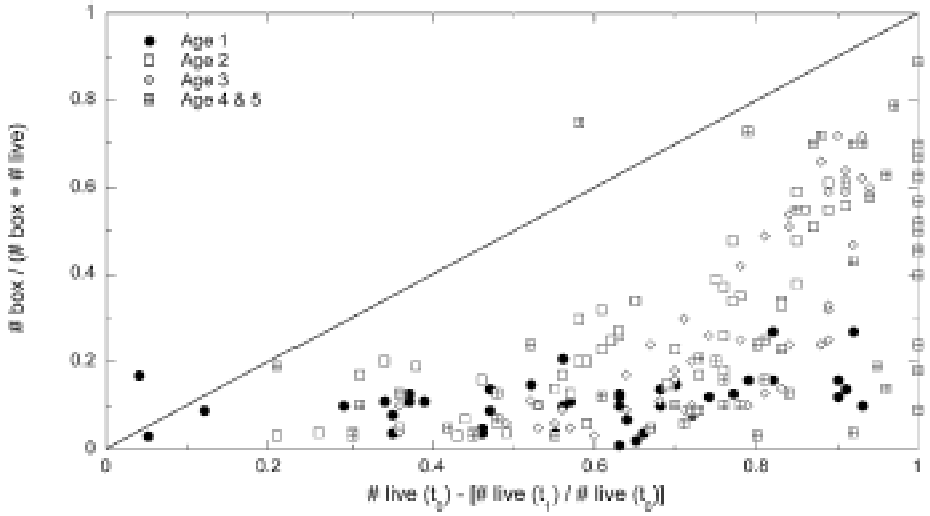


Figure 9. A comparison of age-specific mortality rate based on live oyster counts (x axis) and box counts (y axis) – see text for additional details. The diagonal line represents a 1:1 relationship where the mortality rate from one method equals the rate from the other.

> 0) and the presence of oyster shell (# tongs with total shell volume m^{-2} > 0). A linear relationship is typical here – a negative intercept describes the prerequisite of shell habitat before any oysters can be present.

- Trends in total shell volume as (year x reef).
- Trends in the proportion of brown shell volume (L m^{-2}) and/or total shell volume (L m^{-2}) (reef x year).
- Total shell volume (L m^{-2}) or brown shell volume (L m^{-2}) may be used as a covariate for two 2-factor ANCOVA analyses (reef x year) on oyster density and biomass data.

The end product of such an assessment is an area-specific estimate of oyster density, and thus by (area x density), an estimate of standing stock. Both age and length demographics are produced. Mortality can be estimated from age structure. Given that growth is known in terms of length or biomass as stock descriptors, then quotas, if desired, can be developed. A reference point approach, as used in offshore clam fisheries by NMFS, is a tractable end product if desired. Management by total quotas in the Virginia fishery is not a typical approach. Rather, the fishery is managed by gear, time, and location restrictions, often in combination with daily catch limits per license holder. This is not an ITQ (individually transferable quota) fishery, and limited entry does not apply. The seasonal fishery or location specific fisheries often effectively close before the season ends because of declining catch per unit effort, decreased daily income per participant, and options to move into other seasonal fisheries.

The resultant data underscore remaining difficulties in oyster fishery management. Even with a cumulative 30+years of age-structured demographic data there is no clear description of a predictive stock-recruit relationship in extant Virginia oyster populations. This is not a new conclusion: both the late Jay Andrews and Dexter Haven commented on the recruitment of oysters in Virginia estuaries decades ago and made similar statements.

Managing the shell base in relation to the fishery

The practice of adding shell as either a base for general maintenance of an exploited reef or for specific collection of "seed" prior to its relocation and grow out has a history of over 100 years in the Chesapeake Bay and further afield. Managing shell is central to the management of a fished resource. The current assessment protocols provide some guidance in this process. The general passage of shell is described in Figure 3.

Figure 3: The sources and fates of shell

Recruitment adds to the benthos
⇓
Live oyster shell "pool"(increased by growth, lost by harvest as seed or market product)
⇓
mortality
⇓
Brown oyster shell (oxic, above sediment water interface *subject to loss by biologicalactivity such as borers and endolithic algae, possibly microbial processes, and chemical processes*)
⇓
initial burial / sedimentation
⇓
Brown shell (oxic, below sediment water interface, *loss to neutralization of acids from organic sedimentation into the benthos, biological destruction continues*)
⇓
continued burial / sedimentation – mostly burial
⇓
Black shell (anoxic, *more chemically-mediated loss*)
⇓
continued burial
⇓
Black shell, sub-fossil, not taphonomically active regions

Management of shell for fishery purposes is concerned with the live through brown components as harvestable product or recruitment substrate. The black shell is important as a structural substrate for fished regions. By contrast, restoration ecology is about all of the components listed above, and should be able to quantify them, and the rates of passage of the transitions described by the arrows and processes in italics.

For fishery management the focus is on the live through brown shell components. From the live demographic over a multiple year sequence it is possible to calculate addition of shell to the habitat from mortality on an age-specific basis. This requires a few additional steps for the location, e.g., specific length, age, biomass, and shell weight analyses described earlier. Required are shell length-to-shell volume descriptors. These are not arduous to collect – the methods are given in Mann et al. (2009a). The limitations for the current survey protocols are the single assessment annually and the fact that mortality is a single number from a subtraction exercise: the number in a year class in year *t* minus the number in that (year class +1) in year (*t*+1). The time course of mortality over the intervening period is not known, so the options for estimating shell addition are high and low estimates of individual contribution for each age class – the boundaries being for mortality immediately after a survey and before the subsequent survey. Again, the details are given in Mann et al. (2009a). The shell budget then becomes an accounting exercise where running yearly budgets are constructed from (1) shell base in year t_o based on assessment, plus (ii) addition to the shell base by mortality, plus (iii) addition to the shell base by repletion, minus (iv) shell loss to harvest as seed and/or market oysters. In theory this should give the shell base in year (*t*+1). It does not because of the loss processes associated with the arrows in Figure 3. An informative exercise is to calculate such budgets for extended time frames and compare them to known management actions in that time period. Table 1 is such as exercise for eight reefs in the Piankatank River (Ginney Point, Palace Bar, Bland Point, Stove Point, Hero Point, Cape Toon, Burton Point #1, and Burton Point#2) for the period 1999-2009 (data extracted and modified from Harding et al. in review).

Table 1. A shell budget for the Piankatank River 1999-2009. Expected shell is observed value at year t_o + addition from mortality + addition from repletion - seed harvest - observed value at year (t+1). All values are in L. Total reef area is 719,600 m^2 or 178 acres. Observed/expected ratio gives barometer of loss rate per unit shell. *Negative values, in italics, are increases in the overall result and occur from shell addition by repletion activity*. Losses are estimated in bushels and bushel/acre for the entire system.

Year	Expected value: no loss	Observed value	Calculated loss	Observed /expected	Loss (bu.)	bu./acre loss
1999	1.40E+07	6.04E+06	7.96E+06	0.57	159,269	895
2000	7.29E+06	6.97E+06	3.21E+05	0.04	6,418	36
2001	9.35E+06	8.47E+06	8.79E+05	0.09	17,578	99
2002	9.17E+06	1.22E+07	*-3.07E+06*	*-0.33*	*-61,394*	*-345*
2003	1.43E+07	8.14E+06	6.19E+06	0.43	123,733	696
2004	1.18E+07	6.36E+06	5.49E+06	0.46	109,777	617
2005	9.52E+06	6.19E+06	3.33E+06	0.35	66,558	374
2006	7.15E+06	7.39E+06	*-2.45E+05*	*-0.03*	*-4,891*	*-27*
2007	7.89E+06	7.92E+06	*-3.67E+04*	*0.00*	*-735*	*-4*
2008	1.06E+07	8.52E+06	2.13E+06	0.20	42,522	239
2009	1.48E+07	9.35E+06	5.46E+06	0.37	109,127	614
Mean	1.05E+07	7.96E+06	2.58E+06	0.24	51,633	290

The end point of shell budgeting is that about one bushel of seed is recovered for every four or five bushels of shell planted. The above budgeting exercise is a long-term management tool where the underlying goal is too stabilize the shell base for harvest. This is not a restoration exercise. Restoration requires additional information.

Data needs for oyster restoration – it's actually about a biogenic carbonate budget

To base the success or failure of an oyster restoration project on the presence or abundance of oysters alone is inadequate. Oysters are not the litmus test for restoration; sustainable habitat is. The experiment wherein "habitat" is provided for oysters with their subsequent recruitment being assured has been repeated for at least 2000 years in many places and on literally thousands of occasions (and it has been used for other species, see Kraeuter et al. 2003). If habitat (=substrate) is provided oysters will recruit. But this is not restoration; a self-sustaining population over multiple generations is restoration. Indeed the latest draft of the Chesapeake Bay Executive Order (E.O.) implementation emphasizes self-sustaining. This goal is not negotiable. To date the record shows that the initial recruitment events do not result in self-sustaining populations over multiple generations. Why? Because the practices do not sustain habitat. Mann and Powell (2007) address this issue and argue that there is only modest need for oysters to produce "surplus habitat" over evolutionary time to maintain their status as species central to the ecology of temperate and subtropical estuaries and coastal embayments. Again, the issue is not restoration of oysters, it is restoration of self-sustaining habitat – and we should be measuring that habitat. With the latter the oysters will thrive, without it the initial pulse of recruitment is not sustained over many years and the local population dies. In fact we should not be arguing to support oysters because they are just a small part of larger issue, and that issue is the development and sustenance of a positive biogenic carbonate budget in estuaries and coastal embayments. To date not a single restoration project has done this well, and none has it in its planning prospectus. Two proposals have been submitted to construct the framework of a carbonate budget for parts of the Chesapeake Bay based on extant data and additional experimental work. A third proposal is in the writing stage to develop comprehensive budgets for selected Gulf of Mexico bays. The current Virginia stock assessment effort as described earlier has a component that focuses on the development of shell budget models and their application in managing repletion efforts. The graphic provided earlier (Fig. 3) on sources and fates of shell can be examined as a series of equilibrium pools for fishery management, but the shell management approach does not address the absolute rates of shell production that are required to meet equilibrium with yardsticks set by evolution – namely sea level rise, base subsidence, salinity related shell loss, and site-specific sedimentation rates acting in concert. Before addressing the details of the shell budgeting process, it is important to adequately describe the importance of the biogenic carbonate budget as the larger controlling issue in estuarine and coastal ecosystem biology.

Biogenic carbonate is central to the ecology of the vast majority of targeted invertebrate and vertebrate species that support fisheries in the Chesapeake Bay, and in indeed estuarine and shelf species in general. While the subject of biogenic carbonate in the Chesapeake Bay might superficially appear to be "just an oyster and clam problem", and indeed existing oyster (*Crassostrea virginica*) and clam (*Mercenaria mercenaria*) stock assessment data are being used by the author to construct the first “draft” of such a budget, the impact of carbonate abundance on the biota of the Bay encompasses affects all trophic levels. Biogenic carbonate is the only significant source of hard substrate in temperate sedimentary estuaries in the northern hemisphere (see Milliman 1975, and any geological survey map of the Atlantic coastline as an example). The rare exceptions are rocky outcrops that, on the Atlantic coastline, are absent south of Long Island, NY. In the Chesapeake Bay, above the sediment water interface, biogenic carbonate is the structure of oyster reefs. It is seminal to the perpetuation of such reefs for fishery production (DeAlteris 1988, Powell et al. 2006) and ecological services (Officer at al. 1982, Hargis and Haven 1999, Harding and Mann 1999, 2001, Coen and Luckenbach 2000, Peterson et al. 2003), the latter including positive contributions to the ecology of many, if not the vast majority, of commercially exploited finfish and crabs, and through its impact on water quality and the reduction of open water fetch, the ecology of sea grasses (see reef distribution for example in Moore 1907). Below the sediment water interface biogenic carbonate, originating from the mortality and burial of oyster (*C. virginica*) shells and the mortality of molluscan infauna (*M. mercenaria, Macoma balthica* as examples), is central to neutralization of acids produced by the continual rain of organic material to the benthos (obviously exacerbated in eutrophic conditions) and the delineation of the redox depth (Davies et al. 1989, Walker 2001). In short, biogenic carbonate input to the benthos arguably dictates the quality of the infaunal habitat, diversity and density of the resident infauna, and through this, food resources to commercially valuable species higher in the food chain. Knowledge of the biogenic carbonate budget can quantitatively define the probability of maintenance of epifaunal habitat – that is where oyster restoration is and is not sustainable – and provide quantitative estimates of the sustainability of critical Essential Fish Habitat (EFH, Benaka 1999 and contributions therein) for any species with trophic connections to benthic infauna. The bottom line is that oysters are a very small part of the restoration evaluation, and conclusions based on oyster population data alone are inadequate. In addition, the need for carbonate flux to and into the benthos underscores that we must discount both the impact of aquaculture, that removes carbonate at harvest, and efforts based on artificial substrates, that do not extend the carbonate footprint either into the substrate or laterally over the substrate, in the context of long term restoration.

If biogenic carbonate is so important why have we, as a community interested in both fishery management and restoration ecology, not examined it before? Because we are myopic and narrow minded, often trained linearly rather than laterally, and function poorly outside of our individual comfort zones. Stock assessment and the fishery management process that it supports has historically been dominated by single species plans that focus on traditionally defined, species-specific attributes such as recruitment, age-at-length, mortality, and so forth (see the earlier discussion). The importance of a multi-species approach has gained increasing support over the past decade. Multi-species approaches are difficult, even more so when quantitative aspects of habitat are considered. The EFH concept is valuable in this respect, but in any sedimentary estuary in the northern hemisphere, any hard substrate that contributes to EFH as either physical habitat for target species (singular or plural) or supports trophic levels that are food for the target species (singular or plural) is probably biogenic carbonate (Milliman 1975, Gutierrez et al. 2003). So an examination of this quantity in support of both broad-based EFH and targeted oyster and clam management efforts would appear both prudent and long overdue. Restoration efforts have all but ignored the dynamics of the substrate, especially the chemistry of the buried portion, and been driven by time frames of funding cycles that are simply unreasonably short in terms of any effort reaching equilibrium state.

Protocols for Restoration Evaluation

The base data needs include all that is required for stock assessment, plus that required for shell budget accounting as described earlier. In addition there are needs for defining base shell accretion rate and environmentally driven shell loss rate. When all are known a habitat budget that addresses the aforementioned self-sustaining yardstick can be developed. It cannot be developed beforehand. No current oyster restoration plan includes such a prospectus.

What is an appropriate base requirement for accretion rate? Answer, the rate of sea level rise. This is set by the evolutionary ecology of oysters. Oysters invade estuaries; ephemeral features over evolutionary and geological time, then go locally extinct as sea level falls with the next ice age. The lateral migrations of oysters over the footprint currently occupied by the 10,000-year-old Chesapeake Bay are a good example. So what is the maximum rate of sea level rise encountered by oysters over their 50 million years or so in the fossil record? The current rise rate is about maximum for that period. The actual rate of relative sea level rise (that which accommodates both sea level rise and land subsidence) is location-specific, but on a transect from the Florida Keys to Hudson Bay the maximum value is at the mouth of the Chesapeake Bay (Zhang et al. 2004) at approximately 3.5 mm y^{-1}. This corresponds well with the report of Pyke et al. (2008). But an accretion rate equivalent to 3.5 mm y^{-1} will not maintain a reef structure with sea level rise because that portion of it exposed to chemical and biological degradation process (see Figure 3) will lose shell. There are a number of recent reports of shell loss rates in oyster shell in estuaries (Powell et al. 2006; Powell and Klinck 2007; Mann et al. 2009a). These suggest annual loss rates on the order of 30% of the actively available (for degradation) shell per year. The rate is salinity dependent (see Powell et al. 2006) but for mid to high salinities in the Chesapeake Bay, Mann et al. (2009b) use a value of 30% y^{-1}. When combined with a 3.5 mm y^{-1} sea level rise rate this results in an accretion requirement for equilibrium of (3.5 x 1.3 = 4.55 mm y^{-1}). This number will decrease where relative sea level rise is lower, such as in the upper parts of the Chesapeake Bay towards Maryland where subsidence is also lower, and where salinity is lower. Nonetheless this is a suitable benchmark for restoration efforts to be compared against. A note is important here concerning the time frame for shell to become buried in the gradation illustrated in Figure 3. As the shell is gradually submerged by natural deposition it reaches a depth below the taphonomically-active zone. The time frame of this process is complicated, and there is a need to identify both depth of burial and time frame to immunity of loss in that both natural sedimentation processes (note these are distinct from biodeposition processes) are site-specific, but in the Chesapeake Bay are less than 1 mm y^{-1}, and biodeposition processes that are population-dependent. Abbe (1998) addresses these for thick shell plants in Maryland, very much like those currently deployed in the Virginia portion of the Bay as restoration bases, and his data for recruitment over time post deployment (arguably a good proxy for occlusion of open space within the shell matrix) match the time course of years for degradation of recruitment signals in many long term reef construction projects in Virginia.

It is possible to convert the previously defined base accretion rate of 4.55 mm y^{-1} to an area-specific production rate. This has been described in Mann et al. (2009b), and the population demographics offered therein provide a base against which restoration efforts can arguably be compared for long-term, self-sustaining goals. The conversion functions used in this exercise may be open to debate and modification on a site-specific basis, but the structure of the argument is sound, has passed a critical peer review, and provides a basis for future planning. Anything less is, I argue, not self-sustaining. As I have presented this thesis in recent months, counter arguments have been offered that the accretion rate commensurate with sea level rise is too high because oysters thrive subtidally. I respond that this counter argument is wrong. The life history strategy of the oyster has been successful over geological time frames because they accrete vertically – it is the geological time frame here that is important. Oysters do survive on the subtidal periphery of reefs, but it is the ability to survive intertidally that creates a predation refuge for oysters – and why would oysters have evolved such a complex and extraordinarily successful physiology if they had not been selected to survive in the intertidal? Simply because oysters have been mined to their subtidal current status over centuries in the Chesapeake Bay is not an argument for their optimal survival in the subtidal. The multitude of maps depicting the Chesapeake Bay since the early 1600's bear witness to a thriving oyster population in intertidal locations.

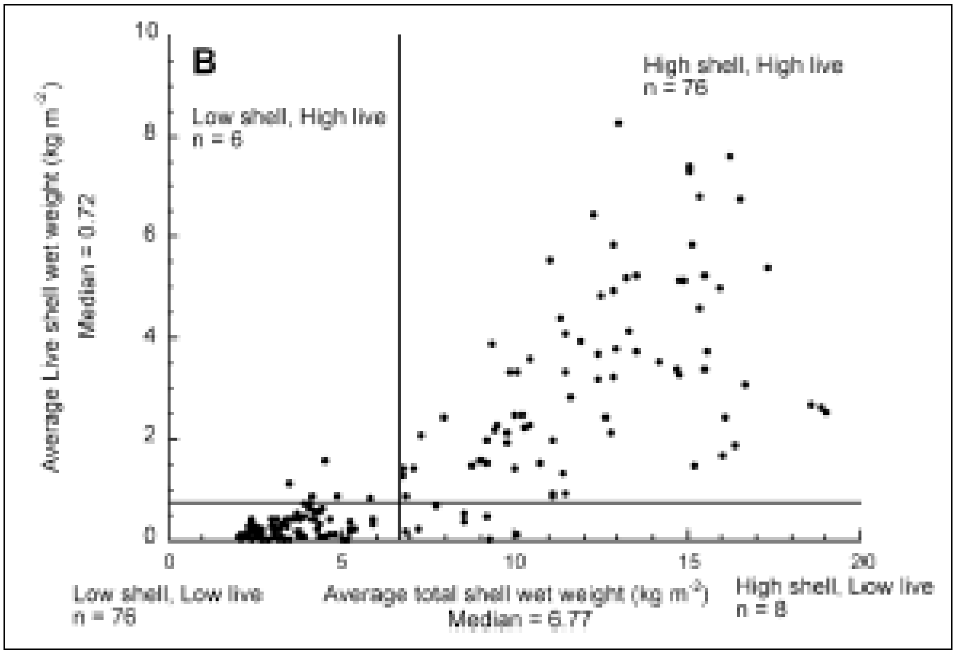
The demographics presented in Mann et al. (2009b) underscore the importance of any measurements of success in restoration being placed in time frames of multiple generations of oysters. Anything less is not defensible. This creates a considerable challenge for programs funded on the basis of instant results and instant gratitude – so be it, some elements of biology will never submit to such time restrictions. Proclamations of short-term success place a speaker in jeopardy of having to retract those statements simply because the time series of observations cannot support the E.O.-required standard of self-sustaining.

So given the complexity of the **equilibrium processes** in Figure 3 and the need to consider **absolute rates** of shell production, what assessment methods can be used to examine progress towards a self-sustaining mode in a restoration project? I argue that an appropriate method is the plot of live shell versus whole shell proffered in Figure 12B in Mann et al. (2009a) for the James River, included here as Figure 4 – and here I gratefully acknowledge my colleague Prof. Eric Powell at Rutgers University for a tutorial focusing on the use of time of passage plots and transition probabilities based on a paper by Rothschild and Mullen (1985). The plot in Figure 4 incorporates both the equilibrium aspects of Figure 3 and the shell production aspects of the 4.55 mm y^{-1} equilibrium rate. The data are for the James River - a system that is not subject to restoration activity but **IS** stale over extended periods in terms of accretion balanced against loss (hence its persistence – the goal of a restored reef). The plot is divided into four quadrants by median values. The bottom left quadrant is low live and low total shell, a degraded but temporally stable state. The upper left quadrant (high live shell with low total shell) and lower right quadrant (low live shell and high total shell) are both temporally unstable. The first is high recruitment on a failing or inadequate shell base, the latter is post-epizootic. The upper right quadrant is high live and high shell, a balanced system commensurate with Figure 3. The distribution of the James River data within the plot is very important – the points exist on a cline between the two stable states with 152 of the total 166 points in these quadrants. There are almost no transitions between quadrants if the individual time series are plotted from a single location. It is not difficult to generate plots on the same axes as Figure 4 for restoration sites, but the process requires time – preferably time periods of multiple generations. Note that the James

River plot in Figure 4 is just that, a multiple generation plot where the underlying base, equivalent to the black shell elements in Figure 3, have remained comparatively undisturbed because gear is limited to hand tongs.

The plot in Figure 4 does not provide rate measurements for the individual biological and chemical degradation processes included in Figure 3. It simply provides the integrated end product, so work remains. The integrated end product is, however, one of the most complete evaluations, for which there is a library of comparative products from stable extant systems, for use in restoration. Unlike oyster abundance data alone it does address the larger questions of biogenic carbonate budgets.

Figure 4: An example of a quadrant plot of live shell per unit area versus total shell per unit area for individual reefs in a river system over a multi-year period: James River 1998-2006. Note the distribution of data and its limitation to stable quadrants.



The way forward.

To date we have developed a fishery-independent stock assessment protocol for the Virginia oyster resource that describes trends in that population adequately for responsible management. The protocol provides information adequate to develop a balanced shell budgeting strategy for habitat management in support of the fishery. It does not address all of the desired data required for development of a biogenic carbonate budget, the argued objective for adequate evaluation of long-term, self-sustaining restoration. Nonetheless, the data collection does allow the construction of live shell:total shell plots that are informative with respect to stability of the biogenic carbonate budget components.

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Appendix 2. Lipcius et al. Monitoring Protocol

Accuracy and precision of habitat-specific abundance estimates in native oyster restoration

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ABSTRACT: Restoration of species and habitats requires assessment methods that are statistically and ecologically credible. Oftentimes assessment encompasses qualitatively different habitats that determine the abundance and distribution of populations, and which should therefore be treated as different strata when estimating density and abundance. Yet in many cases different habitat types are either not quantified or treated as different strata, often due to logistical or financial limitations. This approach can produce inaccurate (biased) and imprecise abundance estimates that at the least hinder effective conservation or restoration, and at worst lead to failure. We illustrate the methods and benefits of statistically and ecologically rigorous estimation of abundance with an example from assessment of the effectiveness of native oyster reef restoration in the Great Wicomico River, a subestuary of Chesapeake Bay.

OVERVIEW OF ASSESSMENT METHODOLOGY

An accurate (i.e. unbiased) and precise (i.e. low variance) estimate of abundance in native oyster reef restoration requires several elements. These are not the characteristics of a successful restoration effort, but merely of the assessment methodology. Our example derives from a field experiment (Schulte et al. 2009) dealing with restoration of native oyster reefs in the Great Wicomico River, a tributary on the western shore of Chesapeake Bay (Fig. 1).

Pre-Construction Sampling and Construction:

1. Prior to construction, sample nominal restoration sites, including biotic and physical characteristics, using stratified random sampling with sample allocation by reef area.
2. Construct restoration reefs (Fig. 2).

Post-Construction Mapping, Video and Sampling:

3. Map reef extent with side-scan sonar (Fig. 2).
4. Verify reef features (e.g. high or low relief) with ROV video (Fig. 3).
5. Apportion reef types into strata (e.g. high-relief reef, low-relief reef, unrestored bottom) using information from #3 (Fig. 4).
6. Generate a grid of all possible sampling sites in each stratum (Fig. 5).
7. Sample a subset of random sites in each stratum to generate variance estimates for the full survey. Variance estimates may also be derived from the literature, when available.
8. Generate random, stratum-specific nominal sampling sites and backup sites, using stratified random sampling with sample allocation by stratum/reef area and inversely proportional to stratum/reef variance and stratum cost.

Stratified Random Survey:

9. Locate a sampling site by GPS coordinates. The sampling sites should be sampled in the order in which they were generated according to the random number site generator.
10. Anchor the vessel (e.g. local waterman) with triple anchors to maintain position.
11. Deploy the ROV to film the physical and biotic characteristics of the sampling site. The ROV can be retrieved or remain on the bottom to film the sampling event.
12. Deploy the patent tong (1 m wide) and retrieve the sample on a processing table aboard the vessel. Take a photo of the sample with its ID visible on a whiteboard.
13. Rinse and bag a complete 0.5 m section (i.e. ½ of the 1 m tong sample) for lab processing.
14. Process samples in the laboratory. Measure and count all live and dead oysters.
15. Measure volume of all live oysters and their attached shell in a graduated cylinder to estimate accreted reef volume.
16. Take any other measurements, such as numbers of fouling organisms, and record observations.

Estimation of Sampling Efficiency:

17. Steps 9-10 are repeated for a new random site.
18. Deploy the efficiency frame, which maintains position of the patent tong within a 1-m^2 sampling area.
19. Deploy the ROV to film the physical and biotic characteristics of the sampling site, and the sampling event. The ROV remains on the bottom for the duration of the sampling event.

20. Deploy the patent tong and retrieve the sample on a processing table aboard the vessel. Take a photo of the sample with its ID visible on a whiteboard.
21. Rinse and bag a complete 0.5 m section (i.e. ½ of the 1 m tong sample) for lab processing.
22. Rinse and bag the remainder of the sample for lab processing.
23. Repeat steps 20-22 until no live oysters are retrieved in the sample, which usually takes 3-4 patent tong deployments.
24. Pilot the ROV into the sampling area to film the sampling area and verify complete sampling of live oysters.
25. Repeat steps 17-24 at a subset of sites from each stratum.
26. To estimate efficiency, divide the number of live oysters in the initial 0.5-m^2 sample by the total number of oysters in all samples at each site.

Calculation of Density, Abundance and Variance:

27. Parameter estimates are obtained using the *R* statistics package (www.r-project.org).

LITERATURE CITED

Schulte, D.M., R.P. Burke and R.N. Lipcius. 2009. Unprecedented restoration of a native oyster metapopulation. **Science** 325: 1124-1128.

FIGURE LEGENDS

Figure 1. Satellite Landsat photo of the Great Wicomico River, a western shore tributary of Chesapeake Bay.

Figure 2. Native oyster restoration reefs in the Great Wicomico River. Baylor polygons (black lines) demarcate historical oyster reef habitat. Red areas are high-relief reef, whereas grey areas are low-relief reef, as determined by a side-scan sonar survey shortly after reef construction in 2004.

Figure 3. ROV photos of (A) high-relief reef, (B) low-relief reef, and (C) unrestored bottom.

Figure 4. Layout of one of the native oyster restoration reefs. Baylor polygons (black lines); high-relief reefs (red); low-relief reefs (grey). Yellow triangles represent one realization of a set of 10 Simple Random Sampling locations within the Baylor polygon. Of the 10 points, two are on high-relief reef, three on low-relief reef, and five on unrestored bottom. This allocation of the 10 points is approximately equal to the area of each of the three habitat types (high-relief reef, low-relief reef, unrestored bottom) in the polygon. Note that 50% of the points missed the reefs and fell on unrestored bottom.

Figure 5. Example of the grid system overlaid on the sampling area, and from which sampling points were selected randomly.

Figure 1

Figure 2

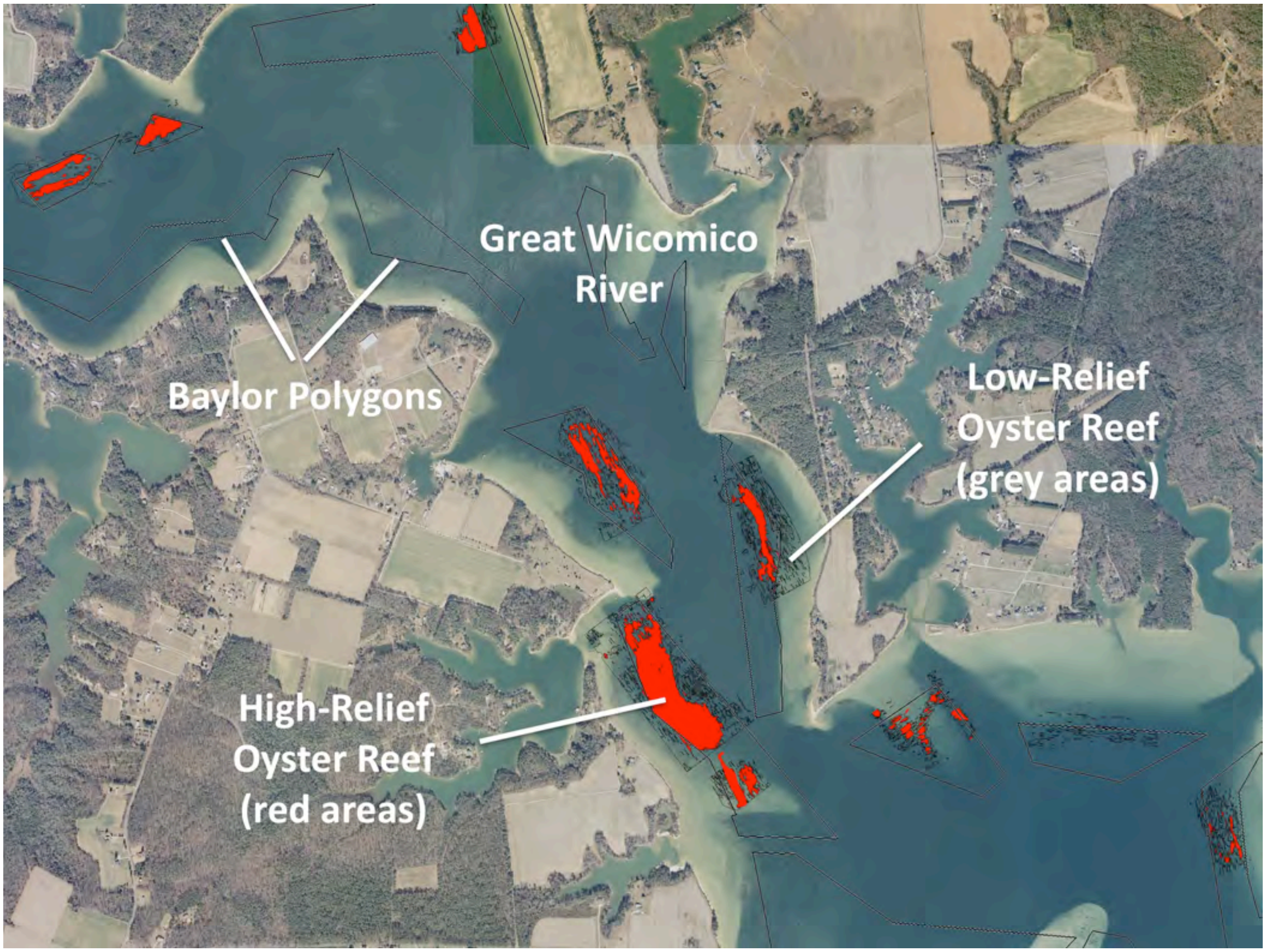

Great Wicomico River
Baylor Polygons
Low-Relief Oyster Reef (grey areas)
High-Relief Oyster Reef (red areas)

Figure 3

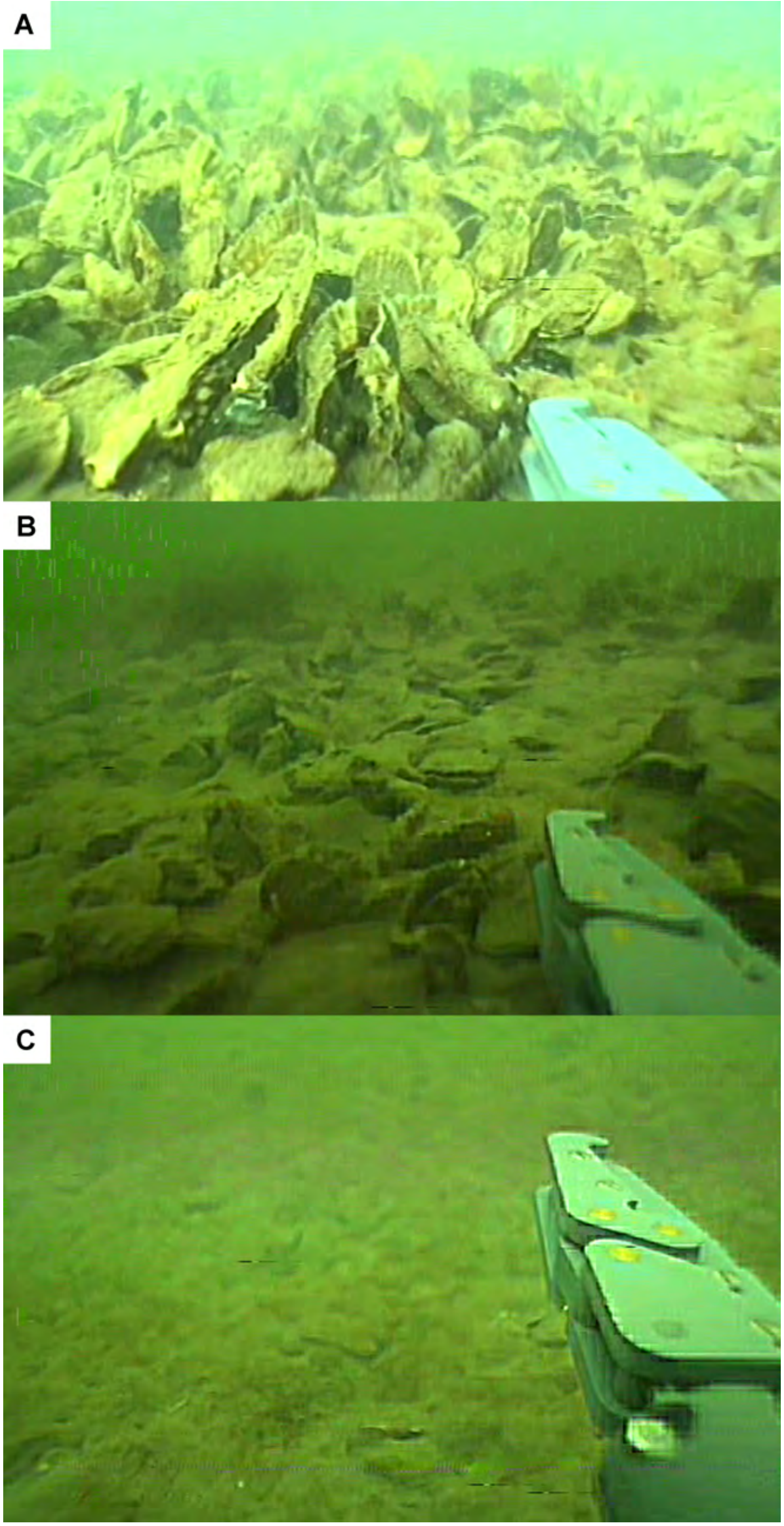


Figure 4

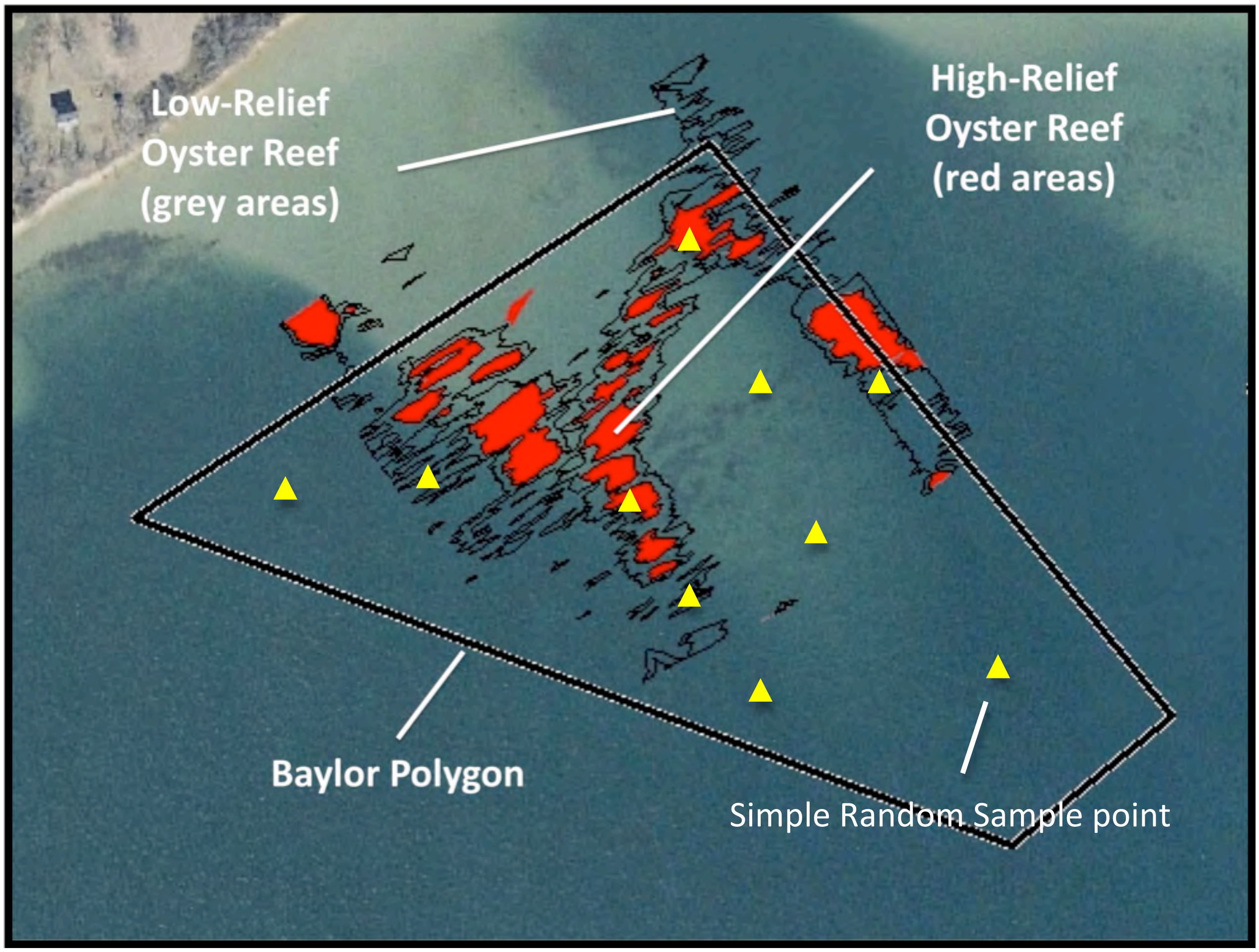
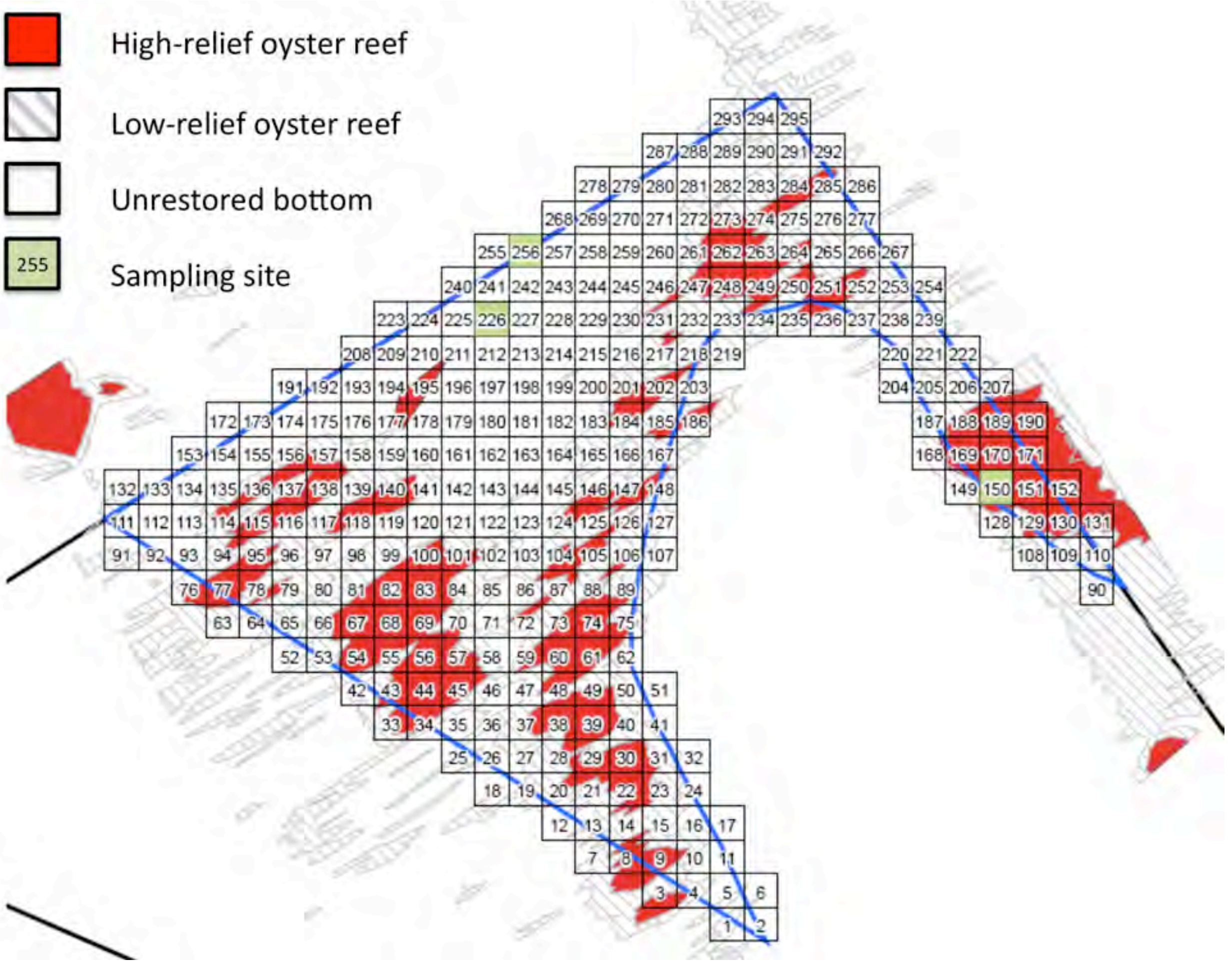

Low-Relief
Oyster Reef
(grey areas)
High-Relief
Oyster Reef
(red areas)
Baylor Polygon
Simple Random Sample point

Figure 5


High-relief oyster reef
Low-relief oyster reef
Unrestored bottom
255
Sampling site

Appendix 3. A Description of Sampling Techniques and Resulting Population Estimates for Native Oyster Restoration

NOAA Oyster Restoration Workshop Summary:

Accuracy and precision of density and abundance estimates in native oyster restoration

Romuald N. Lipcius and John M. Hoenig

Virginia Institute of Marine Science, The College of William and Mary, Gloucester Point, VA

We evaluated the accuracy and precision of abundance and density estimates from two types of surveys on restoration oyster reefs constructed within several polygons in the Great Wicomico River because it has become necessary to determine which of the two surveys is most efficient and accurate. The ultimate goal is to estimate abundance and density on actual constructed reefs. Constructed reefs were meant to fill each of the polygons completely, but in reality the actual constructed reefs only filled portions of each of the polygons due to logistical difficulties encountered by the subcontractor who built the reefs. In addition, two types of reef were constructed: low-relief and high-relief reefs. We compared two survey designs, one that sampled only the parts of each polygon that contained actual constructed reef with optimal allocation to strata defined by reef type (Survey A), and another that sampled each of the polygons with simple random sampling (Survey B). Moreover, we made two assumptions about the simple random sampling, one where it was assumed that the constructed reefs did not fill each polygon (Survey B1) and a second where it was assumed that the constructed reefs did fill each polygon completely when in reality the reefs did not fill each polygon (Survey B2). Survey A is accurate (i.e., unbiased) because it samples only the area where reef material was placed, as determined by side-scan sonar imagery and ROV video. Survey A yields the most precise estimates because samples are allocated proportional to area and variance of each stratum. Survey B1 is accurate because it can eliminate from sample estimates those portions of the polygons where reef material was not placed, but it can be highly imprecise and inefficient because too many samples are allocated to unrestored bottom where reefs were not constructed. Survey B2 is inaccurate (i.e., biased) because it samples areas where oyster reef was not constructed and includes these areas in the estimate of density on reefs, thereby producing artificially low estimates of density and abundance. Survey B2 is also imprecise and inefficient because samples are allocated to portions of each polygon where oyster reef was not constructed. The most efficient and accurate sampling design is Survey A for oyster reef restoration monitoring, when accompanied by estimates of gear efficiency. Assessment of restoration efforts that encompass qualitatively different habitats requires accurate post-restoration delineation of habitat strata. Moreover, to estimate density and abundance accurately and precisely, the strata should be sampled proportional to habitat-specific area and variance, and the gear efficiency determined. When these sampling standards are not met, density or abundance estimates may be inaccurate (i.e., biased) or imprecise.

Appendix 4. NCBO Benthic Assessment Protocol

Acoustic Seabed Mapping in the Great Wicomico River 2009
Habitat Assessment Team
NOAA Chesapeake Bay Office

David Bruce, Jay Lazar, Steve Giordano

March 2010

Note: This report has been slightly revised
by K. Sellner on May 19, 2010, inserting figures,
tables, a few sentences, and several captions from
a S. Giordano presentation made at the VA Oyster

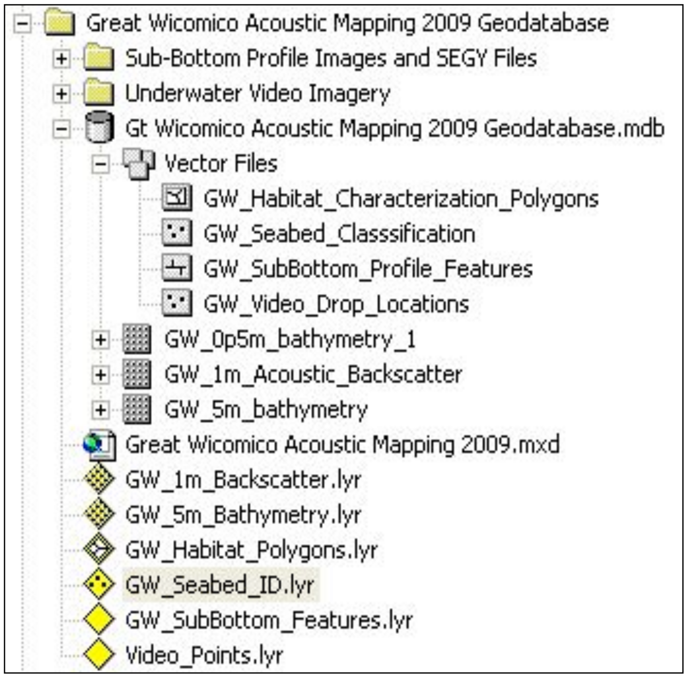
Restoration Monitoring Workshop of 3/31/10.

Background

In early 2009 the NOAA Habitat Restoration Center requested that the NOAA Chesapeake Bay Office Habitat Assessment Team characterize and map benthic habitats in the Great Wicomico River, VA. The spatially explicit benthic data collected is being used to monitor and ultimately assess the status of NOAA restoration activities that have occurred in the system during the past decade. In October 2009 acoustic seafloor mapping systems were used to survey the broad-scale distribution of benthic features at high resolution (1m x 1m). In December an underwater video camera system was deployed to characterize fine scale benthic conditions at selected sites. This document describes the spatial data products created from the acoustic and video data and provides examples of the features identified.

Methods

Dataset Descriptions The spatial datasets referenced in this document include raster grids of acoustic backscatter, coarse to high resolutions of tide corrected phase differenced bathymetry (5m to 0.5m), benthic habitat polygons, point data of single-beam acoustic seabed classification and underwater video drops with derived attributes. Acoustic mapping data and ground truth points are available in an ESRI GeoDatabase format. All associated data is in a file directory titled: Great Wicomico Acoustic Mapping 2009 GeoDatabase (Figure 1) in ESRI ArcGIS format. Spatial data is projected into the UTM NAD83 Zone 18 North Meters coordinate system unless otherwise noted in the filename.



- Great Wicomico Acoustic Mapping 2009 Geodatabase
  - Sub-Bottom Profile Images and SEGY Files
  - Underwater Video Imagery
  - Gt Wicomico Acoustic Mapping 2009 Geodatabase.mdb
    - Vector Files
      - GW_Habitat_Characterization_Polygons
      - GW_Seabed_Classsification
      - GW_SubBottom_Profile_Features
      - GW_Video_Drop_Locations
    - GW_0p5m_bathymetry_1
    - GW_1m_Acoustic_Backscatter
    - GW_5m_bathymetry
  - Great Wicomico Acoustic Mapping 2009.mxd
  - GW_1m_Backscatter.lyr
  - GW_5m_Bathymetry.lyr
  - GW_Habitat_Polygons.lyr
  - GW_Seabed_ID.lyr
  - GW_SubBottom_Features.lyr
  - Video_Points.lyr

Figure 1. Data tree of mapping products.

Data Acquisition

Acoustic data were collected between 27 October and 5 November 2009 on the NOAA Research Vessel LOOKDOWN (F2707). A Trimble DSM232 GPS provided differential corrections to the Applanix POSMV Wavemaster GNSS Aided Inertial Navigation System. The POSMV provides an accurate reference for attitude, heading, heave, position, and velocity. The POSMV records all raw positioning data for post processing to better than decimeter accuracy. A Teledyne Benthos C3D Side Scan Bathymetric Sonar (SSBS) system was used to collect sidescan sonar and phase-differenced bathymetry data at 200 kHz. Sound velocity variations at the sonar head were recorded with a Falmouth Scientific Incorporated NXIC-CTD. Sound velocity profiles were collected every four hours with a Seabird Electronics Seacat SBE19plus CTD. Single- beam seabed classification data was collected with the ROXANN Groundmaster system at 200 kHz. These four sensors were integrated with Hypack Hysweep acquisition software on a central PC. Approximately 7.1 km^2 of seabed were surveyed, from the Sandy Point/Cockrell Point area upstream, to Blackwells Creek, above the Rt. 200 Bridge (Figure 1).

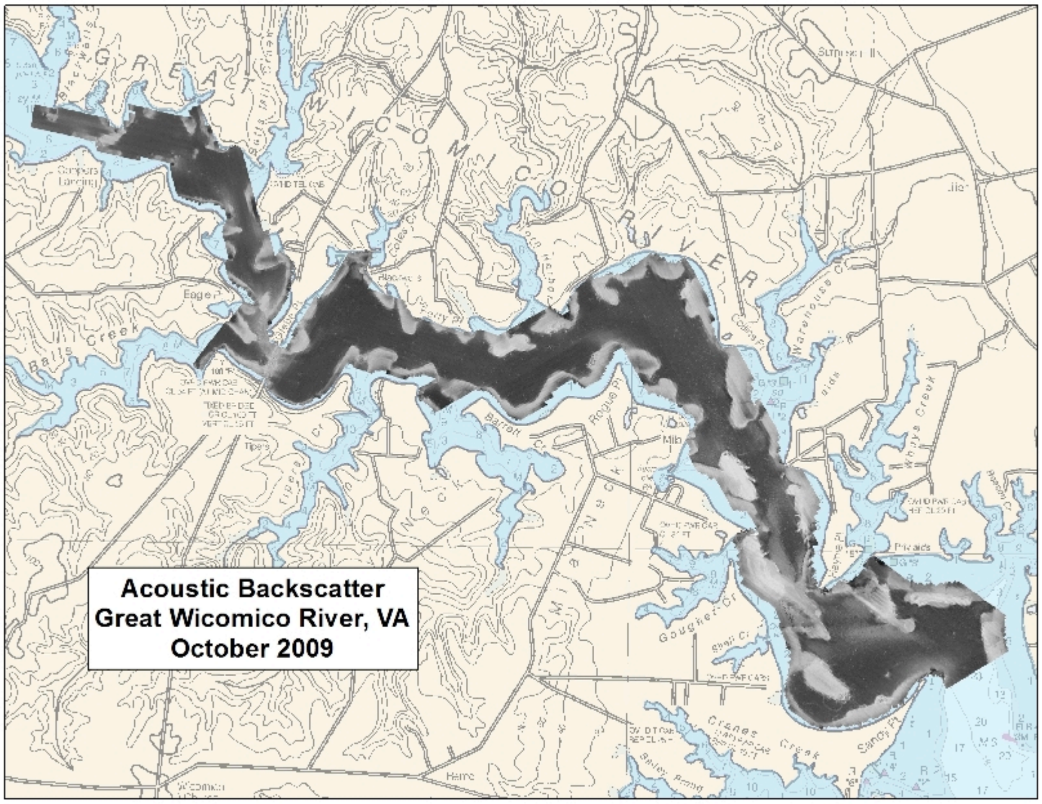


Figure 2. Extent of seabed surveys expressed by acoustic backscatter, Great Wicomico River, VA, 2009.

Range settings and line spacing varied by depth with the intent of providing complete bathymetric coverage.

Limited acoustic sub-bottom profile data were collected with a portable Edgetech 3100 and SB424 towfish that sweeps between the frequencies of 4 kHz and 24 kHz. In addition, an Edgetech 4200 high frequency (600 kHz) side scan sonar system was deployed to survey a shoal area to assess the ability of the lower frequency side scan sonar to penetrate thin veneers of sediment that result in a higher intensity return. Underwater video was collected to ground truth acoustic seabed data on 14 and 15 December 2009 with a SeaViewer^{TM} Underwater Video Systems, Inc. Sea-Drop^{TM} 950 series camera and Sea-Lite^{TM} LED light source configured on a weighted PVC frame. At each validation site, the camera array was dropped to the bottom directly below the survey vessel to collect geo-referenced close up images of the bottom. After the initial drop to the bottom, the camera array was raised a few centimeters off the bottom to collect continuous video along a transect across each site. GPS coordinates of the video samples and transect track lines were recorded in real time and integrated into the video files using the SeaViewer Sea-Trac^{TM} GPS Overlay. Waypoints were collected at intervals along the video transects to geo-reference the additional imagery with acoustic seabed data. Bottom composition information collected from the 2009 VMRC fall oyster survey patent tong samples were also used to validate the acoustics seabed data.

Data Processing

Side scan sonar backscatter data was processed with the Hypack Geocoder module from Hypack 2009 9.0 and output as a one-meter grid of x,y,intensity values in decibels. A 5 meter bathymetric grid was used in Geocoder to normalize backscatter returns for bathymetric features. POSMV GPS position and elevation data were processed in POSPAC MMS 5.3 to create a sbet and rms file for CARIS to ingest in its processing workflow. These files improve the horizontal and vertical accuracies of position data from 2m to less than 10 cm in most situations. The C3D phase-differenced bathymetry acquired in Hypack HSX format was converted in CARIS HIPS 7.0 to HDCS format. In CARIS, the data was sound velocity corrected; the POSPAC data files were loaded; Total Propagated Uncertainty (TPU) values were calculated; GPS Tide values were computed; and all sensor data were merged. Statistical Base Surfaces of depth, uncertainty, and standard deviation were calculated and displayed in CARIS to then be used for bathymetric editing. The depth base surface was output at varying resolutions as a gridded xyz ascii file. The HYPACK Seabed ID utility was used to classify single-beam data, and output format of acoustic classification data was a GIS point file. Video transects for each validation site were archived as discreet Audio Video Interleave (.avi) files. Individual frames were extracted from the video using the image capture utility of VideoLAN VLC media player Version 1.0.3 Goldeneye to closely examine and evaluate the surface character of the benthos at each sample site and are referenced in the video point data database. The contents of each still image were visually scored for: predominant acoustic feature; secondary acoustic feature; sediment type; acoustic feature cover; acoustic modifier; and sediment modifier. The geo-referenced still images are archived as jpeg files. Geo-referenced acoustic and ground truth data were layered within ESRI ArcGIS software and were used to hand digitize habitat polygons using the Habitat Digitizer extension. Habitat polygon boundaries were based on features identified in the acoustic backscatter, bathymetry, and by transitions in classified single-beam echoes. Final classification of habitat polygons was aided with the video and patent tong datasets.

Results

Acoustic Backscatter Side scan sonar backscatter provides broad-scale coverage of acoustic reflectivity (Figure 2). These data differentiate hard (light pixels) and soft (dark pixels) seabed and identify patterns in patchiness or spatial continuity. The most significant features identified by backscatter were shoals, mounds of oyster shell, and flat oyster shell plantings (Figure 3). There was abundant biological activity in the water column predominantly over soft bottom. Although biological reflectors, presumably schools of baitfish, were filtered from the bathymetry data, they could not be removed from the backscatter (Figure 4). The mosaic of

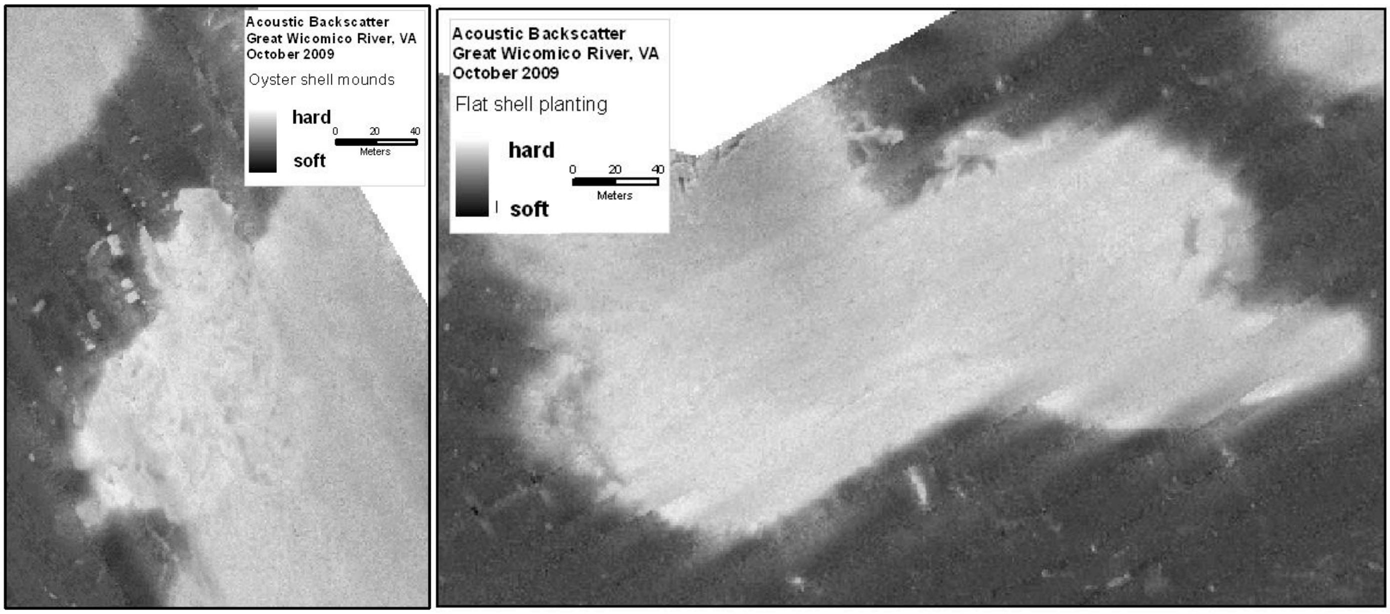


Figure 3 . Acoustic backscatter imagery of shell mounds in the vicinity of Collins Pt (left) and a shell planting in the vicinity of Horn Creek (right), both are 1.0 x 1.0 m pixel resolution.

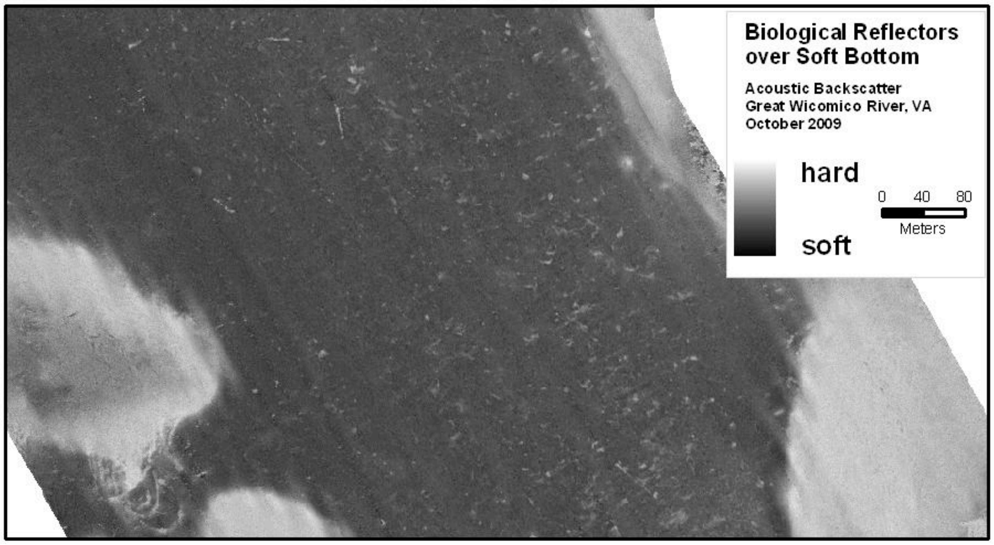


Figure 4. Biological reflectors in backscatter.

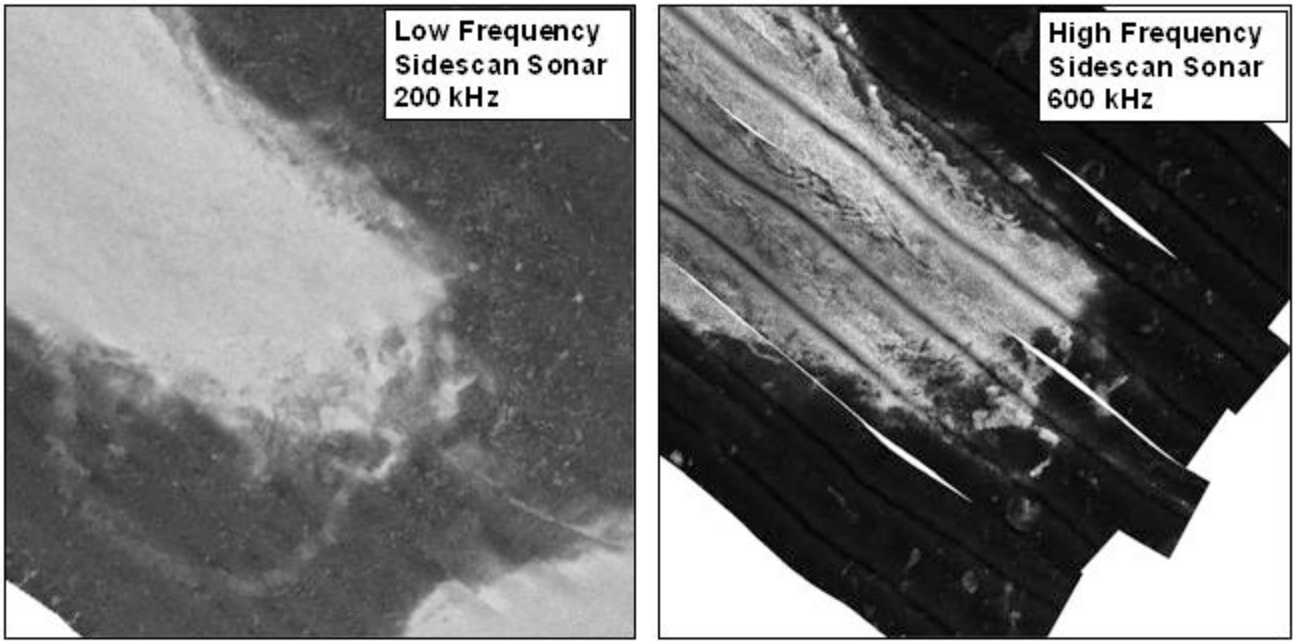


Figure 5. High and low frequency side scan sonar at Shell Bar.

backscatter data built from the C3D 200 kHz has less fidelity for feature recognition because every line collected for bathymetry was used to create the dataset. Because acoustic backscatter from side scan sonar uses a fixed range, using every line has resulted in greater than 300% overlap of data which when merged together averages the resulting data product. The byproduct of this is evident between the images in Figure 5. An attempt to limit the overlap for the final dataset is underway.

Sidescan Sonar Comparison: Low (200 kHz) vs High (600 kHz) Frequency The ability of an acoustic signal to penetrate beneath the surface of the seafloor is dependent upon the reflectivity of the surficial sediments and the frequency of the sonar. Lower frequencies penetrate further than higher frequencies. Resolution, or the ability of a system to detect features of a certain size, increases as frequency increases. The side scan sonar component of the C3D system operates at 200 kHz, a relatively low frequency for side scan sonar in shallow water using short ranges. Note that there is little spatial variability in backscatter on the oyster shell plantings in the 200 kHz backscatter (Figure 5). The high (600 kHz) frequency side scan identified striated features that appear to be oyster dredge tracks on the shell planting at Shell Bar Shoal. Also, the extent of acoustically reflective bottom (light areas) in the low frequency imagery is greater relative to the high frequency imagery, suggesting that in some areas, hard features identified by the 200 kHz C3D system may be under a layer of sediment of varying degrees of thickness.

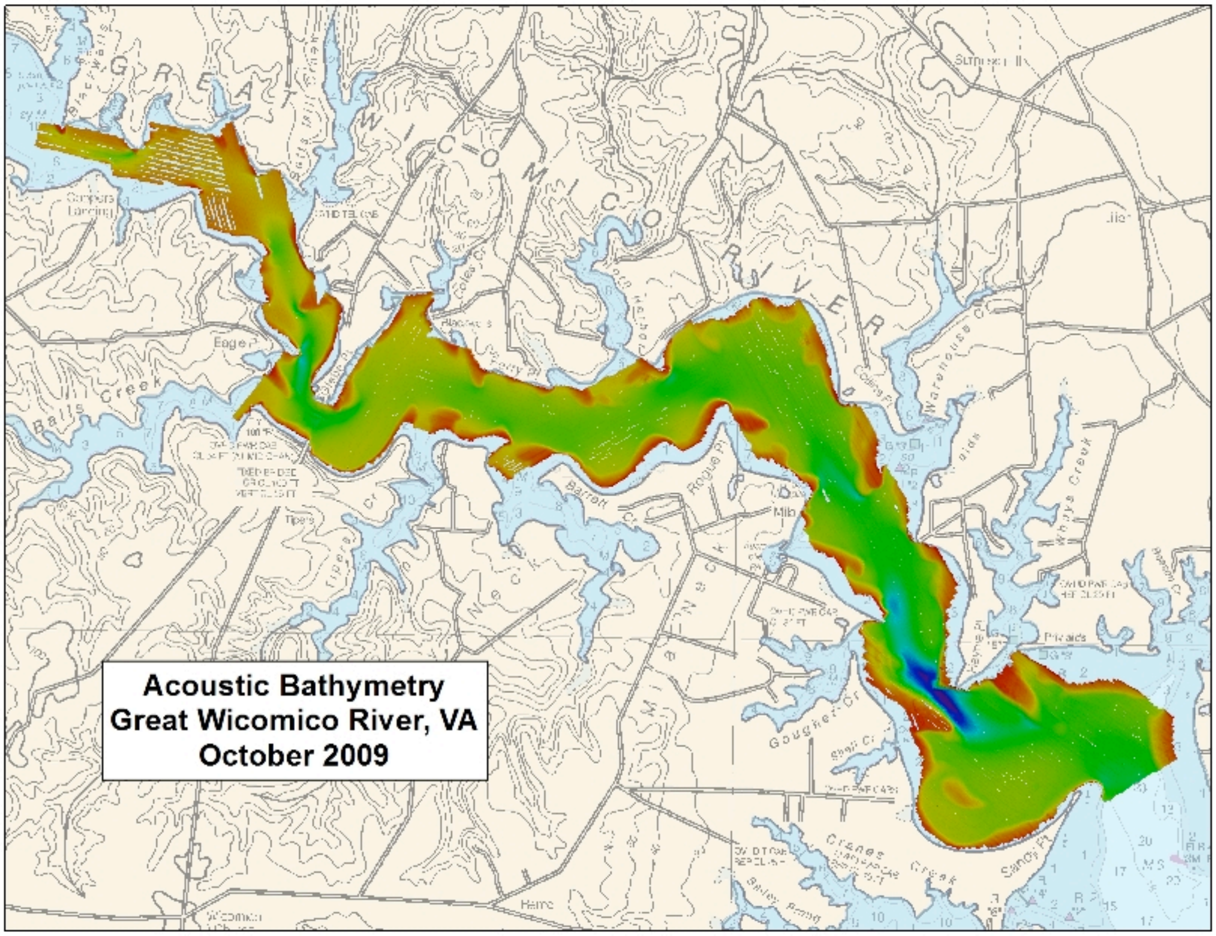


Figure 6. Bathymetry raster, Great Wicomico River, VA, 2009.

Bathymetry All bathymetric grids were generated from a statistical surface derived from the edited bathymetric data; meet charting standards; and should be considered accurate. Survey-wide bathymetry is described with a 5m resolution raster (Figure 6). Surveyed depth ranged from 0 to 12.9m MLLW, and mean depth was 4.5m MLLW. Additional high resolution bathymetric grids of 0.5m pixels provide detail to selected oyster habitat restoration sites (Figure 7). Phase differenced bathymetry from a side scan sonar is made possible by increasing the number of acoustic receive elements from 1 per channel to some number of pairs. The C3D uses 3 pairs of receiver elements per channel to resolve not just the range to an echo but the angle from which it originates. This method of data collection results in less confidence in the system's ability to accurately detect a small feature bathymetrically with a single sounding, more noise in the dataset that needs editing, but greater range in shallow water. Equally, since the bathymetry data is derived from the side scan sonar returns, interference in the water column, as mentioned in the backscatter section, creates false returns that require editing that often results in gaps in the bathymetric surface. Finally, the absorption of the acoustic signal by soft sediments at longer range resulted in linear gaps in the bathymetric surface, most notable in the flat soft channel bottom. The majority of erroneous soundings were removed, but edge artifacts remain in certain areas.

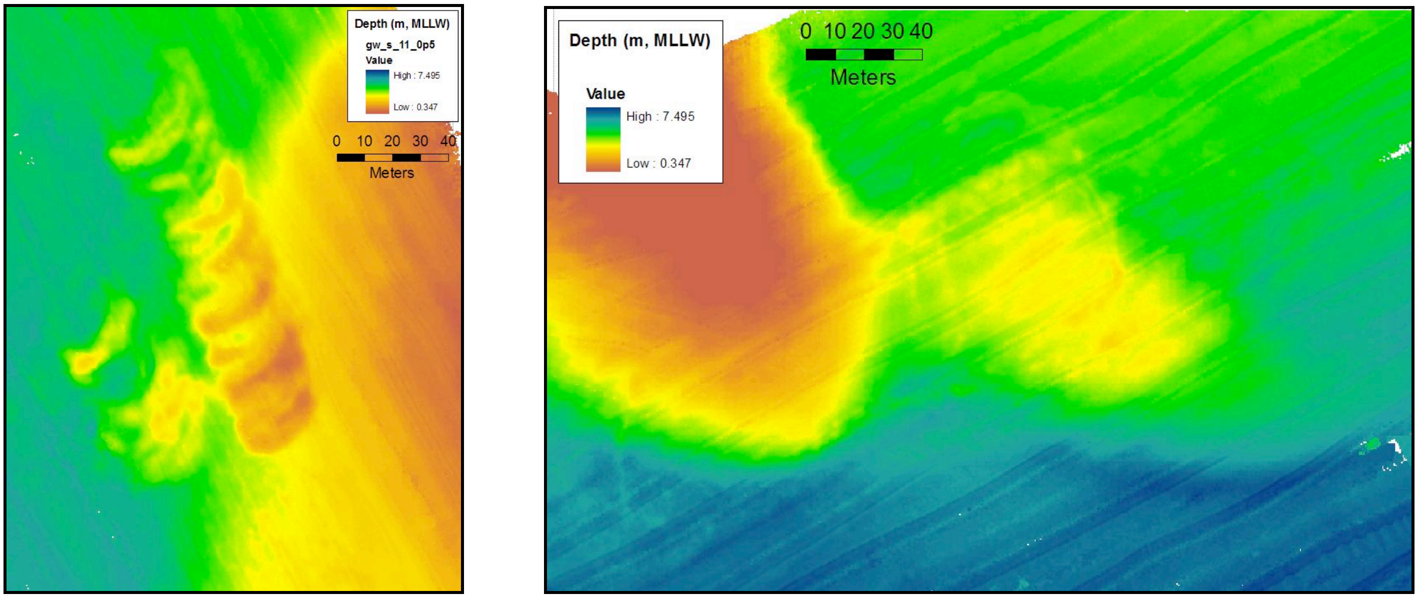


Figure 7 . Shell mounds in the vicinity of Collins Pt (left) and a medium relief shell planting in the vicinity of Horn Creek (right), both are at 0.5 x 0.5 m pixel resolution.

Sub-Bottom Profiles Low frequency acoustic sub-bottom profiling provides cross-sectional imagery of bathymetry and stratigraphy. Bottom penetration depends on system frequency and sediment density. The frequency of our system was 4-24 kHz, and was only able to penetrate the softest sediments. However, we were able to identify four major features based on penetration and bottom morphology (Figure 8). Sub-bottom features are displayed in Figure 9. Soft sediments are flat with a strong surface echo that results from acoustic reflectance of biogenic gases. Gas also creates as strong sub-surface secondary echo. Buried shell is characterized by lumpy features below approximately 0.5 m of soft sediment; the lump features suggest that this relict natural oyster reef. Reclaimed oyster bottom is hard, uniform, slightly elevated, and is spatially coincident with shell features identified in the backscatter. Shoal features have the highest elevation and due to greater acoustic reflectivity also have a secondary echo. Note the lack of reverberation in the water column above the soft sediment features.

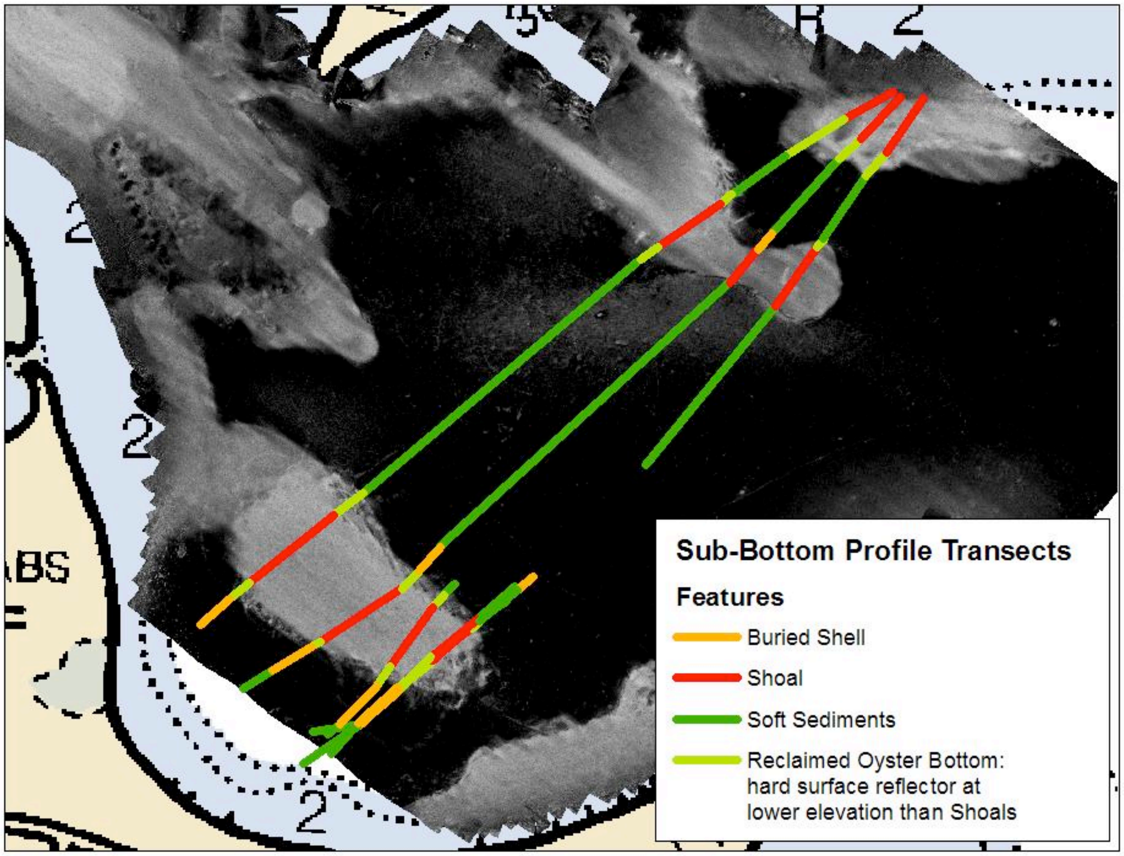


Figure 8. Location of sub-bottom profile transects and identified sub-bottom features relative acoustic backscatter in the vicinity of Shell and Haynie oyster bars.

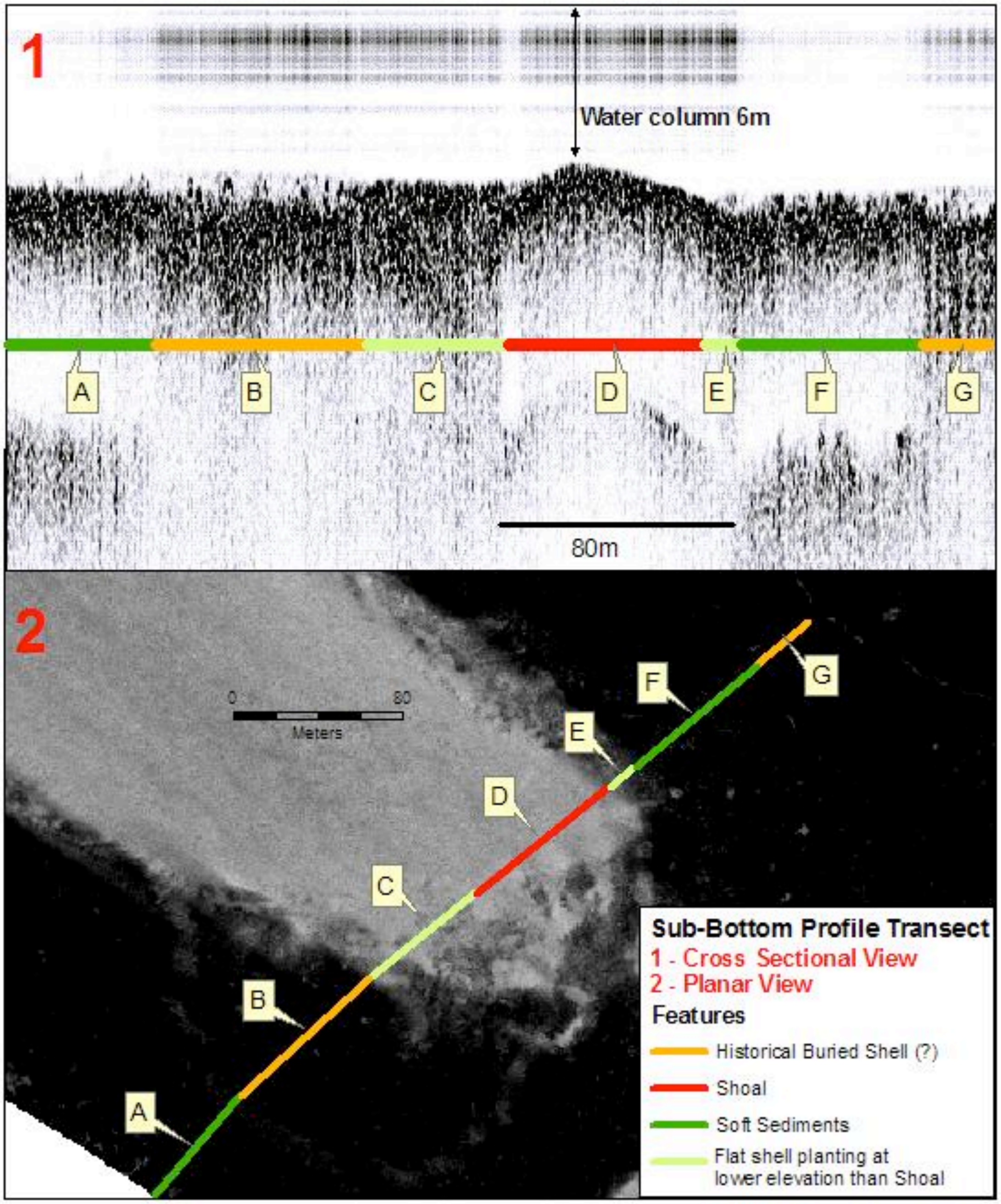


Figure 9. Features identified in the sub-bottom profile record (1) and same features relative to acoustic backscatter at Shell Bar (2).

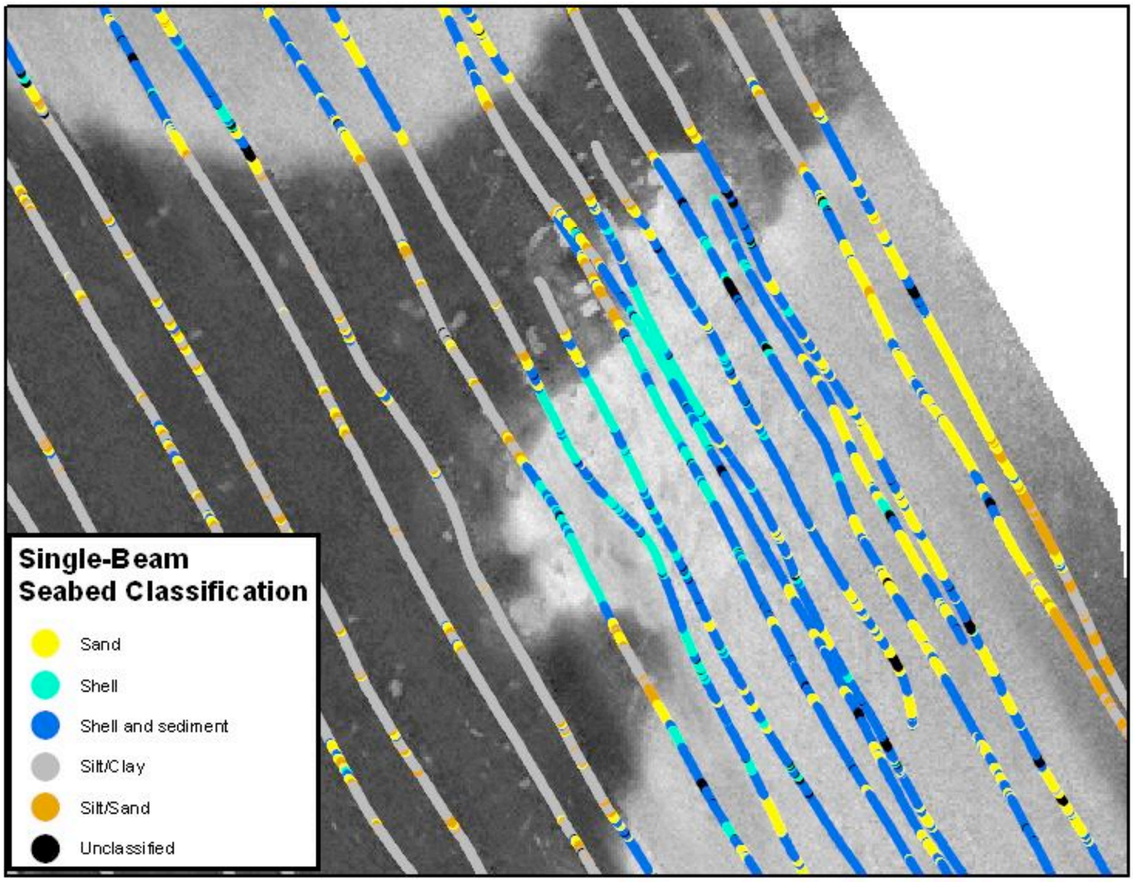


Figure 10a. Single-beam classification using the Roxann system at shell mounds in the vicinity of Collins Point.

Single-beam Seabed Classification Single-beam seabed classification (Figure 10a) provides a coarse depiction of the distribution of acoustically similar bottom types. Classification is based on hardness and roughness metrics derived from single-beam echoes collected over ground truth sites. The catalogue used to classify bottoms in the Great Wicomico was derived from one used in the upper Chesapeake Bay that was based on 135 benthic grab samples. Characterization of the entire system is noted in Figure 10b, at the end of the document (sentence, figure inserted by K. Sellner for this report of the 3/31/10 VA Oyster Restoration Monitoring Workshop).

Underwater Video Imagery Underwater video is used to first, validate the acoustic classifications and second, provide fine scale resolution of benthic condition. Video transects and point drops were collected on Dec 14 and 15 primarily in the lower river with a few sites selected upriver of the Rte 200 Bridge (Figure 11).

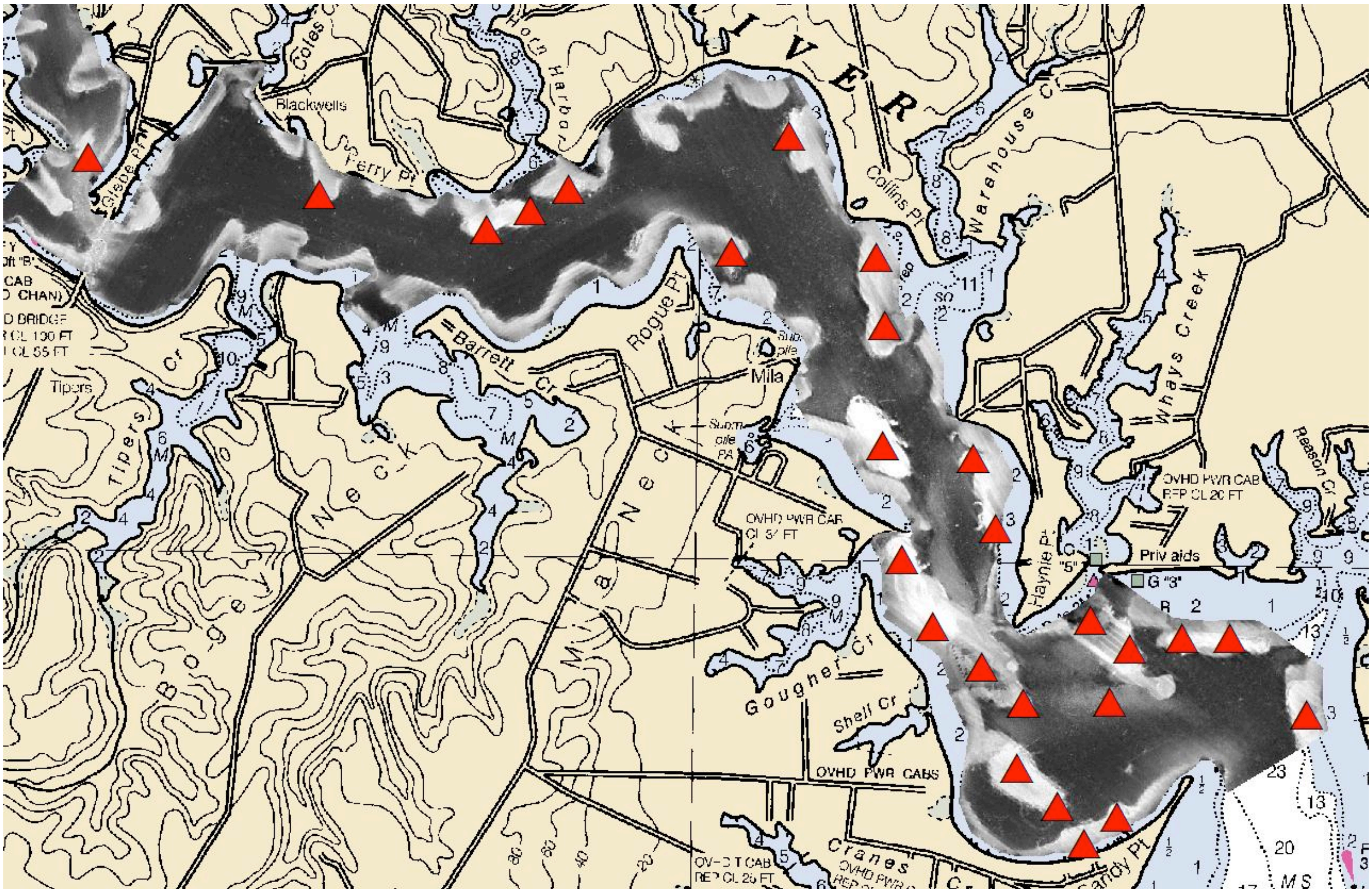


Figure 11. Video sampling sites

The video was reviewed and individual frames were selected and scored qualitatively to identify predominant acoustic feature, secondary acoustic feature, sediment type, sediment amount, and modifiers for acoustic features and sediment. Additional comments (e.g., additional physical and biological features) were also recorded in a comment field. Screen captures of the video at each site were recorded with the filename entered into the database. The imagery will be linked to the point data for review in a GIS. Figure 12 and 13 are examples of images captured for analysis.

Figure 12. Low relief area, with abundant sediment covering shell (caption suggested by K. Sellner, as part of report).

Figure 13. Medium relief area, with more abundant shell on sediment surface (caption suggested by K. Sellner, as part of VA Oyster Restoration Monitoring Workshop report).

Bottom description and image filename are referenced in the attribute table of the GIS point file for all drops. Video clips and image files are archived in the database. Combining all 3 data sources, backscatter, bathymetry and video, can yield detailed spatial distributions of bottom habitat (see Figure 14), enabling estimates of habitat areas (Table 1) as well as total acres with shell (Table 2) (this last sentence, Fig. 14, and Tables 1 and 2 added by K. Sellner from S. Giordano presentation delivered at the 3/31/10 VA Oyster Restoration Monitoring Workshop).

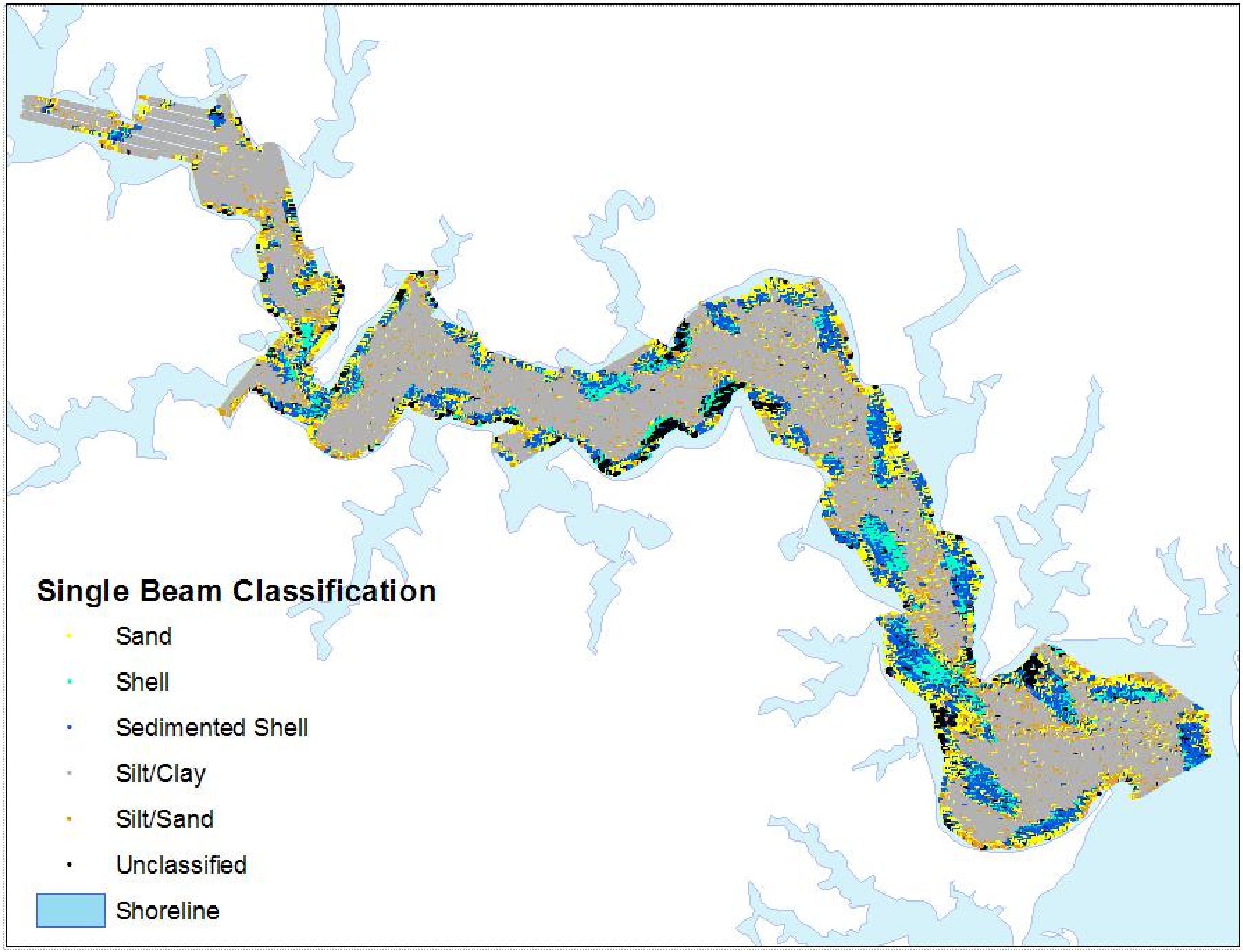


Figure 10b. Great Wicomico bottom type from 2009 single beam survey (inserted by K. Sellner from the S. Giordano VA Oyster Restoration Monitoring Workshop presentation on 3/31/10).

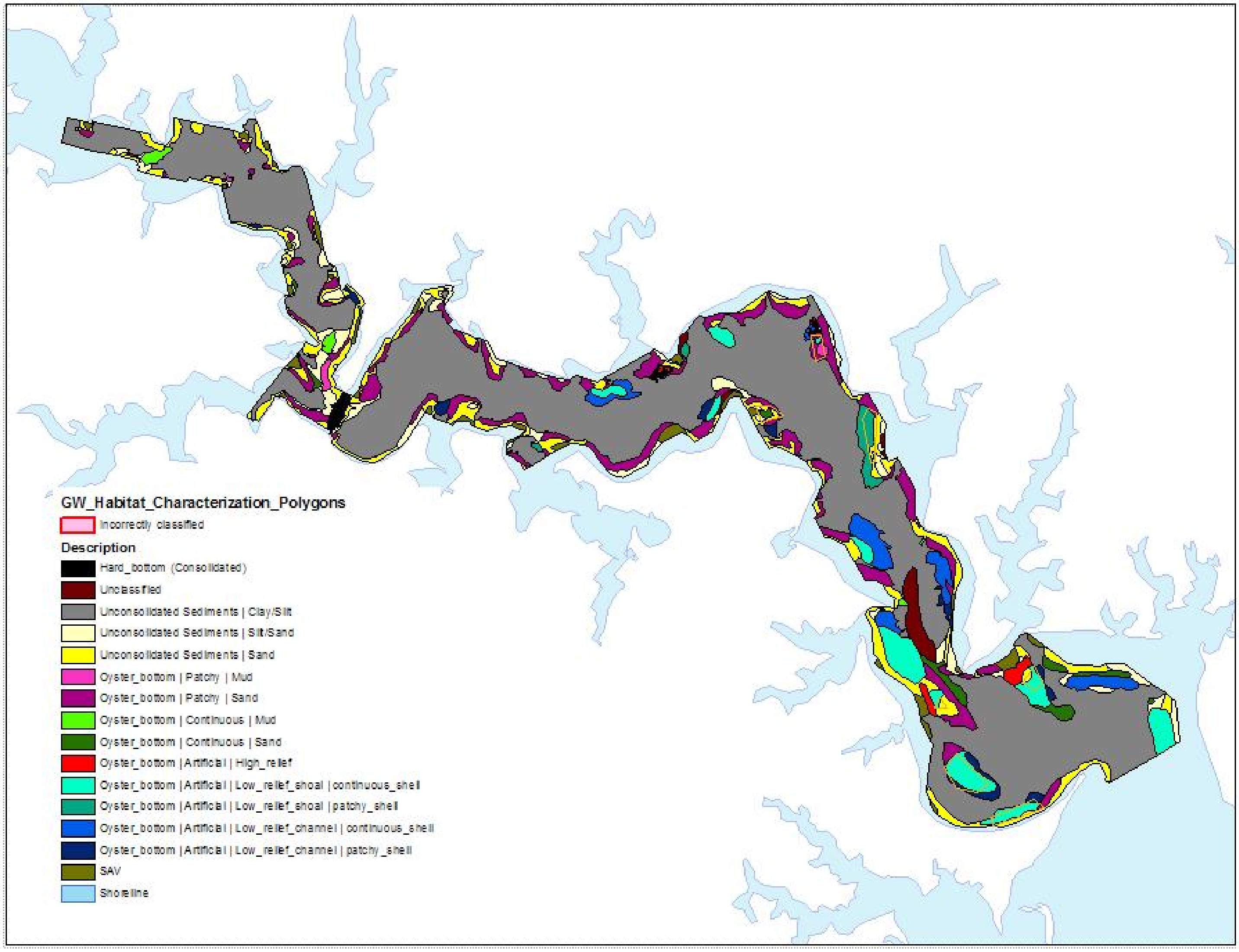
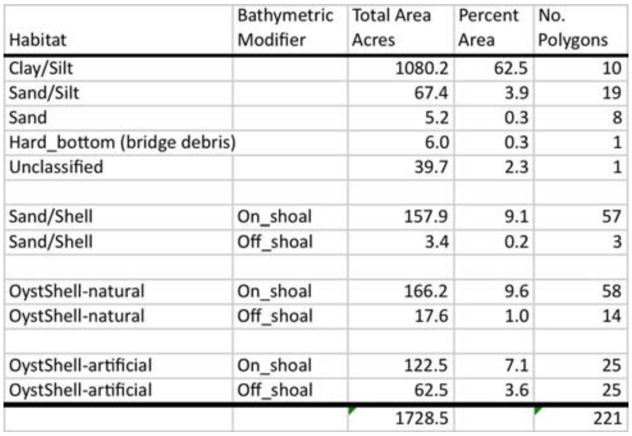
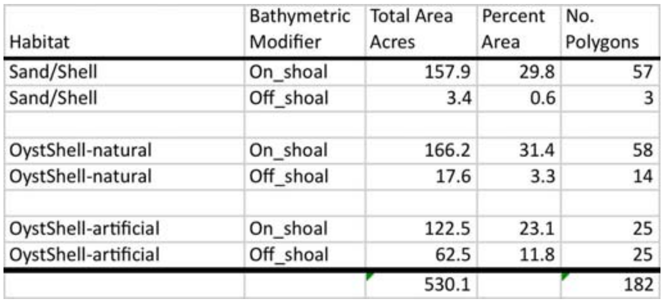


Figure 14. Digitized habitat polygons for the Great Wicomico, determined from backscatter, bathymetry and video, in the NCBO Benthic Assessment program (inserted by K. Sellner from the S. Giordano presentation at the VA Oyster Restoration Monitoring Workshop of 3/31/10).



Habitat	Bathymetric Modifier	Total Area Acres	Percent Area	No. Polygons
Clay/Silt		1080.2	62.5	10
Sand/Silt		67.4	3.9	19
Sand		5.2	0.3	8
Hard_bottom (bridge debris)		6.0	0.3	1
Unclassified		39.7	2.3	1
Sand/Shell	On_shoal	157.9	9.1	57
Sand/Shell	Off_shoal	3.4	0.2	3
OystShell-natural	On_shoal	166.2	9.6	58
OystShell-natural	Off_shoal	17.6	1.0	14
OystShell-artificial	On_shoal	122.5	7.1	25
OystShell-artificial	Off_shoal	62.5	3.6	25
		1728.5		221

Table 1. Summary table of habitat polygon areas in the Great Wicomico in 2009 (copied by K. Sellner from the 3/31/10 S. Giordano presentation at the VA Oyster Restoration Monitoring Workshop).



Habitat	Bathymetric Modifier	Total Area Acres	Percent Area	No. Polygons
Sand/Shell	On_shoal	157.9	29.8	57
Sand/Shell	Off_shoal	3.4	0.6	3
OystShell-natural	On_shoal	166.2	31.4	58
OystShell-natural	Off_shoal	17.6	3.3	14
OystShell-artificial	On_shoal	122.5	23.1	25
OystShell-artificial	Off_shoal	62.5	11.8	25
		530.1		182

Table 2. Area of shell habitat in the Great Wicomico in 2009 (copied by K. Sellner from the S. Giordano presentation at the 3/31/10 VA Oyster Restoration Monitoring Workshop).

Appendix 5. Lipcius Oyster Monitoring Design Workshop

Native Oyster Restoration Monitoring Protocol Development

June 14, 2010 - August 16, 2010

Organizer: R. Lipcius, VIMS
Participants: Mann, Hoenig, Paynter, Miller, Wilberg, and others.

Background: Native oyster restoration in the Chesapeake Bay has been implemented by a number of organizations (state departments, non-governmental organizations, citizens, and research institutions and groups) for the past half-century, with differing goals for each organization. Goals for these efforts are diverse and generally unidentified but can include supporting the oyster fishery, developing a sustainable oyster population, and creating and fostering ecosystem services associated with viable reefs and populations. In an attempt to provide sound quantitative monitoring protocols for use across the region, thus enabling quantitative comparisons of oyster densities across multiple projects with differing goals, regional oyster researchers will draft a whitepaper listing identifiable restoration goals for the native oyster, and then through discussions in a small workshop and rapid document distribution, editing, and review, recommend specific monitoring protocols for each goal. These goals and recommended monitoring procedures will then be distributed to the regional restoration organizations and the larger community ideally for adoption and use in the coming decades of native oyster restoration in Chesapeake's tidal waters.

Goal: Generate a list of native oyster restoration goals for tidal Chesapeake Bay waters and identify specific monitoring protocols for quantifying changes in oyster population characteristics (numbers, age structure, recruitment, boxes, shell budgets, etc.) through time.

Products: Native oyster restoration goals and standard monitoring protocols, in a regional researcher-derived whitepaper.

Timeline:
June 14-July 15: Lipcius, Mann, Hoenig, Paynter, Miller, Wilberg et al. prepare oyster monitoring report.
July 16-August 1: Conduct a limited workshop and submit report for review (workshop participants and reviewers TBD).
August 1-15: Reviewer comments incorporated into report.
August 16: Report presented to VMRC, MDNR, PRFC, NOAA, other agencies, and the larger research, restoration, and management communities.