Appendix A

Characterization of Individual Sanctuaries

Oyster Management Review:

2010-2015

A Report Prepared by

Maryland Department of Natural Resources

Draft Report

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Introduction

This appendix presents available data on oyster populations within the 51 individual sanctuaries as a means to examine the general characteristics, background information, and trends over time for each unique area. Recognizing that trends for any given area may shift as future environmental conditions change, an examination of oyster populations before and after 2010 will facilitate informed discussion of the effectiveness of the locations of the management areas. This appendix presents detailed data on each sanctuary. Chapter 4 and 5 will provide interpretations of these data to assess the effectiveness of sanctuary locations against the original objectives for the sanctuary program.

Not all types of data are available for all sanctuaries, and the scientific value of the different types of data may vary. This report leverages data from partners and other department programs which have particular data on specific sanctuaries. These studies often have limitations related to short study duration, initiation after the creation of sanctuaries in 2010 (no pre-sanctuary data), or a study design that was designed for purposes other than the type of assessment presented in this report (e.g. bottom sonar surveys targeting derelict gear, but which could be used to characterize bottom substrate).

Data used in this assessment include the following: bay bottom characteristics, replenishment and restoration activities, oyster population characteristics (density, recruitment, size structure, and mortality), water quality, and ecosystem services (Table A0-1).

The various data sources used in the assessment of each sanctuary are described below. For each data source, the objective and term of the sampling program are presented, the specific data sets derived from the program are described, and the value and limitations of each of the data sets for assessment purposes are identified.

Data Sources

Bay Bottom Surveys

Bay bottom mapping is important to determine the different substrate types of the bay bottom and, if possible, oyster bar boundary delineation. Three surveys are used in the sanctuary assessment: the Yates survey which delineated oyster bars from 1906 to 1912, the Bay Bottom Survey which categorized areas of the bay by bottom type from 1974 to 1983 (design and planning in 1974; survey conducted 1975 to 1983), and site-specific sonar surveys occurring between 2005 and 2013.

The Yates survey, conducted from 1906 to 1912, was the first comprehensive survey of Maryland’s oyster bars. The primary objective of the survey was to delineate the legal boundaries of the oyster bars to facilitate leasing grounds outside of the bars for aquaculture. Using a chain dragged over the bottom, the survey examined 350,000 acres of bay bottom and mapped 780 bars covering 216,000 acres over a six year period. After the Yates survey, additional areas were mapped and bars delineated. These new bars were amended to the list of Maryland oyster bars. Currently (as of 1983), there are 1,105 historic bars covering 330,202 acres[1]. The bars mapped by Yates as well as the additional areas are referred to as Maryland's historic oyster bars. It should be noted, however, that these historic oyster bars do not necessarily represent current viable oyster habitat with oysters and substrate. It has been estimated that only 36,000 acres of the historic oyster habitat is viable today[2].

Maryland Department of Natural Resources conducted the Bay Bottom Survey from 1975-1983 using a dragged acoustical device, sonar, and patent tongs to map the bottom types found in Maryland's portion of the Chesapeake Bay (approximately 630,000 acres). Bottom type categories included cultch (oyster shell), hard bottom, mud, mud with cultch, sand, and sand with cultch. Cultch and mixed cultch are important to oyster population as these bottom types provide settlement substrate for oyster larvae. Hard bottom may serve as a platform for placing spat on shell. The greater the area of cultch, mixed cultch, and hard bottom, the greater the potential for restoration. A sounding pole or divers were used for ground-truthing.

Maryland Geological Survey (MGS) and NOAA conducted side scan sonar surveys on 32 of the 51 oyster sanctuaries between 2005 and 2013. In some cases, a sub-bottom profiler was used to elucidate subsurface features. The results of these surveys were used in conjunction with ground-truthing Van Veen grab samples and underwater video to create maps of bottom type. In Harris Creek, Little Choptank River, and Tred Avon River sanctuaries, NOAA used multi-beam sonar to create high-resolution bottom type maps of areas that appeared suitable for restoration (capable of supporting oysters or reef building substrate) based on the side scan sonar surveys.

In addition to surveying oyster sanctuaries to map bottom type, MGS also conducted sonar surveys for other purposes, such as the identification of derelict fishing gear. Where possible, the data collected from these surveys were re-analyzed to produce bottom type maps.

NOAA uses the Coastal and Marine Ecological Classification Standard (CMECS)[3] for bottom types. CMECS provides a comprehensive national framework for organizing information about coasts and oceans and their living systems. This information includes the physical, biological, and chemical data that are collectively used to define coastal and marine ecosystems. To compare the results of NOAA, MGS, and Bay Bottom Surveys, NOAA reclassified the MGS and Bay Bottom Survey bottom types to CMECS, matching categories as closely as possible. The Bay Bottom Survey categories of cultch, mud with cultch, and sand with cultch were classified as oyster reef, as were the MGS catergories of shell, mud with shell, and sand with shell. Man-made reefs were also classified as oyster reef habitat. The bottom maps in this appendix present simplified results of the surveys, showing only oyster reef habitat and non-oyster reef habitat bottom. The bottom maps provide valuable information on habitat, and comparing the results of

[1] Maryland Department of Natural Resources. 1997. Maryland's Historic Oyster Bottom: A Geographic representation of the traditional named oyster bars. http://dnr.maryland.gov/fisheries/Documents/maryland_historic_oyster_bottom.pdf

[2] U.S. Army Corps of Engineers, Norfolk District. 2009. Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster. http://dnr.maryland.gov/fisheries/Pages/eis.aspx

[3] Federal Geographic Data Committee (FGDC). 2012. Coastal and Marine Ecological Classification Standard. Report no. FGDC-STD-018-2012. https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf

the Bay Bottom Survey with more recent MGS and NOAA sonar surveys allows the visual examination of change in habitat over time.

Replenishment and Restoration Efforts

Almost every oyster bar in Maryland has been manipulated over time through replenishment and restoration efforts to improve oyster bar productivity. Replenishment efforts were intended to enhance the public fishery for economic benefit and occurred prior to the establishment of the sanctuaries. Restoration efforts were those activities occurring after the establishment of the sanctuary with the objective to restore oyster populations for ecosystem and ecological benefits. The types of enhancements employed in both replenishment and restoration include planting fresh and dredged shell, transplanting natural, wild seed, and planting hatchery-reared spat in hopes of increasing oyster populations. Records of these activities date back to 1960, but shell and seed plantings only since 1990 will be presented in this appendix so to be consistent with the time period of comparison of the general oyster population characteristics to be described for each sanctuary.

The amount of replenishment and restoration activities differs widely among the 51 sanctuaries. Some sanctuaries have received numerous plantings of both shell and seed over time, while others received very few or none of either. The annual planting information provides a general sense of how each sanctuary was manipulated over time. An analysis to determine if replenishment or restoration activities contributed to an increase in oyster population is beyond the scope of this report, since a robust statistically designed project would have to be conducted in order to assess shell and seed planting effectiveness. This type of project is ongoing for Harris Creek, Little Choptank River, and Tred Avon River sanctuaries by organizations other than the department and may be referenced when applicable.

There is some uncertainty around the planting activity data recorded in earlier years. This is due to the precision of technology used to record planting locations and incompleteness of records. Prior to around the year 2000 seed and shell plantings were charted using coordinates obtained with LORAN-C, then transposed by hand onto paper or mylar charts, and then digitized by hand for use in electronic format, specifically with ArcGIS and other computer mapping software. Each step is a potential source of error. According to the manufacturer, the absolute accuracy of LORAN-C varies from 0.10 to 0.25 nautical miles (185 to 463 meter) compared to GPS which is typically less than three meters. The location of plantings prior to 2000 are not known with the same level of accuracy as those post-2000 and could be off potentially by up to 0.25 nautical miles, or an order of magnitude more than modern plantings. With this margin of error, there is much uncertainty of where historic plantings were with regard to modern sanctuary lines or with the digitized Yates bar boundaries.

When the records exist, the volume and area of historic planting is known relatively well. Barges of known volume and carrying capacity were used and carefully measured, and individual workboats used to haul seed were measured and each load was inspected prior to planting.

Unfortunately, many records are missing or incomplete. In several cases the volume was known but the area was not recorded or was lost. In some cases the area was recorded but the volume was not recorded or was lost. A few years ago, Department staff spent a considerable amount of time going through old records and reports to try to fill in as many blanks as possible to update a database and GIS layer with this information. In many cases over the five decade time series, including those between 1990 and 2010, a "best guess" for the volume of material had to be calculated based on available information such as average density of plantings and estimated acreage. Post-2010, the completeness of the planting records has improved as has the precision with which area has been measured. Due to these two issues (lack of precision and incompleteness) surrounding older plantings, caution must be exercised when stating the total amount of planning activity since 1990 in a given area.

Longevity of plantings should also be considered when examining replenishment activities. On average, it is thought that, in the absence of disease, oysters can live up to 20 years[4]. Even without disease related mortality, seed plantings in the Chesapeake Bay for harvest purposes are not likely to last more than three to five years due to harvest pressure. Longevity of shell can vary due to type of shell, pH and alkalinity, sediment burial, and attack from shell-boring organisms. The shell dissolution rate for fresh shell has been found to be much faster than for dredged shell. The half-lives of shell were computed by Waldbusser et al (2011)[5] and the results ranged from roughly one year for fresh shell under mid and low pH to nearly 40 years. This rate however does not account for loss of shell due to burial, transport, and attack from sponges and other shell-boring organisms, all important sources of shell loss in Chesapeake Bay. A further understanding the fate of historic plantings is important but beyond the scope of this report.

Another source of smaller-scale restoration planting data comes from the Marylanders Grow Oyster Program (MGO). MGO is an outreach and educational program designed to engage the public in oyster restoration by having them grow oysters at their piers in cages and then plant the oysters in local sanctuaries to enhance the oyster population. Growers (individuals in the program) receive spat in cages around September each year. The cages are tended to by the growers over the winter and spring. Around June, the approximately nine month old oysters are planted in sites within a sanctuary. The shell height of these oysters are approximately one to two inches.

The program began in 2008 in the Tred Avon River and has grown considerably since then. The MGO Program is large in terms of geographic scope (currently in 32 tributaries of the bay), the degree of public involvement (over 2,000 oyster growers and over 5,000 school students), and the effort invested to grow oysters (7,000 cages are being utilized). It is likely the largest community-based oyster growing program in the country. But it is actually a small scale program in terms of the acreage of sanctuary bottom restored and the number of oysters planted. Approximately two million oysters are planted on a few acres of oyster bottom annually. In comparison, large scale restoration can plant 2 million oysters in a day (i.e. Harris Creek

[4] Buroker NE. 1983. Population genetics of the American oyster Crassostrea virginica along the Atlantic coast and Gulf of Mexico. Marine Biology 75:99-112.
[5] Waldbusser, G.G., R. A. Steenson, and M. A. Green. 2011. Oyster Shell Dissolution Rates in Estuarine Waters: Effects of pH and Shell Legacy. Journal of Shellfish Research, Vol. 30, No. 3, 659–669

Sanctuary). However, in tributaries where large scale restoration is absent, MGO may be the only source of restoration activity.

Annual Fall Oyster Dredge Survey

The purpose of the department's Annual Fall Oyster Dredge Survey (Fall Survey), conducted since 1939, is to assess the overall health of the Maryland's oyster population. The Fall Survey represents the longest continuous and most geographically comprehensive oyster survey in Maryland. Although the Fall Survey was not developed explicitly for sanctuary monitoring and cannot be used to determine the density of oysters or calculate the total population size, it is useful for tracking general long-term trends of the oyster population characteristics.

The original Fall Survey design included the sampling of spatfall and relative oyster abundance at a subset of Maryland's oyster bars. This report utilizes Fall Survey data since 1990, when the sampling methodology was altered to include disease and biomass components along with the spatfall and relative abundance information. In the fall each year, between 311 and 385 samples are collected. Some sanctuaries may have samples taken on multiple bars annually, some sanctuaries have only one oyster bar sampled annually, and some sanctuaries have not been sampled at all by the Fall Survey. For each sample, one or (in the case of the 43 fixed disease and biomass bars) two half bushel subsamples of material are collected by an oyster dredge. Detailed methods for the fall survey may be found in Tarnowski (2015[6]).

For each sample collected by the Fall Survey, the number of live oysters per one bushel of material collected is counted. Oysters are classified as spat, small-sized oysters, or market sized oysters. Spat are less than one year old. Small-sized oysters are between one and two years old, and generally greater than 40 millimeters and always less than 76 millimeters. Market-sized oysters are always greater than 76 millimeters and generally older than three years. Changes in the number of oysters over time can provide a general sense of change in oyster abundance and age/size structure.

Samples taken on a fixed 43 bar subset of all the oyster bars sampled provide more detailed information on oyster sizes annually. Oyster shell height in millimeters is recorded for all oysters collected. Oyster size structure can be assessed by calculating the frequency distribution of oysters in each five mm size class. A healthy oyster population would have a size distribution with oysters in all size classes from 0-5 millimeters to greater than 120 millimeters. This would indicate multiple age classes in the population.

Biomass is estimated from field-collected oyster shell height using laboratory-derived height-weight relationships. Weight is calculated as grams of dry tissue weight. Increases in biomass may reflect increase in the number of oysters and/or oyster size. Greater biomass results in greater water filtration capacity.

[6] Tarnowski, 2015. Maryland Oyster Population Status Report, 2014 Fall Survey. http://dnr.maryland.gov/fisheries/Pages/shellfish-monitoring/reports.aspx

Total Observed Mortality is an indicator of annual mortality rates of small and market sized oysters. Mortality can occur from disease or other natural factors such as freshets. Mortality is estimated based on the total count of small and market-sized live oysters and the total count of small and market-sized boxes (dead oysters with the valves still articulated).

Information on oyster diseases is collected from the same fixed subset of 43 bars on which shell heights are collected. Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*) infection prevalence (the percentage of oysters infected) and intensity (the severity of infection) are measured from 30 oysters collected at each site. Disease prevalence and intensity both relate to mortality. For example, all of the oysters in a sample may be infected with a disease, but at such low intensity levels that few oysters are in danger of dying in the near future. Intensity is based on a 0 to 7 scale with values of 5 or greater representing lethal levels.

The Fall Survey data will be used to explore general characteristics of the oyster populations within those sanctuaries that were sampled in the Survey. Data presented will examine changes over time, based on the average number of oysters per a bushel of material, oyster shell height, live oyster biomass, recruitment, mortality, and disease on oyster bottom within each sanctuary.

Patent Tong Surveys

Patent tong population surveys have been conducted by the department since the establishment of the 2010 sanctuaries. These surveys use hydraulic patent tongs to obtain spatially explicit estimates of oyster density, as well as information on oyster size and the amount of cultch present. Data of this type cannot be derived from the Annual Fall Dredge Survey because of the type of sampling gear used in that survey. Patent tong surveys conducted by the department used a stratified random sampling design, with strata based on substrate type. The number of sampling points for each survey on each sanctuary ranged from 50 to 300, depending on the area of potential oyster habitat present in each sanctuary. Most sanctuaries have been surveyed at least once, and two sanctuaries have had two surveys conducted prior to sanctuary establishment.

During each patent tong survey all oysters are counted and classified as spat, small-sized, or market-sized. Oyster shell heights in millimeters are also measured for each sample in each survey. The size structure derived from patent tong surveys may differ from the one derived from the Fall Survey data. This is due to the patent tong surveys being based on samples taken across the entire sanctuary and the Fall Survey size structure being based on just one bar within the sanctuary.

The fixed area of the patent tongs ($1m^2$) allows for the calculation of oyster density. An average density of oysters based on all samples collected within a sanctuary can be used to derive the overall density of oyster habitat in the entire sanctuary.

The patent tong surveys also measure the volume of surface shell in each sample. Exposed oyster shell is the preferred settlement substrate for oyster larvae; therefore the greater the volume of exposed shell, the greater the potential for spat set.

The large number of samples taken during targeted patent tong surveys allows for an examination of the spatial distribution of oysters in a sanctuary, information that is unavailable from the Fall Survey due to the integration of data over the length of a dredge tow and the small number of samples taken in each sanctuary. Comparison of Fall Survey and patent tong survey results is difficult given the difference in sampling efficiency and area between the two gear types; therefore, in this appendix the results from the two surveys are presented separately.

In this appendix oyster density and oyster shell height distribution from the patent tong surveys will be presented, where available, along with the Fall Survey information. In addition to the patent tong surveys conducted by the department, additional patent tong surveys were conducted by the Paynter Labs of the University of Maryland and Versar, Inc using a systematic sampling design. Results of these surveys may be referenced in this appendix.

Seafood Dealer Reports and Oyster Harvester Reports

Harvesting wild oysters in a sanctuary is prohibited. However, harvest data collected prior to an area being established as a sanctuary may be used to examine harvesting activity in that area. The Department collects harvest data using two methods: seafood dealer reports and oyster harvester reports. The volume of oysters caught each day by each license holder is reported to the department on both forms in bushels. One Maryland oyster bushel is approximately 46 liters, notably larger than a standard U.S. bushel (35 liters).

Seafood dealers must report their oyster purchases to the department. These reports are called buy tickets and have been collected since the 1970's. Information reported on the buy tickets includes the broad location where harvest occurred (called the NOAA Code Area), quantity of oysters harvested, and date of harvest. Both the dealer and the harvester must sign the buy ticket and include their names and license numbers. Harvest reported on buy tickets has been reviewed only since 1990, when NOAA Code Area reporting was implemented. Furthermore, buy ticket harvest is only relevant to this assessment when the sanctuary area aligns exactly with the NOAA Code Area. For example, the Severn River Sanctuary covers exactly the same area as NOAA Code Area 082.

Starting in 2009, the department required oyster harvesters to report their catch every month. Information provided on the harvester reports include bar-specific harvest location, quantity of oysters harvested, gear used, and the date of harvest. For oyster bars located within the sanctuaries created in 2010, harvest data are only available for 2009, when bar-specific reporting was first implemented. No bar-specific harvest data are available for oyster sanctuaries created prior to 2010. Harvest reported up until June 1, 2016 will be presented in this appendix.

Due to the longer time series available from the buy ticket record, this is the standard data source for long-term trends in harvest. For applications where gear or oyster bar name is considered critical, the oyster harvester report data source is often used because generally these reports are more complete with regard to gear type and oyster bar name.

Water Quality

Water quality may influence patterns in oyster life history parameters and disease as well as the effects of sanctuaries and active restoration efforts on the environment. Oyster survival, growth, reproduction, and disease incidence are related to water quality parameters including salinity, temperature, and dissolved oxygen. Oyster reproduction (spat fall) and disease-caused mortality both decline with decreasing salinity. Therefore in areas where reproduction is lowest, survival of mature oysters may be highest. Oysters also impact the quality of water in which they live. For example, some water quality characteristics such as clarity may be related to oyster biomass, as greater biomass results in a greater filtration rate. However, the association between water quality improvements and oyster population size is complex, since a number of other factors, such as land use practices and water treatment facilities, greatly impact water quality.

Water quality is monitored in Maryland through the department's Eyes on the Bay program. Although water quality data are collected throughout the bay, most of the sampling stations are located outside oyster sanctuaries. Only 12 of the sanctuaries have water quality information. Parameters measured by the Eyes on the Bay program include temperature, salinity, dissolved oxygen concentration, pH, total suspended solids, Secchi depth, chlorophyll a concentration, and nutrient concentrations.

In addition to bay-wide water quality monitoring, there are two sanctuary-specific monitoring efforts. In Harris Creek, the first tributary chosen for large-scale oyster restoration, there are three water quality instruments or sondes. Two are moored to the bottom, and one is a mounted on a vertical profiler that takes samples throughout the water column. In the Tred Avon River, there is one sonde is mounted on a vertical profiler. Each sonde measures temperature, salinity, dissolved oxygen concentration, pH, turbidity, fluorescence, and total chlorophyll concentration. Additionally, biweekly water samples are collected in Harris Creek and alkalinity calculated based on total inorganic carbon.

Oyster bars in Maryland are located in the mesohaline salinity classification (5-18 ppt). Within this mesohaline zone, Maryland oyster bars are further classified into three zones: Zone 1 has an average salinity between 5 to 11 ppt; Zone 2 has an average salinity between 12 and 14 ppt; and Zone 3 has salinities greater than 14 ppt (Figure 3-3). Data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program were used to create a Maryland-wide salinity dataset. Oyster sanctuaries are classified by salinity zone using average bottom salinity during the oyster growing season (April to October) in 2005 and 2006, two years with average rainfall.

Sanctuaries within Zone 1 (43 sanctuaries and 173,513 acres) were chosen to increase oyster biomass through stocking and long-term survival. Oysters within Zone 1 are characterized by having lower levels of disease and better survival but low reproductive capability[7]) Oysters are also subject to intermittent freshets that can result in substantial mortality.

Sanctuaries within Zone 3 (3 sanctuaries and 17,671 acres) were chosen to foster disease resistance and enhance reproduction. Oysters in this zone are subjected to heavy disease pressures which normally results in mortality[8]. Those oysters that do survive past 4 years are thought to harbor some diseases resistance or tolerance since they did not succumb to disease related mortality. In Zone 3, there is also high recruitment rates that provide a fairly constant influx of new oysters.

Sanctuaries within Zone 2 (13 sanctuaries and 62,257 acres) represent transition areas incorporating the goals of Zones 1 and 3. Oyster located in Zone 2 may have fluctuating characteristics based on the climatic variation between wet and dry years[9]. Annual spat settlement can range from low to moderate to high based on salinity. Mortality related to disease can also fluctuate from year to year. In years with low disease-caused mortality, the oyster populations in this area can recover as long as there is also successful recruitment. However, the reverse can also occur.

Ecosystem Services

Ecosystem services provided by oysters include: habitat for fish and invertebrate species; biogeochemical processes including denitrification; filtration and water clarity; adjacent shallow water habitat stabilization; and shoreline protection. Several studies assessing ecosystem services in Harris Creek and the Tred Avon River are underway. NOAA's Oyster Reef Ecosystem Services project is attempting to quantify and estimate the economic value that restored oyster reefs provide to other organisms and the environment. Researchers from the Virginia Institute of Marine Science and University of Maryland are quantifying macrofaunal productivity and nutrient removal associated with restored oyster reefs. Researchers from the University of Maryland are using computer models to estimate larval supply from sanctuaries to public fishery areas. Scientists from the Smithsonian Environmental Research Center and the University of Maryland are assessing the effects of restored oyster reefs on chlorophyll uptake.

As these studies are ongoing, findings regarding ecological services will need to be addressed in a future report. However, current data can inform conversations about ecological services as a number of these services (e.g. water filtration and provision of habitat) can be linked to measurable parameters such as oyster density and total biomass.

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[7] Chesapeake Bay Oyster Management Plan: 2004 http://www.chesapeakebay.net/content/publications/cbp_12889.pdf
[8] IBID
[9] Chesapeake Bay Oyster Management Plan: 2004 http://www.chesapeakebay.net/content/publications/cbp_12889.pdf

Table A0-1. List of oyster data collected in each sanctuary. BB = Bay bottom data. MN = Maryland Geological Survey and NOAA side scan sonar surveys between 2005 and 2013. P = data present prior to the establishment of the sanctuary. A = data present after the establishment of the sanctuary.

Sanctuary Name	Bottom Type Surveys	Replenishment and Restoration Efforts	Annual Fall Oyster Dredge Survey	DNR Patent Tong Population Survey	Seafood Dealer Reports and Oyster Harvester Reports	Water Quality Monitoring
Big Annemessex	BB		A			P,A
Breton Bay	BB, MN	P	P,A			P
Calvert Shore	BB, MN	P	P,A	A		
Cedar Point	BB, MN			A		
Chester ORA Zone A	BB, MN	P	P,A	A		P
Choptank ORA Zone A	BB, MN	P,A	P,A	A		
Cook Point	BB, MN	P,A	P,A			
Cox Creek	BB, MN	P	P	A		P
Eastern Bay	BB, MN		P	A		P
Fort Carroll						
Harris Creek	BB, MN	P,A	P,A		P	P,A
Herring Bay	BB, MN	P	P,A	A		
Hooper Strait	BB, MN	P,A	P,A	A		
Howell Point	BB	P,A	A			
Kitts Creek	BB	P	P,A			P,A
La Trappe Creek	BB		A			
Little Choptank	BB, MN	P,A	P,A	A		
Lower Chester River	BB, MN	P,A	P,A	A		P
Lower Choptank River	BB, MN	P,A	P,A	A		P
Lower Mainstem Bay	BB	P	P,A	A		
Lower Patuxent River	BB, MN			A		
Magothy River	BB, MN	P			P	P,A
Man O' War/Gales Lump	BB	P,A		A		
Manokin River	BB/MN	P	P,A	A	P	P,A
Miles River	MN	P	P,A	A		P
Mill Hill	BB, MN	A	P,A			
Nanticoke River	BB, MN	P	P,A		P	P,A
Neal Addition	BB	P,A	P,A			

Table A0-1. Continued						
Sanctuary Name	**Bottom Type Surveys**	**Replenishment and Restoration Efforts**	**Annual Fall Oyster Dredge Survey**	**DNR Patent Tong Population Survey**	**Seafood Dealer Reports and Oyster Harvester Reports**	**Water Quality Monitoring**
Oxford Laboratory	BB, MN	A				
Piney Point						
Plum Point	BB					P,A
Point Lookout	BB	P,A	P,A	A		
Poplar Island	BB	A	A			
Prospect Bay	BB, MN	P,A	P	A		
Prospect Bay-Cabin Creek				A		P
Ringgold	BB, MN		P,A			
Roaring Point						
Sandy Hill	BB, MN	P,A	P,A	A		
Severn River	BB, MN	P,A	P,A	A	P	P,A
Solomons Creeks						
Somerset	BB	A	A	A		
South River	BB, MN	P,A	P,A	A		P,A
St. Mary's River	BB, MN	P	P,A	A	P	P
Tilghman Island	BB			A		
Tred Avon River	BB, MN	P,A	P,A	A	P	P
Upper Chester River	BB, MN	P,A	P,A	A	P	P,A
Upper Choptank River	BB, MN	P,A	P,A	A		P,A
Upper Patuxent River	BB, MN	P,A	P,A	A	P	P,A
Webster	BB					
Wicomico River (West)	BB					
Wye River	BB, MN	P	P,A	A	P	P

Section A.01: Big Annemessex Sanctuary

The Big Annemessex Sanctuary is located in a high salinity (greater than 14 ppt) region of Maryland's lower eastern portion of Chesapeake Bay (Figure A.01-1). The sanctuary was created in 2010 and encompasses 749 acres of which 361 acres (48%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are four historic oyster bars within the sanctuary[10], two of which lie almost entirely outside the sanctuary and account for only 0.9% of the total area of the entire sanctuary and two of which lie almost entirely within the sanctuary boundary.

Bottom Habitat Characteristics

A small portion of the sanctuary (54 acres) was examined during the Bay Bottom Survey (1974 to 1983) to determine bottom type (Figure A.01-2). No oyster reef habitat was found within the 54 acres surveyed, which consisted primarily of sand. More recent side scan sonar bottom surveys have not been conducted in this sanctuary.

Restoration and Replenishment Activities

This area has not received any active restoration or replenishment efforts since 1990.

Oyster Population Characteristics

The Fall Survey did not sample any oyster bars within this area between 1990 and 2014. In 2015, one sample was collected and no oysters were found.

No patent tong population surveys have been conducted to date in the sanctuary by the Department.

Harvest

The sanctuary encompasses 10% of the 7,343 acres in NOAA Code Area 005; therefore, seafood dealer buy tickets cannot be used to assess harvest in this area. According to oyster harvester reports for the 2009-2010 season, no harvest occurred in the area now established as a sanctuary.

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[10] See chart 45 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Water Quality Data Hub recorded monthly water quality at station XBJ2003 (latitude 38.03373, longitude -75.82832) in the sanctuary from 2011 to 2013 (Figure A.01-3). Surface water quality was analyzed for salinity, water temperature, secchi disk depth, total suspended solids, and chlorophyll a. Water quality was favorable for oysters during the period examined.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

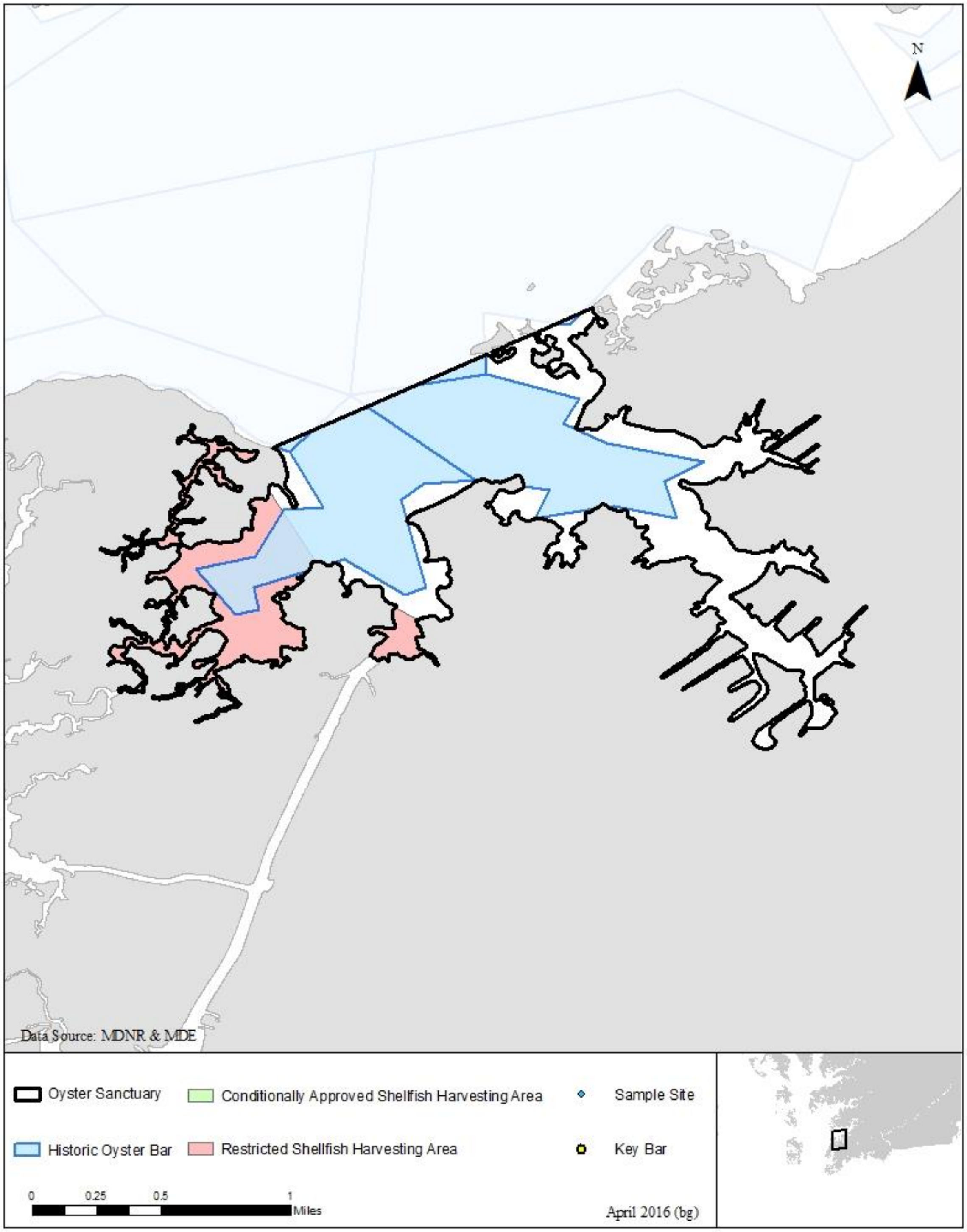


Figure A.01 -1. Big Annemessex Sanctuary.

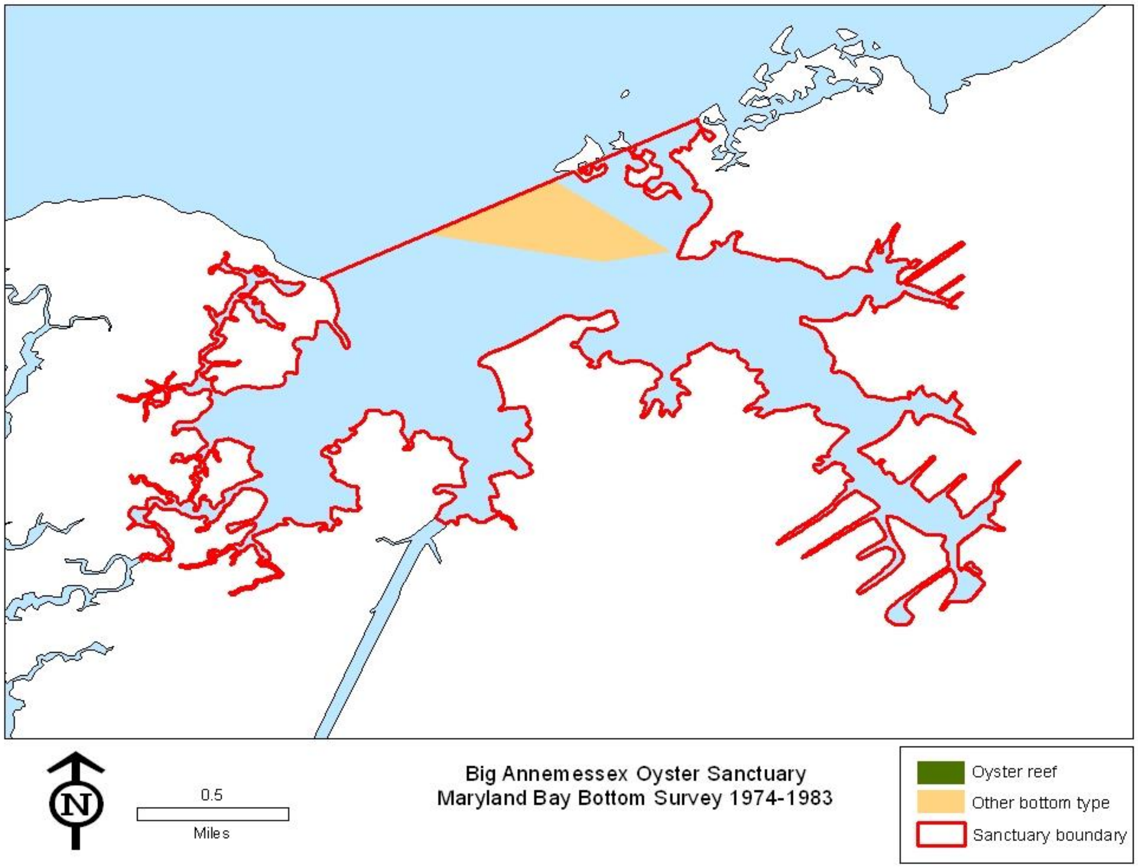


Figure A.01 -2. Big Annemessex Sanctuary bottom types. Data from Maryland Bay Bottom Survey of 1974-1883. Tan and green colored areas depict areas examined during the survey.

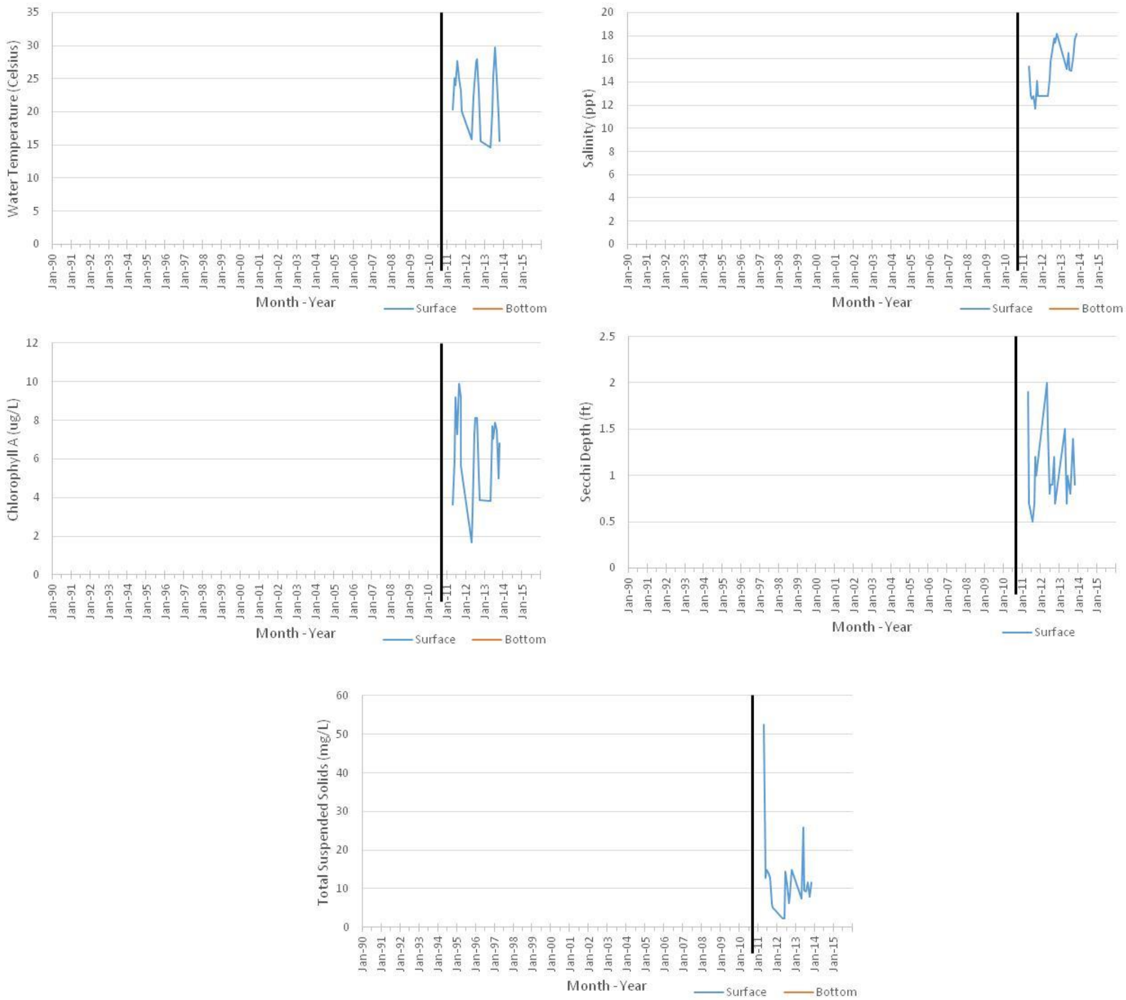


Figure A.01-3. Water quality data collected at Station XBJ2003 in Jones Creek within Big Annemessex Sanctuary from 2011 to 2013. Black line denotes the date the sanctuary was established.

Section A.02: Breton Bay Sanctuary

The Breton Bay Sanctuary is located within Breton Bay on the North shore of Potomac River, a low salinity (less than 12 ppt) region (Figure A.02-1). The sanctuary was created in 2010 and encompasses 3,212 acres, of which 888 acres (28%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 10 historic oyster bars within the sanctuary[11].

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.02-2). Of the 847 acres surveyed within the sanctuary, 581 (69%) were classified as oyster reef habitat. In 2010 Maryland Geological Survey conducted a more thorough side scan sonar survey of the area. Of the 2,334 acres surveyed in 2010, 311 acres (13%) were classified as oyster reef habitat. The much greater coverage of the Maryland Geological Survey's side scan sonar work. Lack of overlap between the coverage areas of the Bay Bottom Survey and Maryland Geological Survey's side scan sonar work precludes comparison of the two surveys.

Restoration and Replenishment Activities

The sanctuary has not received any active restoration efforts since it was established in 2010; however, this area received replenishment efforts once when 1.3 thousand of bushels of wild seed was planted in 1996 (Table A.02-1). No shell or hatchery spat-on-shell has been planted since 1990.

Table A.02-1. Replenishment planting activities occurring since 1990 in the area established as the Breton Bay Sanctuary in 2010.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1996	Wild Seed	2.14	1.3	-

[11] See chart 34 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

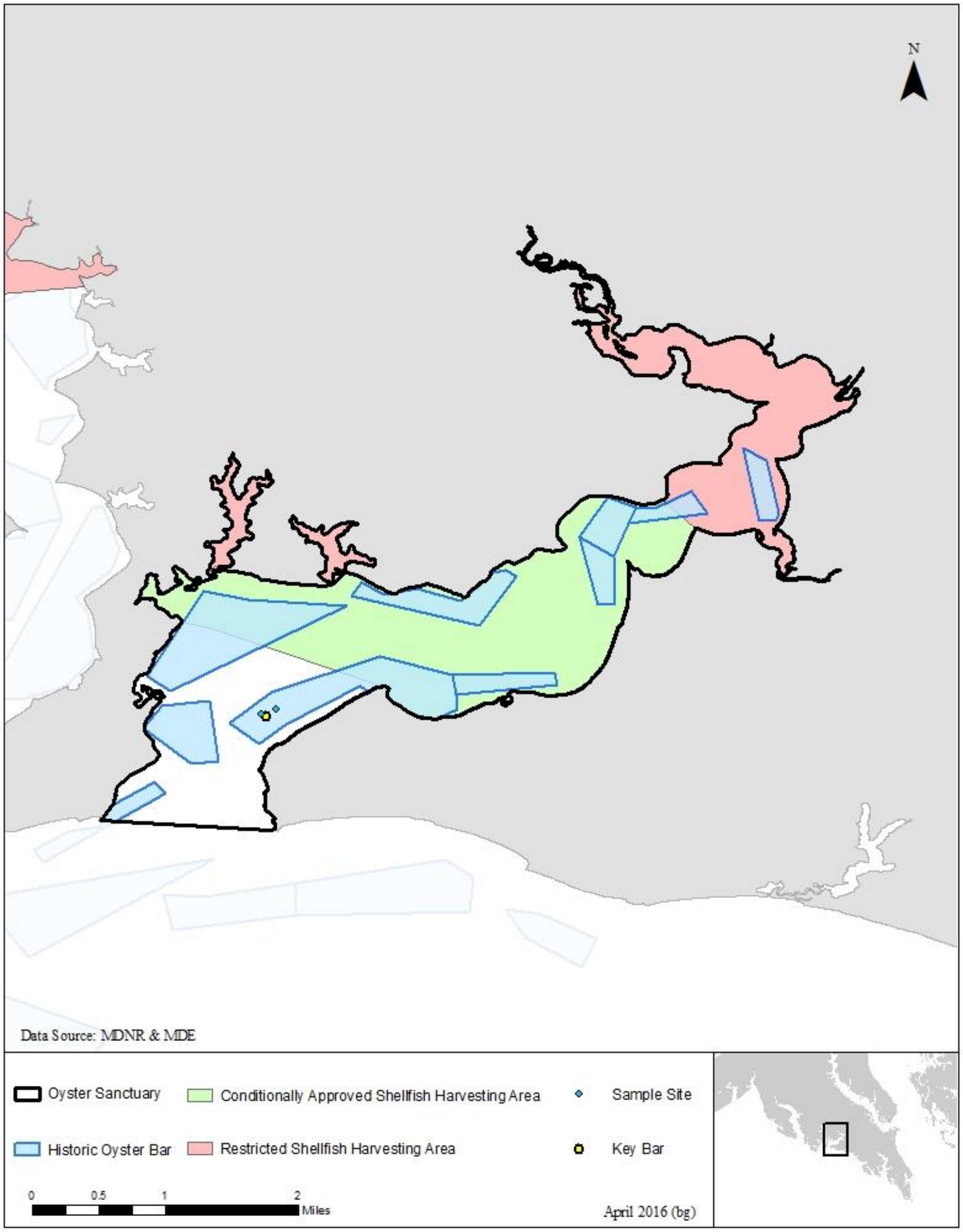
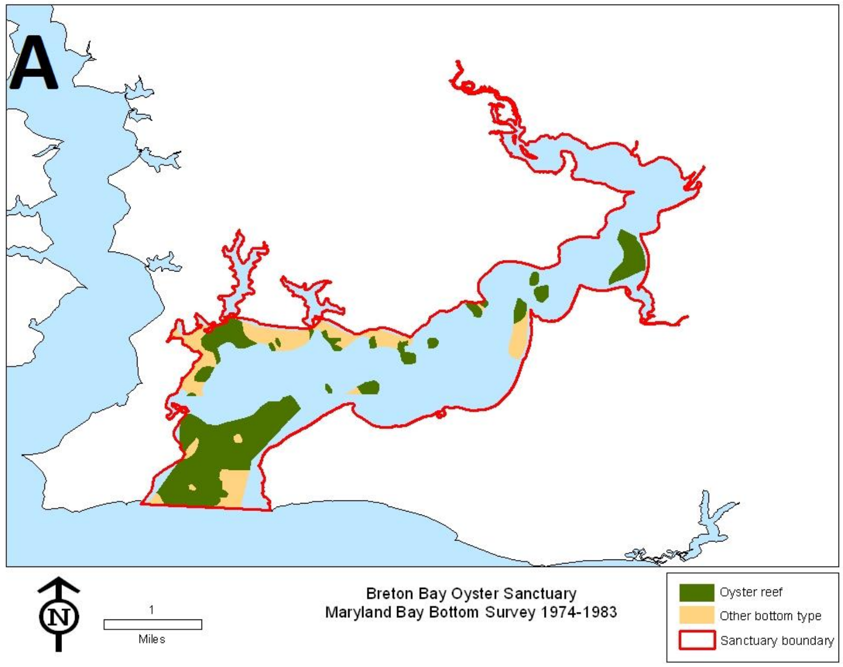


Figure A.02 -1. Breton Bay Sanctuary.



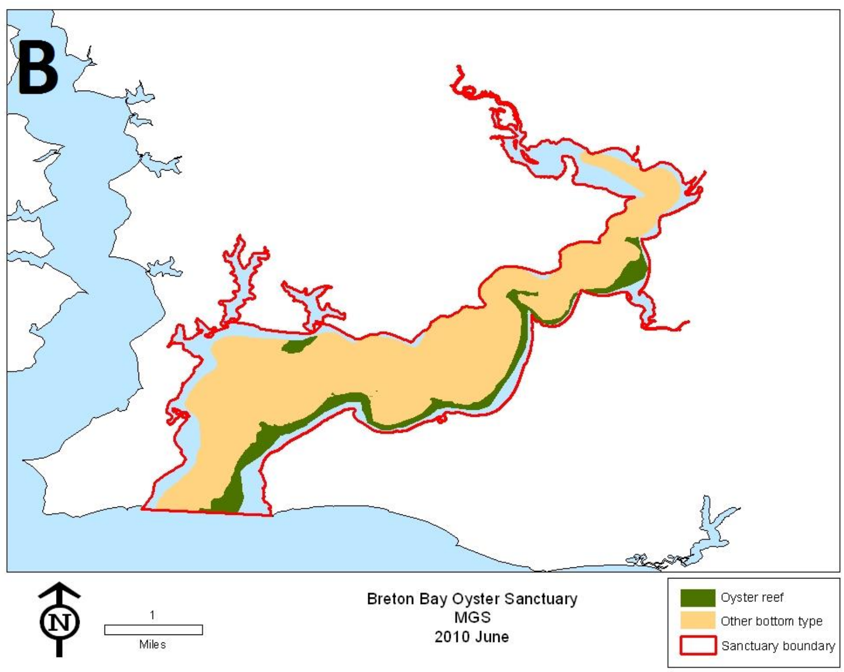


Figure A.02 -2. Breton Bay Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1883. (B) Data from Maryland Geological Survey of 2010. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has taken one sample on one oyster bar (Black Walnut) in this area annually since 1990, with the exception of 1996 and 1997 when 2 samples were collected on Black Walnut bar. The average number of total live oysters per bushel (market, small, and spat) from 1990-2009 was slightly higher than the average from 2010-2015 (Table A.02-2; Figure A.02-3). The average number of small-sized and market-sized oysters per bushel from 1990-2009 was slightly higher than the average from 2010-2015.

Table A.02-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Breton Bay Sanctuary in 2010. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 22	6 / 6
Number of Live Oysters per Bushel	34 ± 7	25 ± 11
Number of Live Small-Sized Oysters per Bushel	14 ± 4	7 ± 7
Number of Live Market-Sized Oysters per Bushel	20 ± 4	17 ± 5
Live Oyster Biomass (g Dry Weight per Bushel)	72 ± 11	38 ± 9
Mortality (%)	36 ± 5.6	14 ± 4.9

The Department has not conducted patent tong population surveys in the sanctuary.

Oyster Size Structure

Oyster shell height information was collected during the Fall Survey from 1990 to 1997 and 2011 to 2013 (Figure A.02-4). The lack of data from 1998 to 2010 and 2014 to the present precludes evaluation of changes in size structure.

Biomass

Biomass of oysters collected by the Fall Survey increased from 2011 to 2013; however, it is still lower than the highest biomass occurring in 1990 (Figure A.02-5; Table A.02-2).

Recruitment (Spatfall)

Based on the Fall Survey, spatfall is low and intermittent in this area. Measurements ranged from 0 to 6 spat per bushel from 1990 to 2015 with the highest occurring in 1991 (Figure A.02-3). There were extended periods of low spatfall from 2003-2009 and 2011-2014. In 2015, spatfall was 3 spat per bushel which is equivalent to the 1999 measurement and the second highest in the time series.

Mortality

The average mortality prior to the area becoming a sanctuary was higher than after the sanctuary was established (Figure A.02-6, Table A.02-2). These findings are consistent with high bay-wide disease pressure from 2000 to 2003. No mortality was observed in 2009 and 2010.

Disease

No Fall Survey disease samples have been taken since 1990.

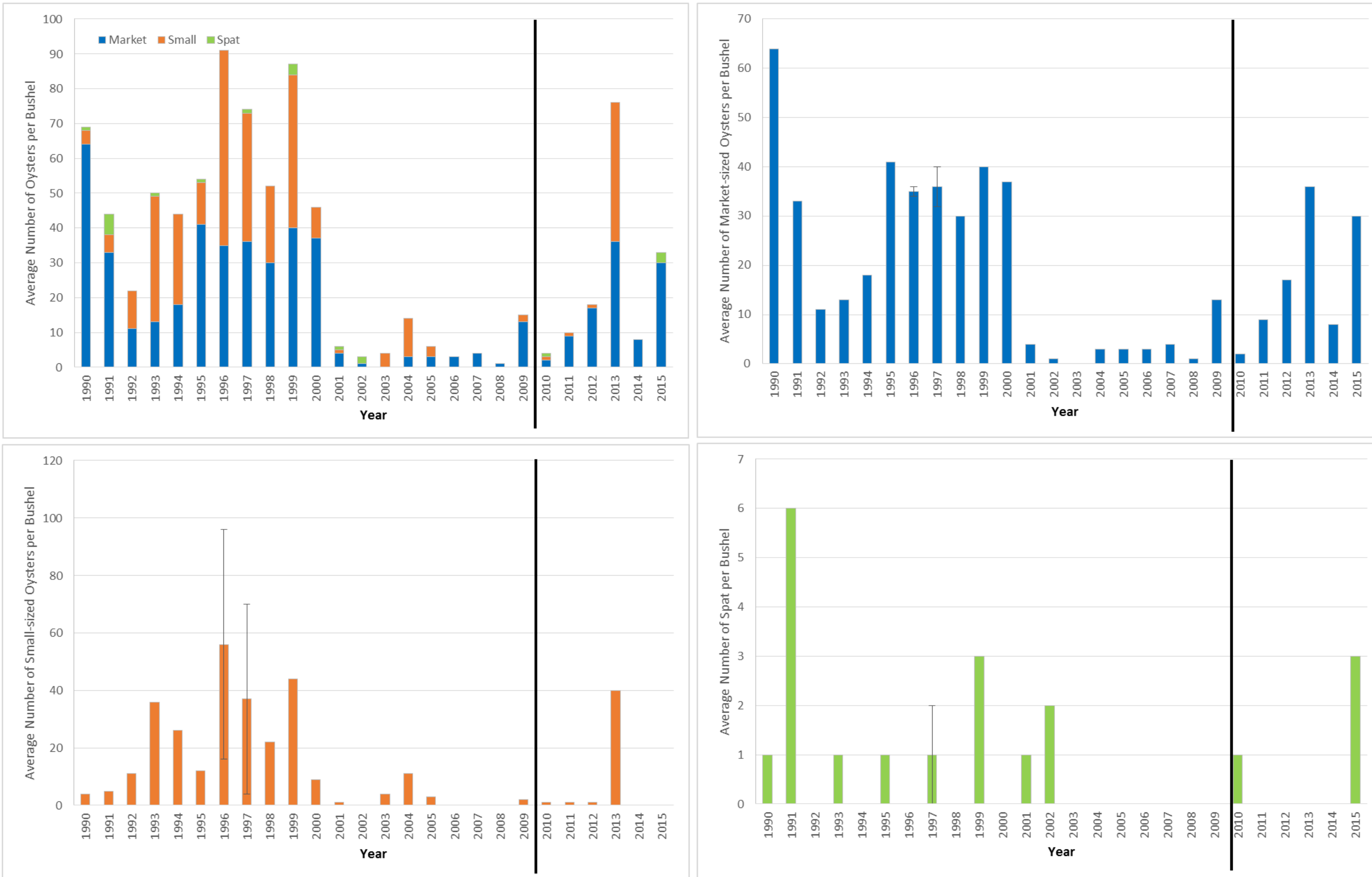


Figure A.02-3. Average number of live oysters per bushel of material by size class in the Breton Bay Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

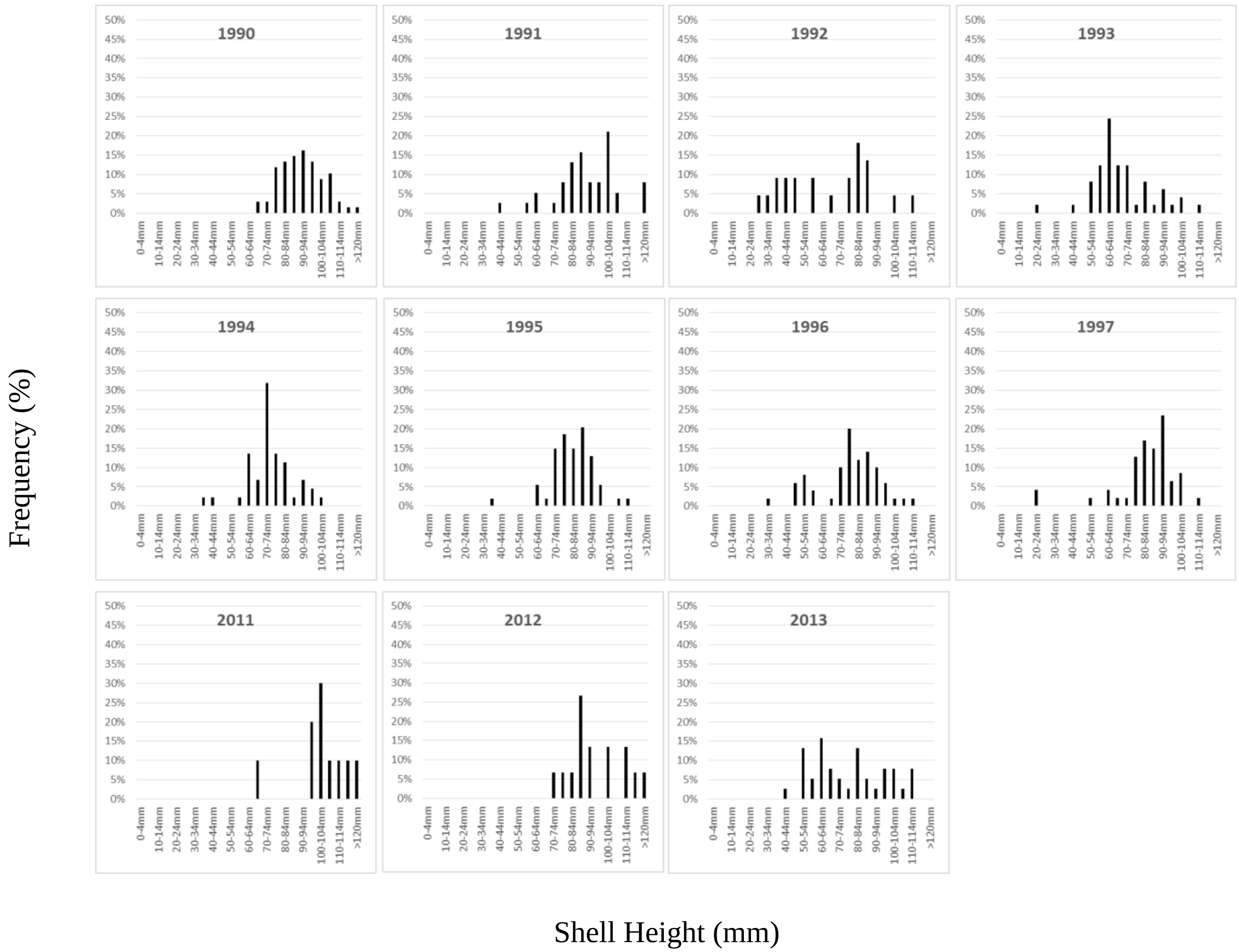


Figure A.02-4. Shell height frequencies of live oysters from 1990 to 2015 in the Breton Bay Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. The black line denotes the year the sanctuary was established. Size data were collected from 1990 to 1997 and 2011 to 2013.

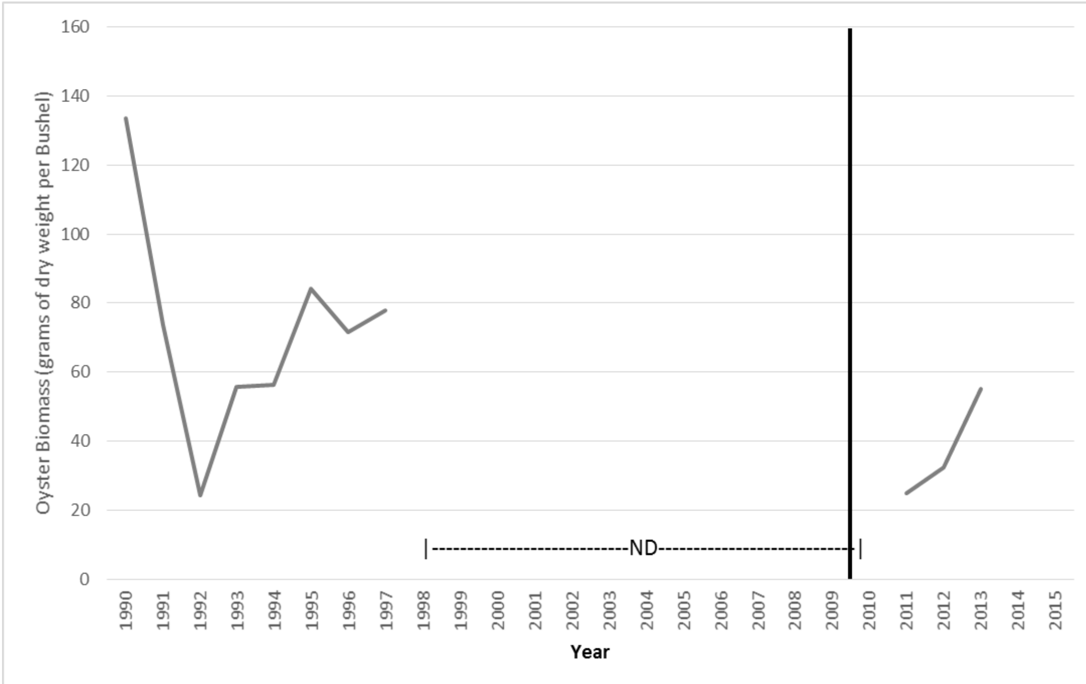


Figure A.02-5. Oyster biomass (grams dry weight per bushel of material) from 1990 to 2015 in the Breton Bay Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line indicates the date the sanctuary was established. Biomass data were collected from 1990 to 1997 and 2011 to 2013. ND = No Data.

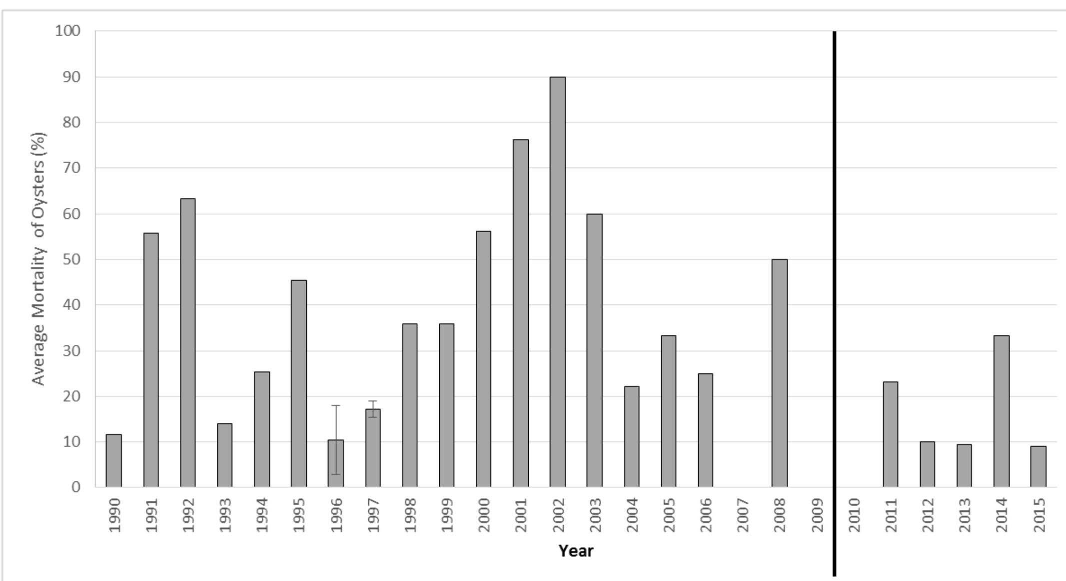


Figure A.02-7. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Breton Bay Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

Harvest

The sanctuary encompasses 46% of the 7,045 acres in NOAA Code 174. Because harvest for NOAA code 174 may have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. Oyster harvester reports show no harvest from bars located in this area in 2009-2010, the season immediately prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Data Hub has recorded monthly water quality at station XCD5599 (Latitude 38.259, Longitude -76.6713) in this area (Figure A.02-8). Chlorophyll a, salinity, secchi depth, total nitrogen, total suspended solids, and water temperature were collected from 2006 to 2009. Water quality was favorable for oysters except for periods of low salinity in the spring of 2007 and 2008. There is no information about water quality after the establishment of the sanctuary in 2010.

To date, we are unaware of any studies explicitly examining oyster ecosystem services in the sanctuary.

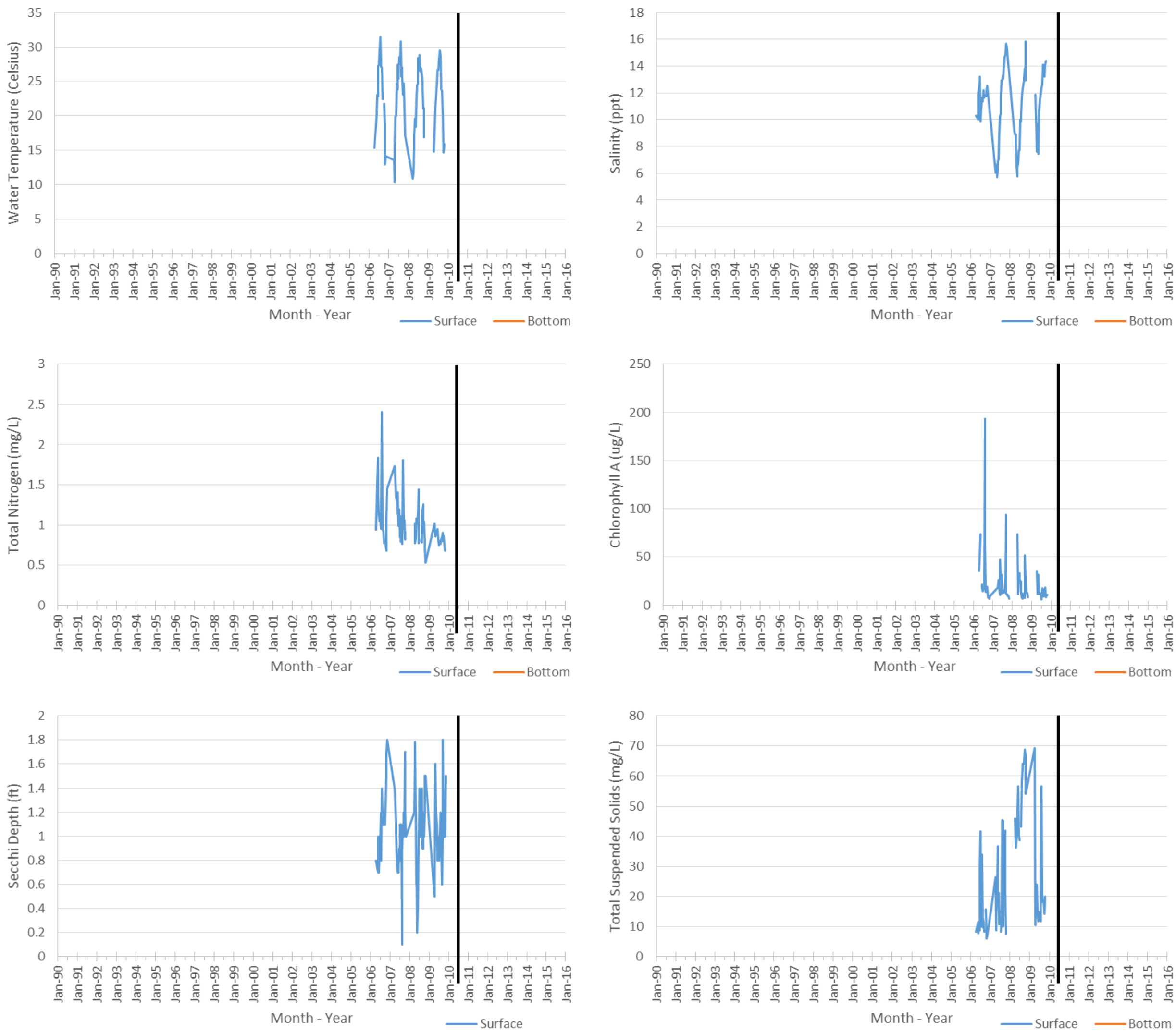


Figure A.02-8. Water quality data collected at Station XCD5599 within Breton Bay Sanctuary from 2006 to 2009. Black line denotes the date the sanctuary was established. Data from Chesapeake Bay Program Data Hub.

Section A.03: Calvert Shore Sanctuary

The Calvert Shore Sanctuary is located in medium salinity (12 to 14 ppt) region of Maryland's lower western portion of Chesapeake Bay (Figure A.03-1). The sanctuary was created in 2010 and encompasses 2,214 acres of which 673 (30.4%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There is one historic oyster bar within the sanctuary, Flag Pond.

Bottom Habitat Characteristics

Part of the area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.03-2). Of the 1,266 acres surveyed within the sanctuary, 158 (12%) were classified as oyster reef habitat. In 2009 Maryland Geological Survey conducted a side scan sonar survey of a small portion of the Calvert Shore Sanctuary. Of the 301 acres surveyed in 2009, 49 acres (16%) were classified as oyster reef habitat. The much greater coverage of the Bay Bottom Survey precludes comparison of the two surveys.

Restoration and Replenishment Activities

The Calvert Shore Sanctuary has not received any active restoration efforts since it was established in 2010. A single replenishment planting of fresh shell occurred in 1999 (Table A.02-1).

Table A.03-1. Replenishment planting activities occurring since 1990 in the area established as the Calvert Shore Sanctuary in 2010.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1999	Fresh Shell	0.83	2.4	-

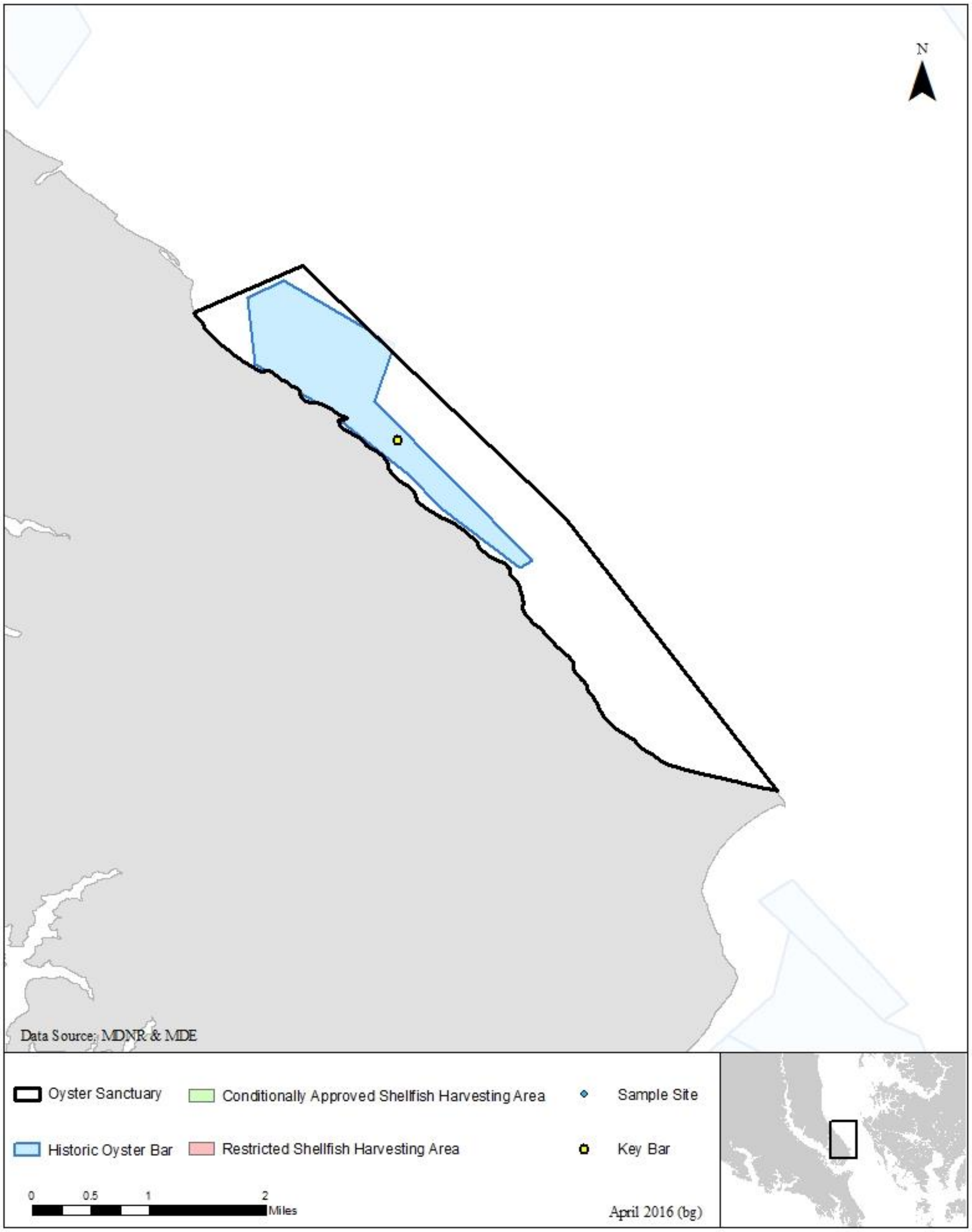


Figure A.03 -1. Calvert Shore Sanctuary.

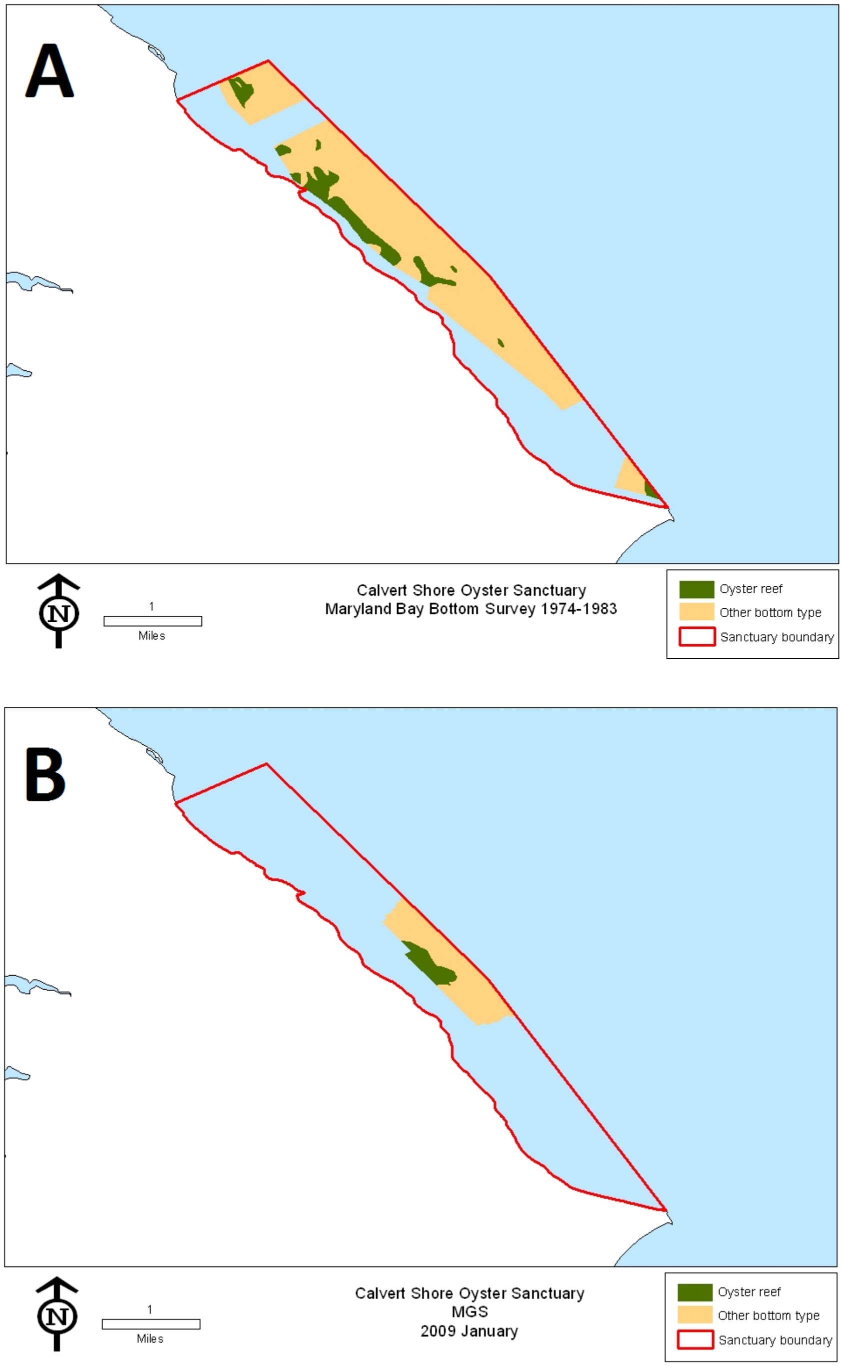


Figure A.03 -2. (A) Calvert Shore Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2009. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled one oyster bar (Flag Pond oyster bar) in the area of the sanctuary since 1990. One sample was collected annually except for 1992 through 1994 when two samples were collected. The average total live oysters per bushel (market, small, and spat) was similar before and after creation of the sanctuary (Table A.03.2; Figure A.03-3). The average number of small-sized oysters per bushel was also similar before and after creation of the sanctuary. The number of market-sized oysters per bushel generally increased after sanctuary creation, and the number of market-sized oysters in 2014 and 2015 (73 and 75 oysters per bushel, respectively) was the highest since 1990.

Table A.03-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Calvert Shore Sanctuary in 2010. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 23	6 / 6
Number of Live Oysters per Bushel	47 ± 20	49 ± 14
Number of Live Small-Sized Oysters per Bushel	13 ± 3	9 ± 3
Number of Live Market-Sized Oysters per Bushel	15 ± 4	33 ± 13
Live Oyster Biomass (g Dry Weight per Bushel)	40 ± 9	34 ± 11
Mortality (%) (Average ± Standard Error)	21.1% ± 5.0	10.7% ± 2.9

A patent tong population survey was conducted in 2015 (Figures 4.03-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of oysters was 0.1± 0.04 oysters m^{-2} (mean ± standard error, n= 136) with the density of market-sized oysters being generally greater than the density of small-sized oysters (0.09 ± 0.03 m^{-2} and 0.01 ± 0.01 m^{-2} , respectively). 92% of samples contained no live oysters or boxes. Live oyster density generally increased with total shell volume (Figure A.03-5). Some samples contained shell but no oysters, suggesting lack of larval supply or poor survivorship in these areas.

Oyster Size Structure

The Fall Survey has measured oyster shell heights at Flag Pond bar since 1990 (Figure A.03-6). Shell heights were also measured during the 2015 patent tong population survey (Figure A.03-7). Shell height increased between 2012 and 2015, with a notable increase in the proportion of oysters greater than the legal harvest height of 76 millimeters. The increase in height most likely resulted from growth of the strong 2010 and 2012 year classes coupled with absence of harvest. Between 1998 and 2001, few oysters were collected by the Fall Survey, thus making the size distribution skewed towards those few oyster heights (4 oysters in 1998, 1 oyster in 1999, 5 oysters in 2000, and 10 oysters in 2001).

Biomass

Biomass of oysters collected by the Fall Survey increased from 2011 to 2013. Biomass post-sanctuary creation is lower than the highest biomass occurring in 1990-2010, however (Table A.03-2; Figure A.03-8).

Recruitment (Spatfall)

Fall Survey spat counts ranged from 0 to 330 per bushel, with 1991 having the highest spat count (Figure A.03-3). Spat settled every year from 2010 to 2015, the longest continuous series of spat sets since 1990. The average spat set from 2010 to 2015 was 8 ± 2 (mean ± standard error) per bushel. No spat were found during the 2015 patent tong population survey.

Mortality

Based on Fall Survey box counts, average mortality decreased after the establishment of the sanctuary (Table A.03-2; Figure A.03-9).

Disease

Disease pressure from dermo has fluctuated over the years (Figure A.03-10). From 1990 to 2015, dermo prevalence ranged from 0% to 97% and dermo intensity ranged from 0.7 to 5.7 (scale of 0 to 7 with values greater than 5 indicating lethal infections). Since 1990 there have been three periods with dermo prevalence greater than 80%: 1991 to 1994, 1995, and 2007 and only one year (1992) in which dermo intensity reached lethal levels. MSX prevalence ranged from 0% to 53% from 1990 to 2015.

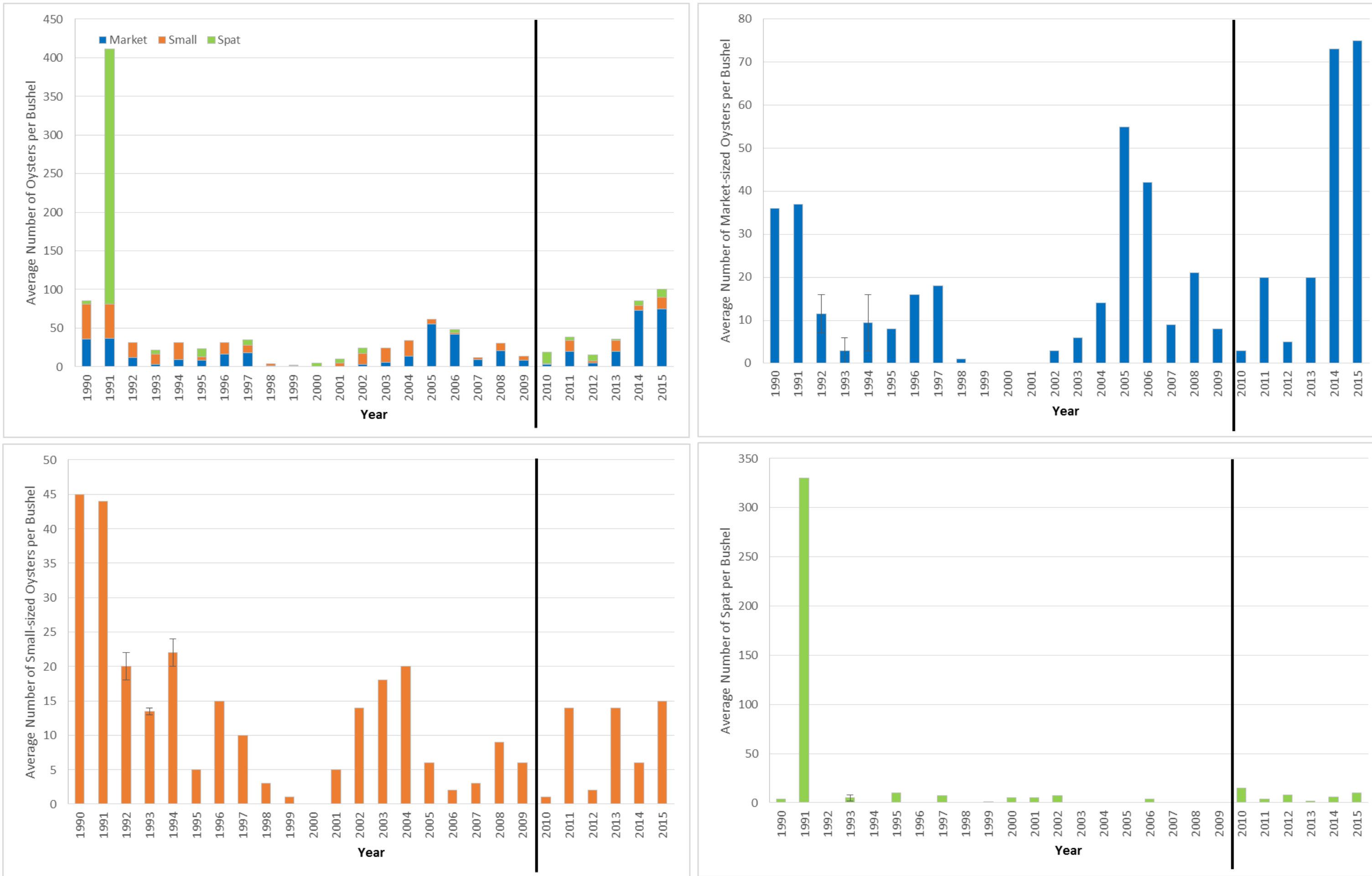


Figure A.03-3. Average number of live oysters per bushel of material by size class in the Calvert Shore Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

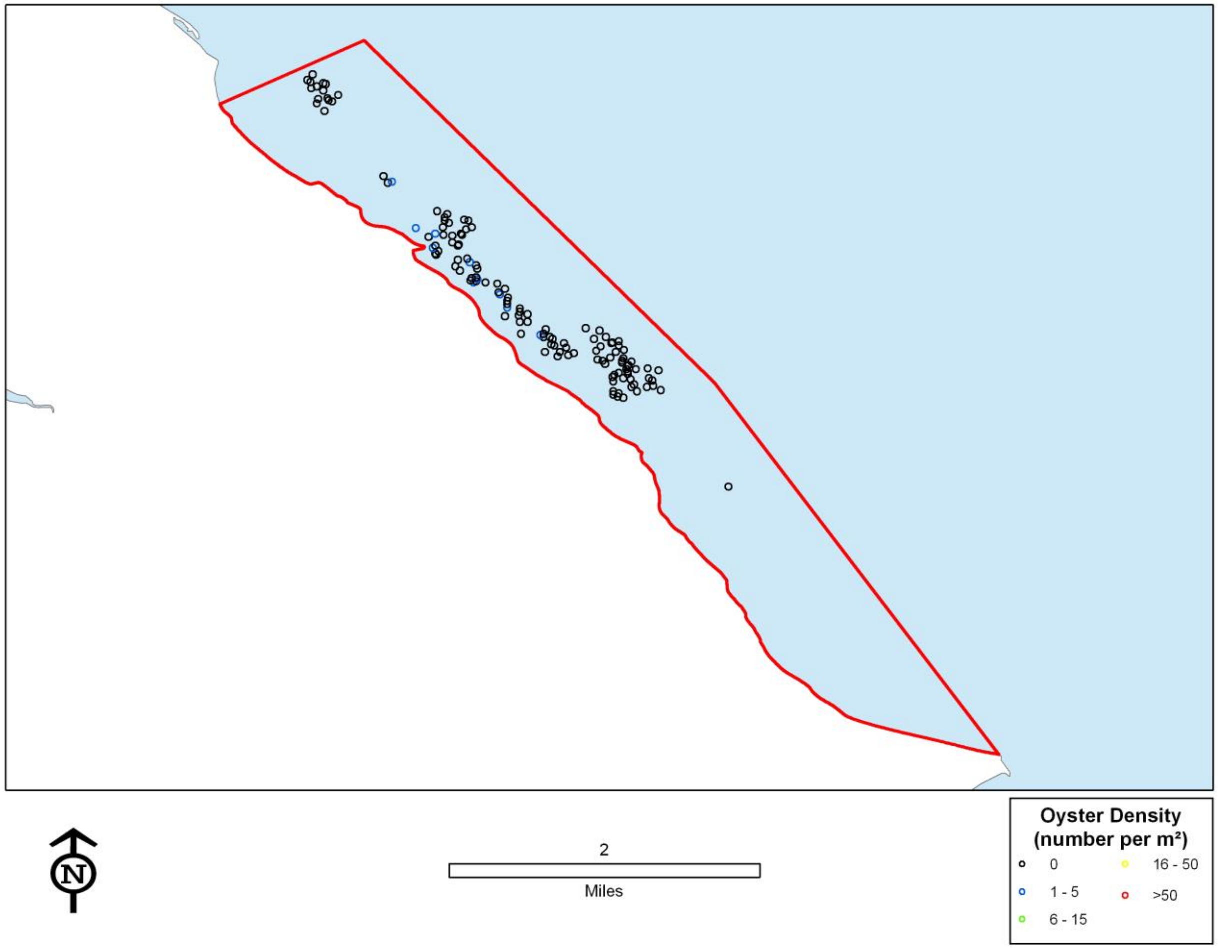


Figure A.03-4. Map of 2015 oyster density in the Calvert Shore Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

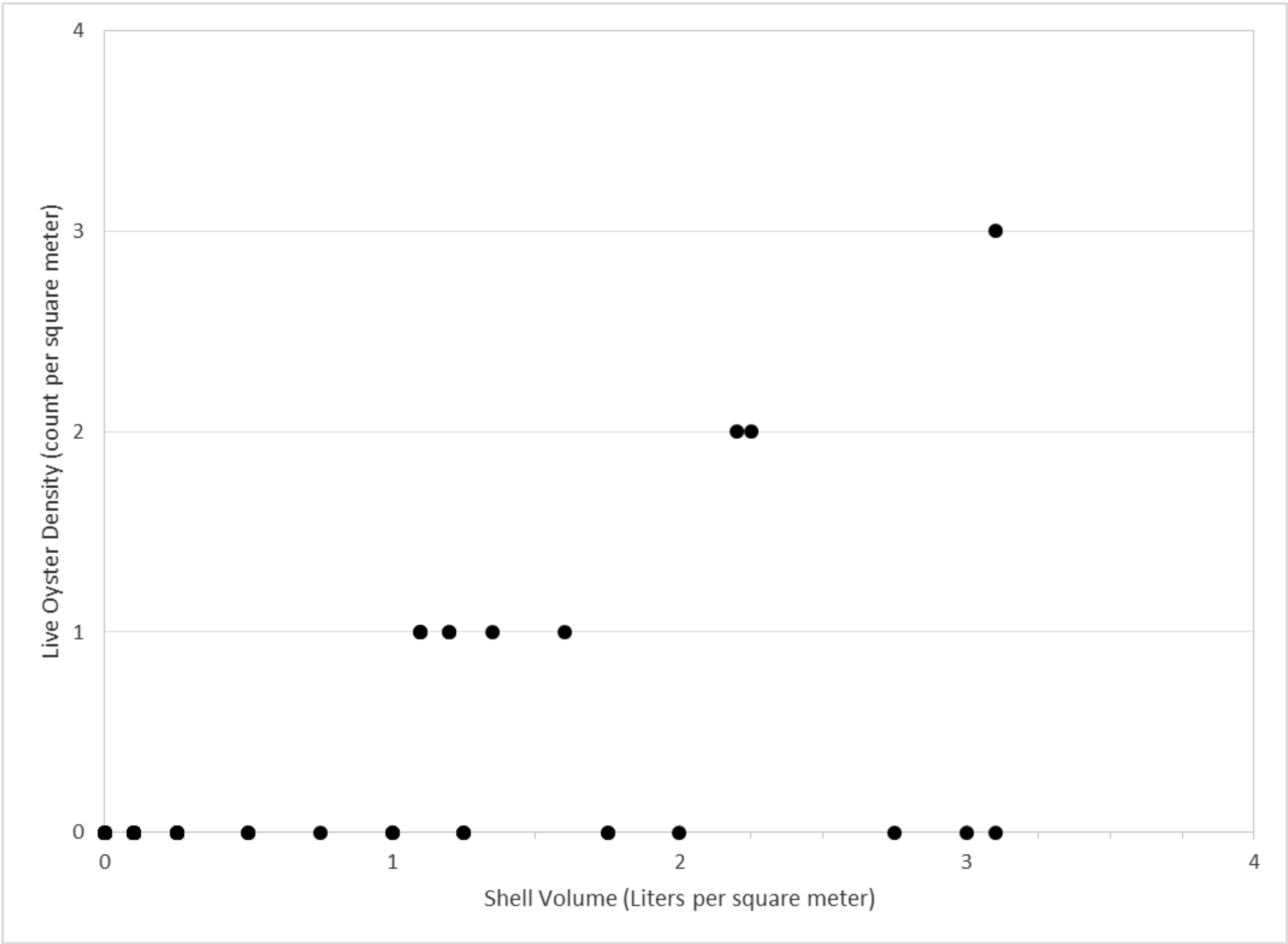


Figure A.03-5. 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Calvert Shore Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

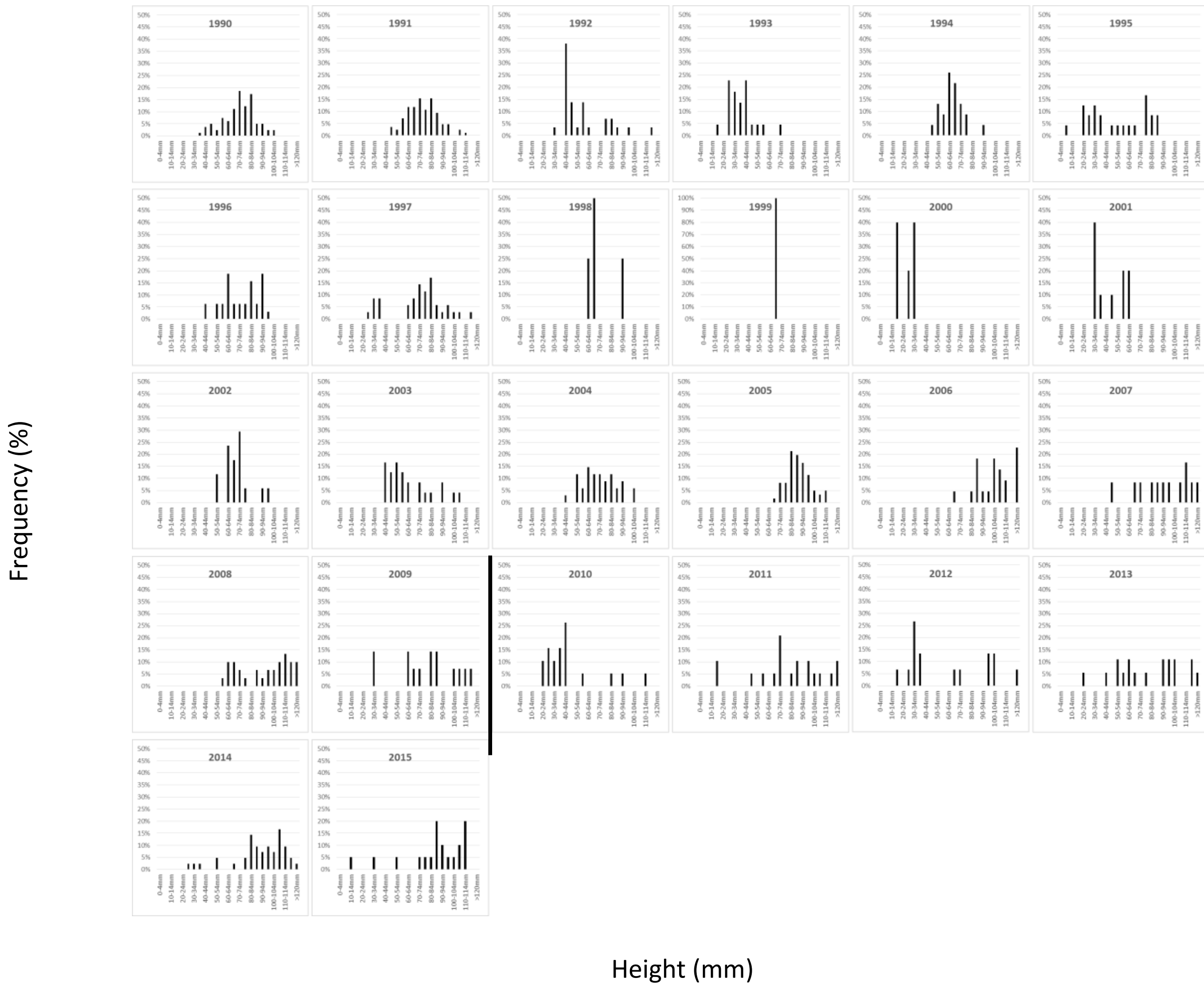


Figure A.03-6. Shell height frequencies of live oysters in the Calvert Shore Sanctuary from 1990 to 2015. Data from Maryland's Annual Fall Oyster Dredge Survey. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

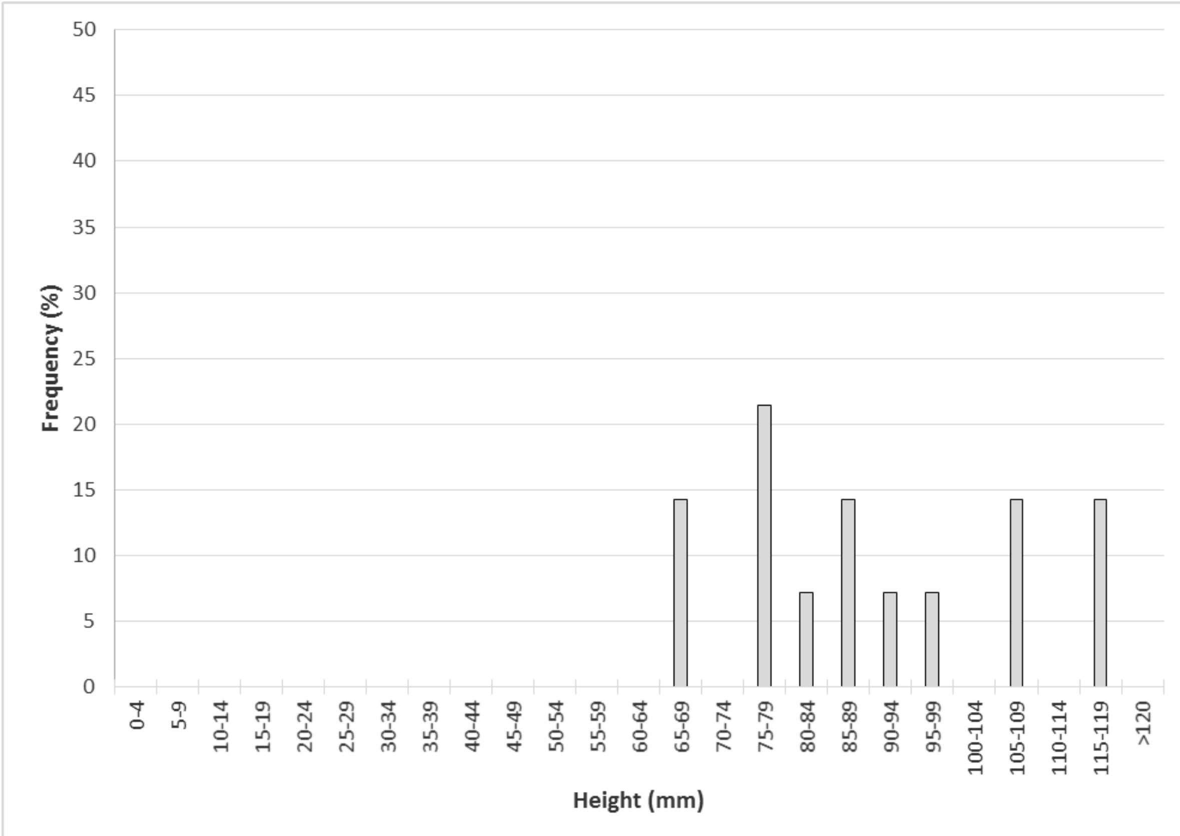


Figure A.03-7. Shell height frequencies of live oysters in the Calvert Shore Sanctuary in 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

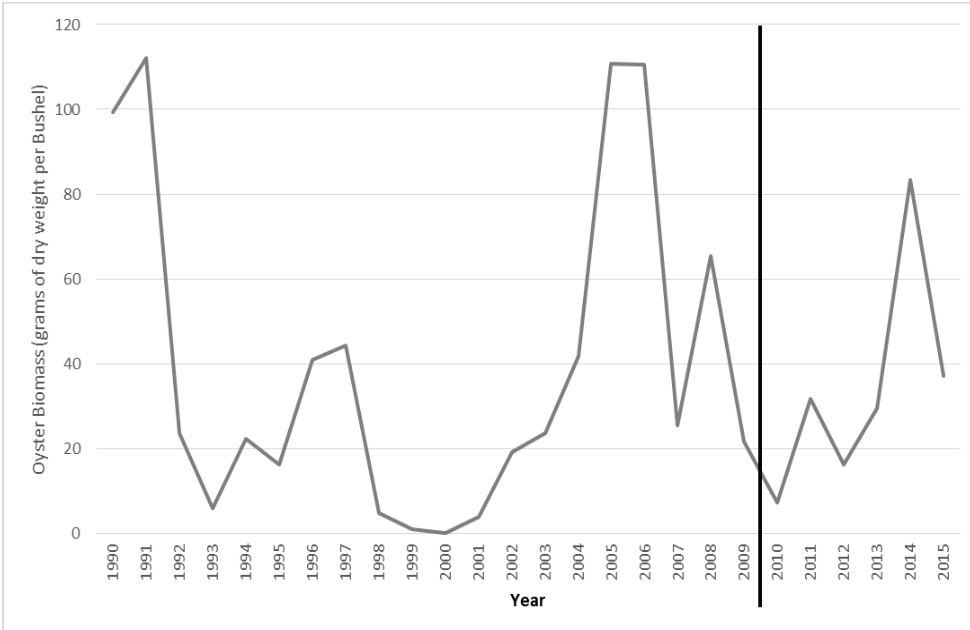


Figure A.03-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Calvert Shore Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line indicates the date the sanctuary was established.

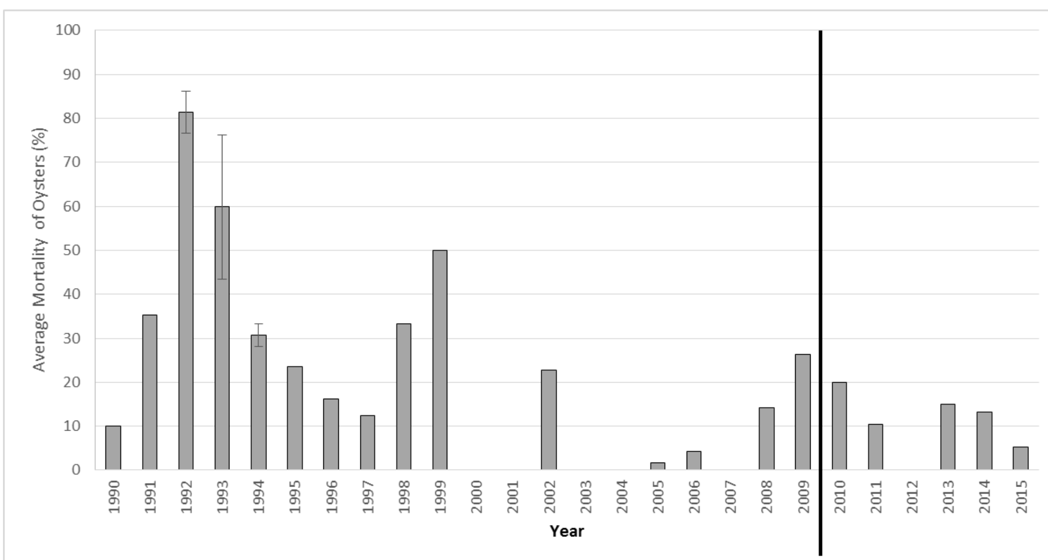


Figure A.03-9. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Calvert Shore Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

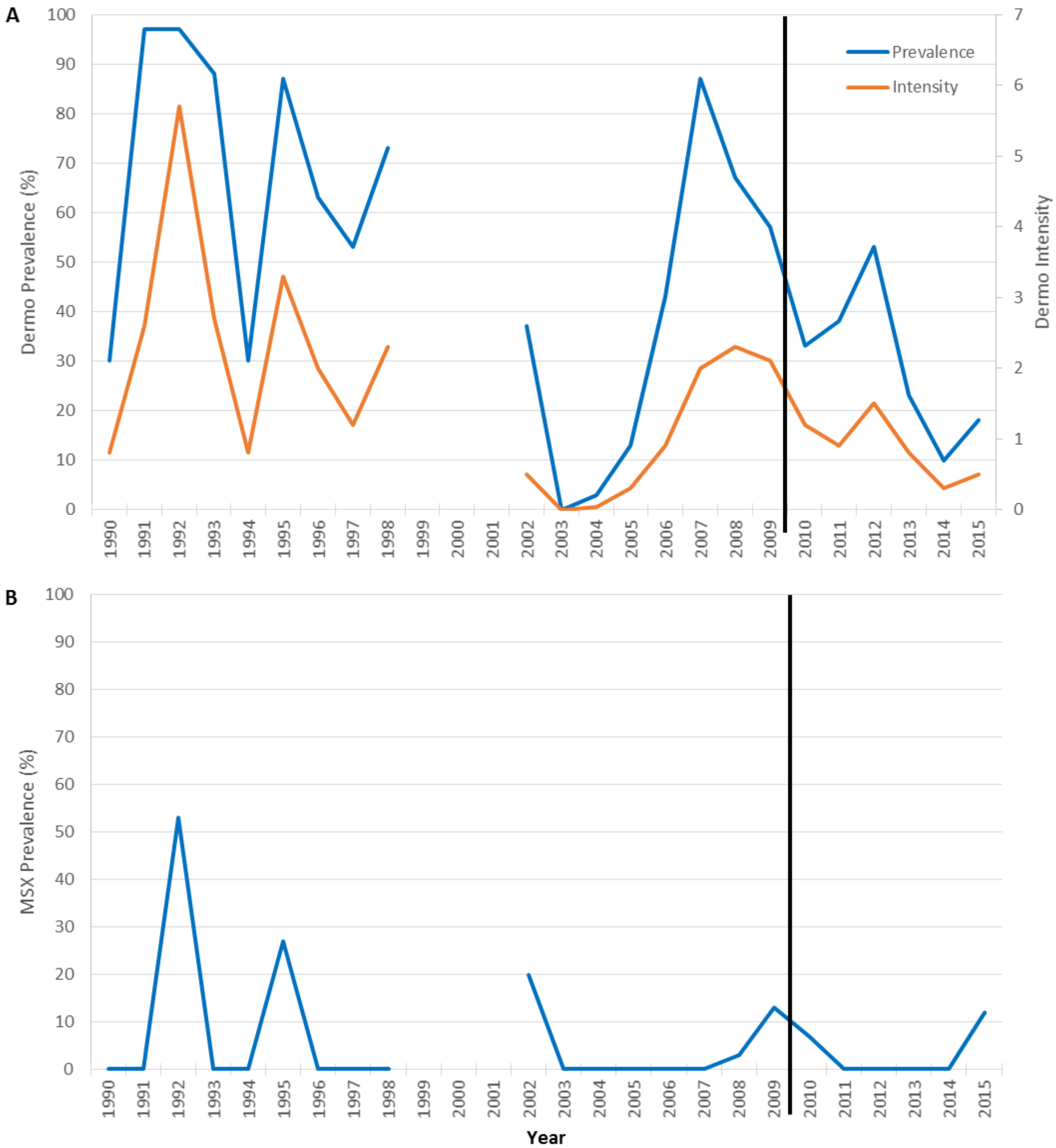


Figure A.03-10. Oyster disease prevalence and intensity from 1990 to 2016 in the Calvert Shore Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey. No disease analysis was performed from 1999 to 2001.

Harvest

The sanctuary encompasses 1.2% of the 186,830 acres in NOAA Code 027. Because harvest for NOAA Code 027 may have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. Oyster harvester reports show no harvest from bars located in this area in 2009-2010, the season immediately prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

To date, we are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in the sanctuary.

Section A.04: Cedar Point Sanctuary

The Cedar Point Sanctuary is located on the upper St. Mary's Shore, a medium salinity (12 to 14 ppt) region (Figure A.04-1). The sanctuary was created in 2010 and encompasses 3,473 acres of which 2,839 (82%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are two historic oyster bars within the sanctuary[12]; however, one of the bars only has 40% of its area within the sanctuary.

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.04-2). Of the 3,031 acres surveyed within the sanctuary, 1,460 acres (48%) were classified as oyster reef habitat. In 2013 Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 3,005 acres surveyed in 2013, only 195 acres (6%) were classified as oyster reef habitat, indicating a substantial loss of oyster habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

The sanctuary has not received any active restoration efforts since it was established in 2010, nor has it received any replenishment activities from 1990 to 2009.

Oyster Population Characteristics

The Fall Survey has not sampled any oyster bars within this area since 1990.

A patent tong population survey was conducted in sanctuary in 2013 (Figure A.04-3). Of the 158 samples collected, 98% of them had no live oysters or boxes. The average density of live oysters was 0.05 ± 0.03 individuals m^{-2} (mean ± standard error, n= 158). The average density of small-sized oysters was higher than market-sized oysters (0.03 ± 0.03 and 0.01 ± 0.01 oysters m^{-2}, respectively). The average density of spat was 0.01 ± 0.01 oysters m^{-2}. Oyster density increased with the volume of shell available (Figure A.04-4). The oyster height distribution showed mostly spat and small oysters with one market-sized oyster (Figure A.04-5).

[12] See chart 35 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

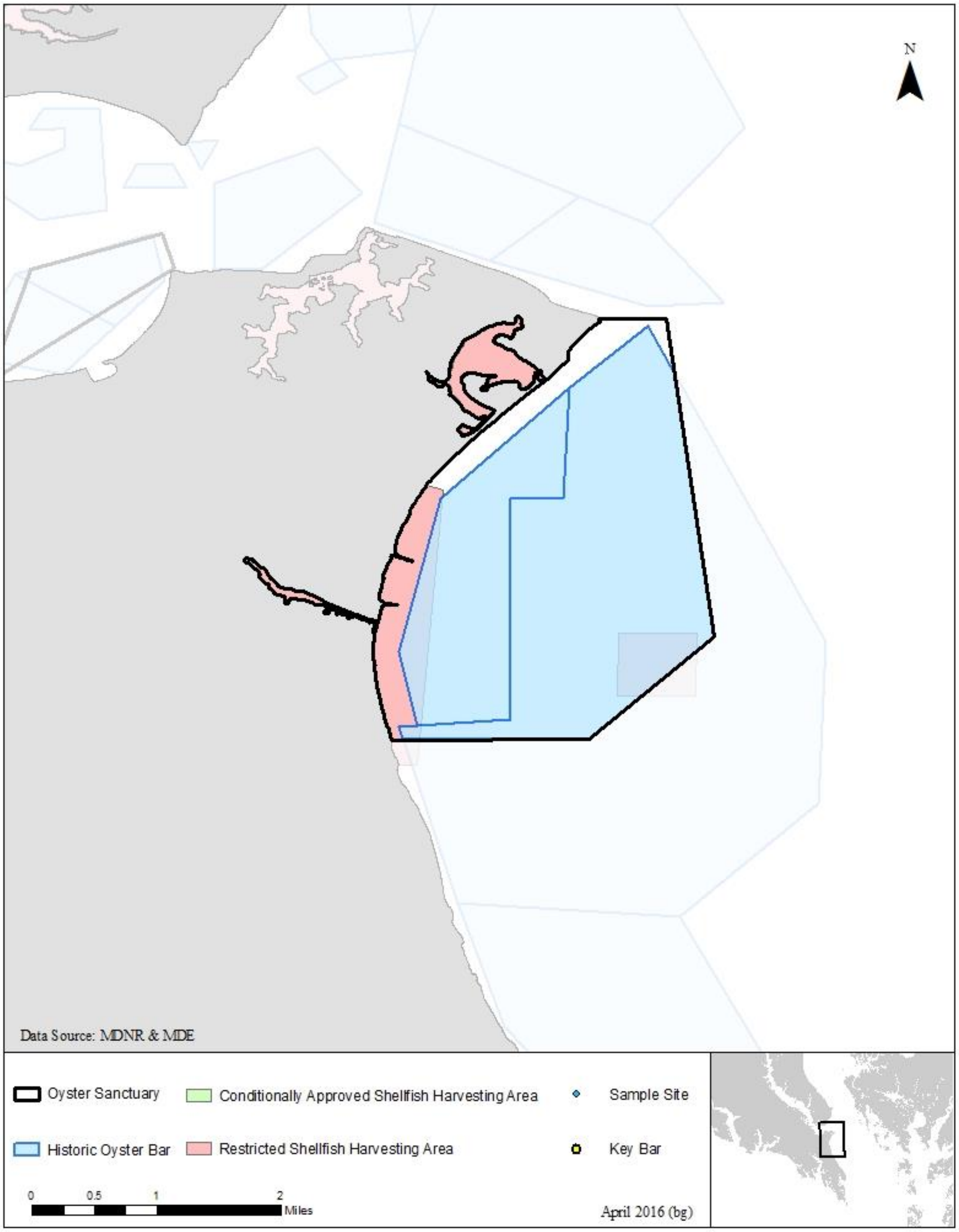


Figure A.04 -1. Cedar Point Sanctuary.

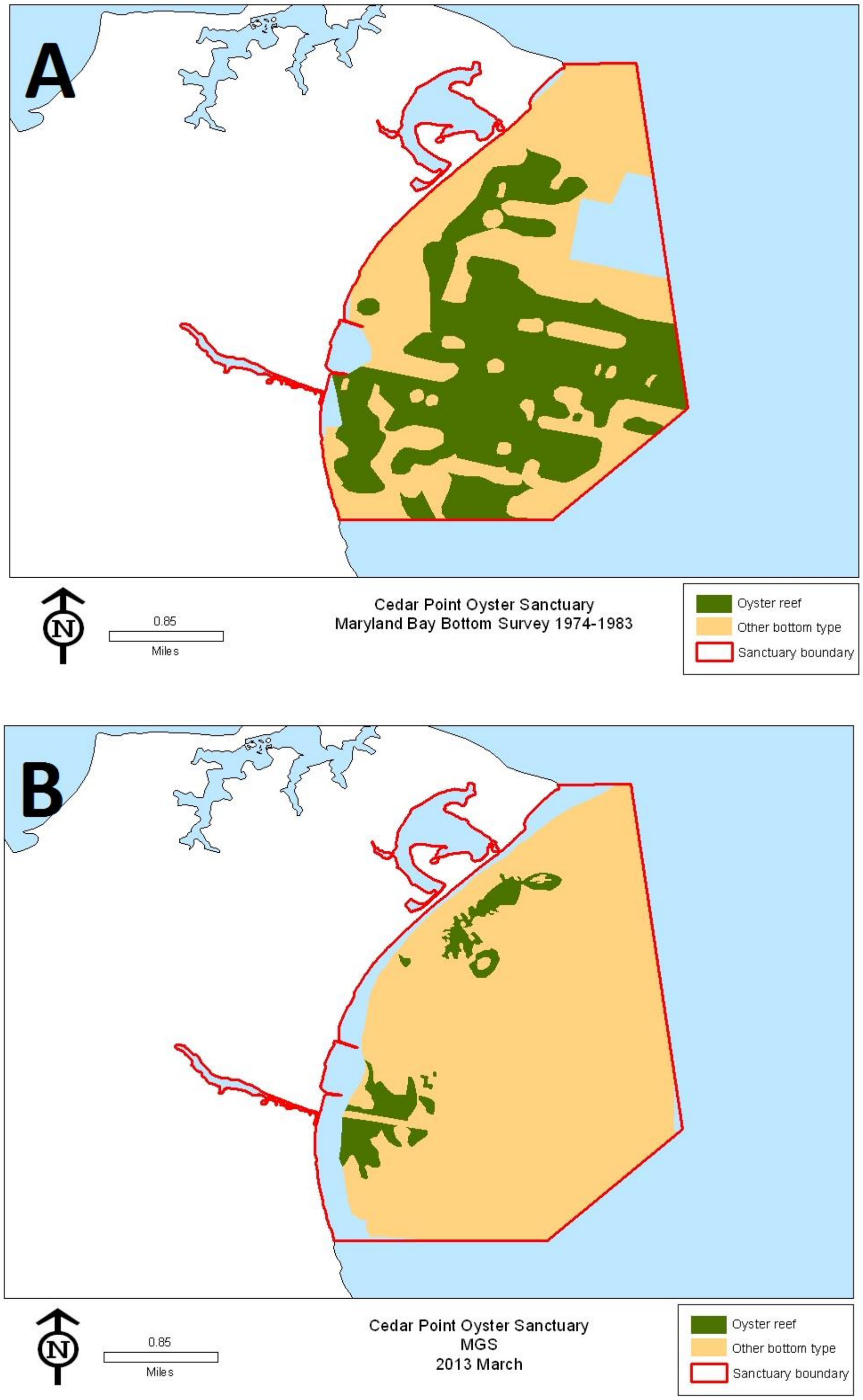


Figure A.04 -2. Cedar Point Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2013. Tan and green colored areas depict areas examined during the surveys.

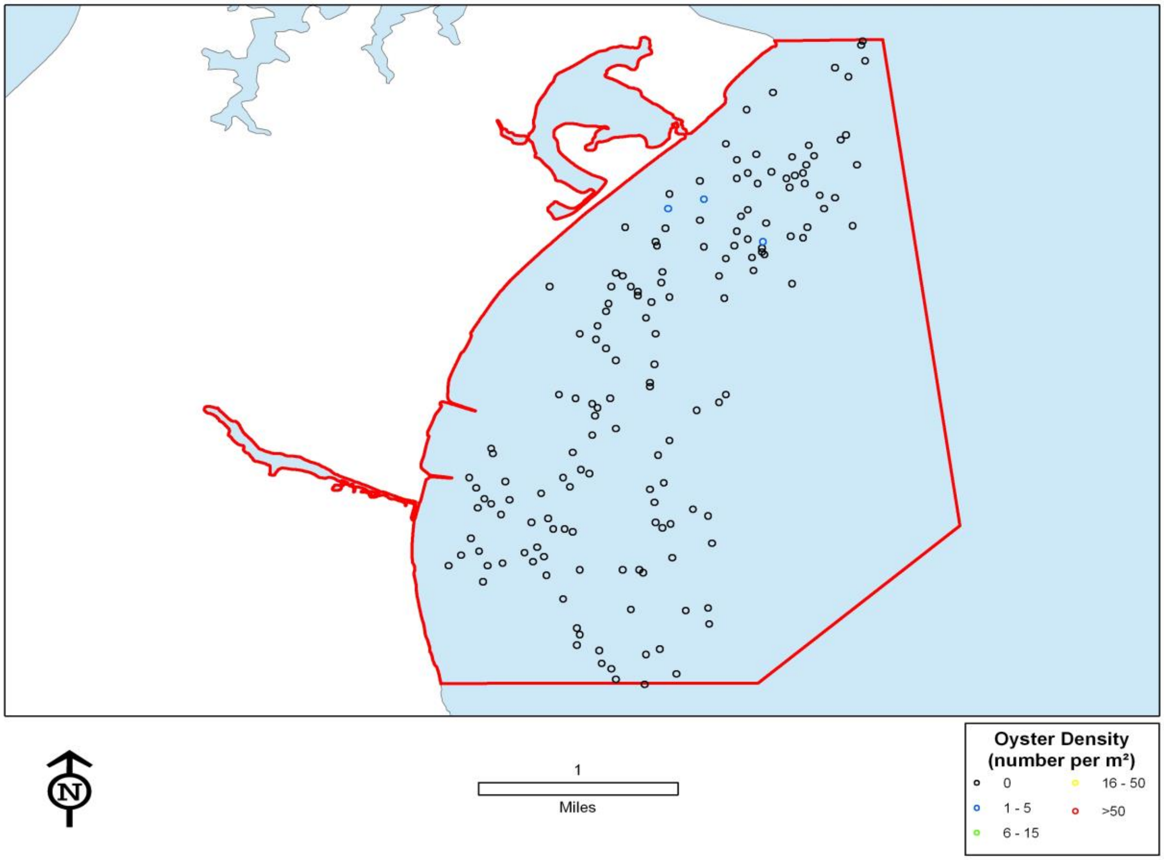


Figure A.04-3. Oyster density in the Cedar Point Sanctuary, 2013. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

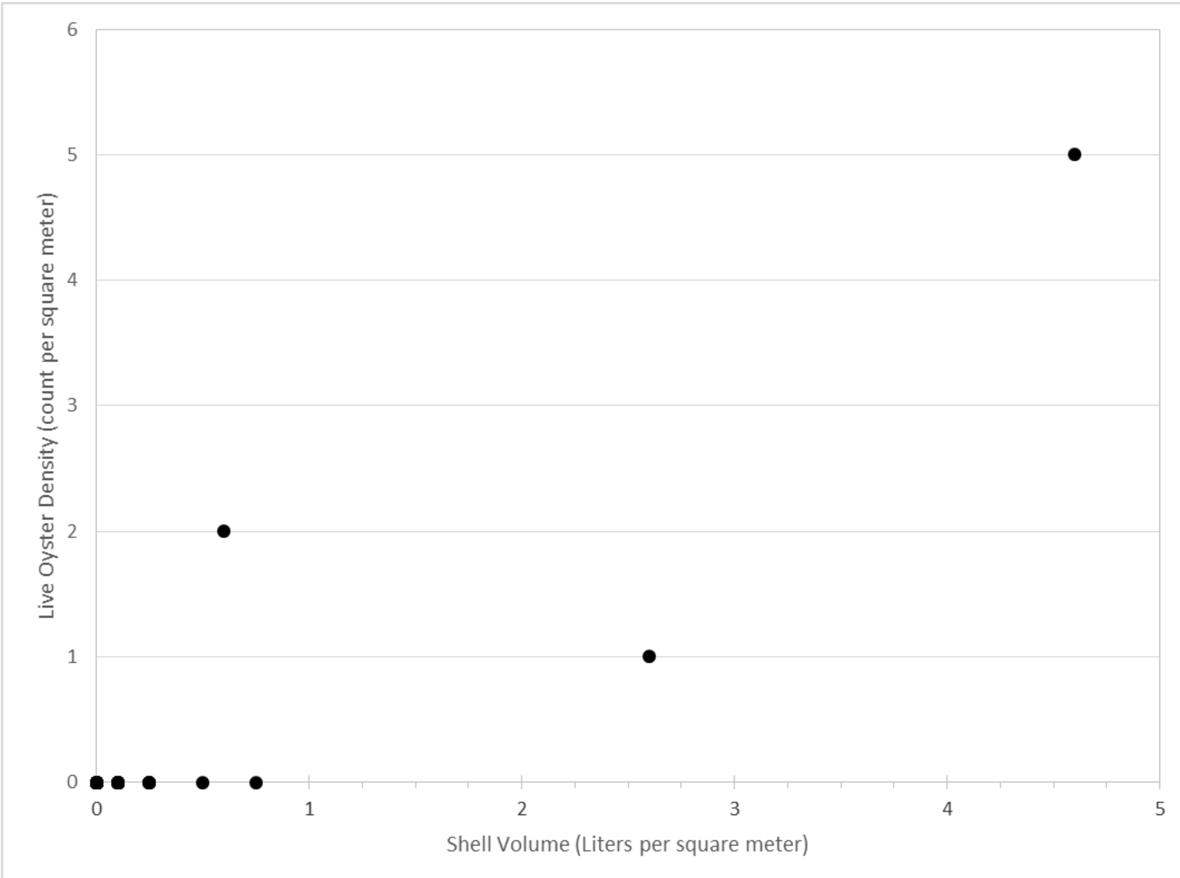


Figure A.04-4. 2013 live oyster density vs. shell volume (live oysters, boxes, and surface shell) in the Cedar Point Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

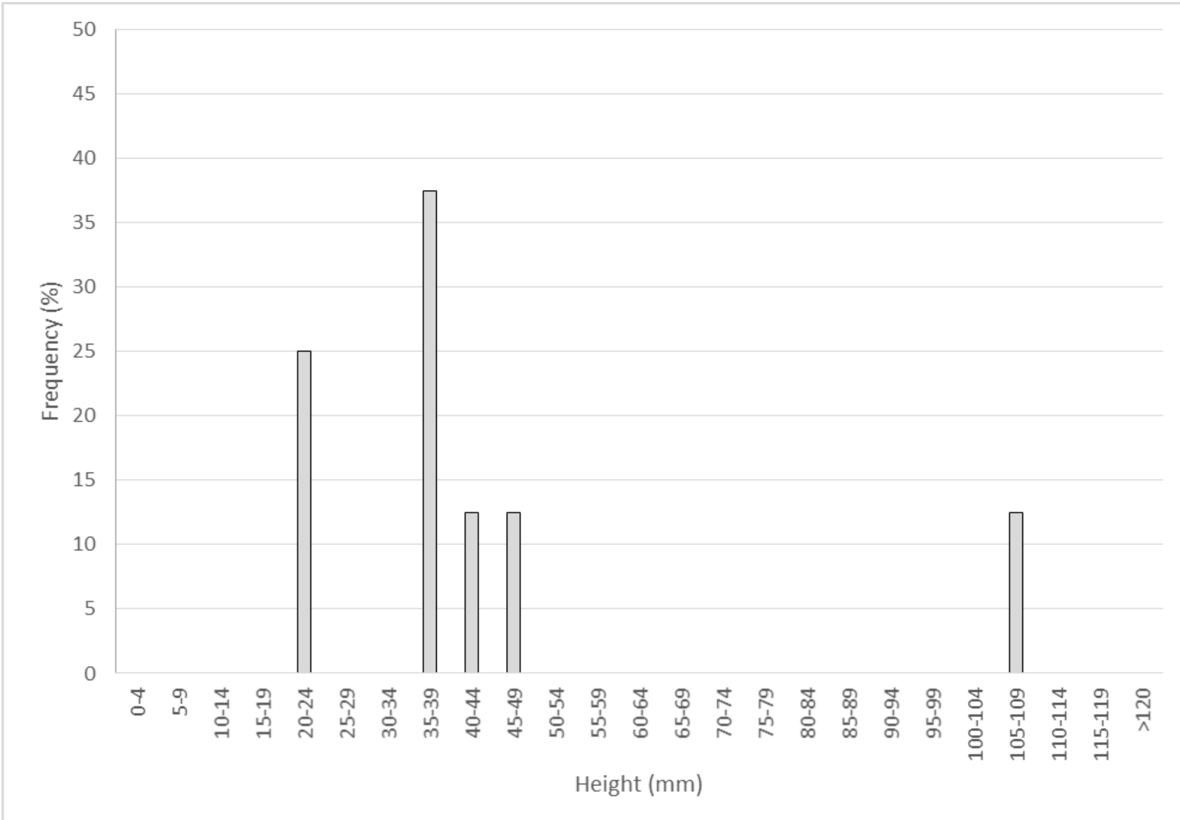


Figure A.04-5. Live oyster height distribution in the Cedar Point Sanctuary in May 2013. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

Harvest

The sanctuary encompasses 3.3% of the 105,377 acres in NOAA Code 229. Because harvest for NOAA code 229 may have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to say anything about harvest in the sanctuary area. Oyster harvester reports show no harvest from the area that is now established as this area in 2009-2010, the season immediately prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continual water quality monitoring) or oyster ecosystem services in the sanctuary.

Section A.05: Chester River ORA Zone A Sanctuary

The Chester Oyster Restoration Area (ORA) Zone A Sanctuary is located in the upper Chester River, a low salinity (less than 12 ppt) region of Maryland (Figure A.05-1). The sanctuary was created in 1996 to evaluate methods for oyster restoration, culture, and production as recommended by the Maryland Oyster Roundtable in 1993. The sanctuary encompasses 6,189 acres of which 184 (3%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are nine historic oyster bars within the sanctuary[13]. The majority of the sanctuary is classified as a conditionally or permanently restricted shellfish harvest area by Maryland Department of the Environment based on the potential presence of fecal coliforms and other bacteria in the shellfish.

Bottom Habitat Characteristics

The downstream area of the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.05-2). Of the 1,019 acres surveyed within the sanctuary, 693 acres (68%) were classified as oyster reef habitat. NOAA conducted side scan sonar surveys of the area from 2003-2007 and in 2012. Of the 772 acres surveyed by NOAA, 200 acres (26%) were classified as oyster reef habitat, suggesting a loss of oyster habitat since the Bay Bottom Survey was conducted. Results must be interpreted cautiously as some of the shallower shoreward areas examined by the Bay Bottom Survey were not surveyed by NOAA.

Restoration and Replenishment Activities

In 1998, 18.5 thousand bushels of dredged shell were planted in the sanctuary for restoration purposes (Table A.05-1). No planting activity occurred from 1990 to 1997 or after 1998.

Table A.05-1. Restoration planting activities occurring since 1990 in the area established as the Chester River ORA Zone A Sanctuary in 2010. S = planting occurring in the sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1998 (S)	Dredged Shell	6.0	18.5	-

[13] See chart 8 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

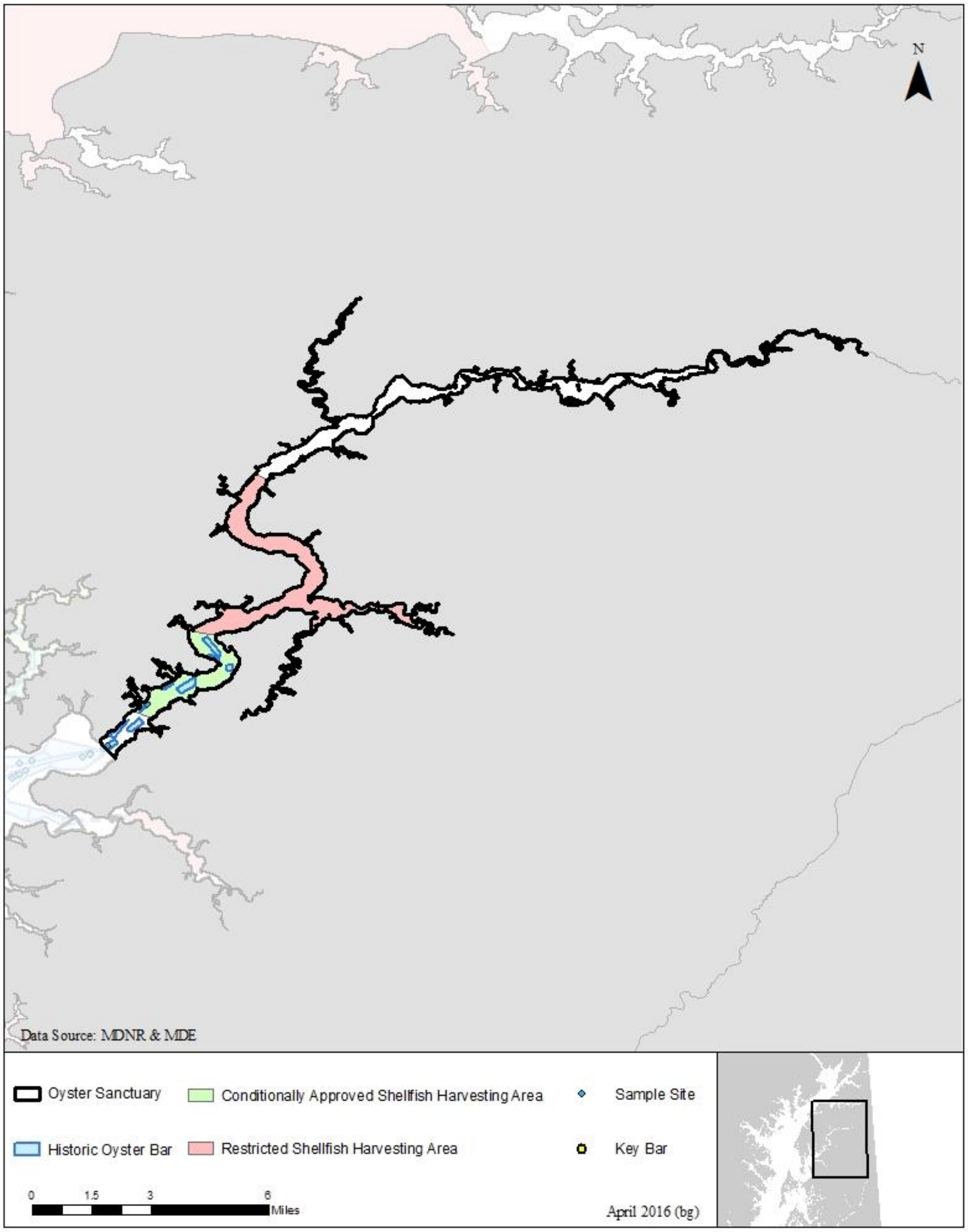


Figure A.05 -1. Chester River ORA Zone A Sanctuary.

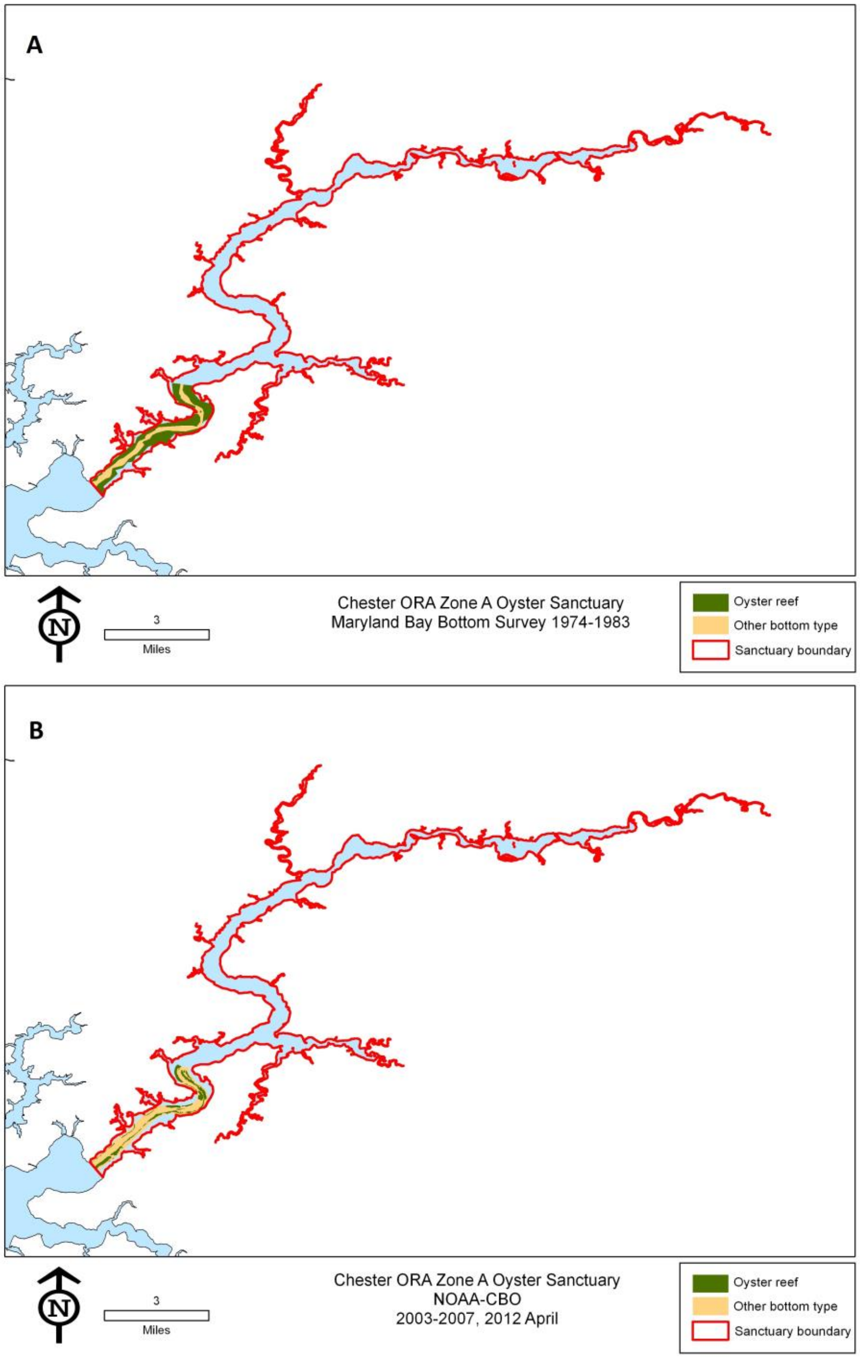


Figure A.05 -2. Chester River ORA Zone A Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2003 to 2007 and 2012. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled two oyster bars in this area since 1992. The area was not sampled in 1990 or 1991. The number of total live oysters per bushel (market, small, and spat) has fluctuated over the years (Figure A.05-3). The average number of all live oysters per bushel (market, small, and spat) decreased after the establishment of the sanctuary (Table A.05-2; Figure A.05-3). The average number of small-sized oysters per bushel was similar before and after sanctuary establishment, whereas the number of market-sized oysters per bushel decreased after sanctuary establishment.

Table A.05-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Chester River ORA Zone A in 1996. ND = No Data. Values are given as means ± standard error.

	1990-1995	**1996-2015**
Number of Years Sampled / Number of Samples	4 / 6	20 / 40
Number of Live Oysters per Bushel	34 ± 13	25 ± 3
Number of Live Small-Sized Oysters per Bushel	3 ± 2	4 ± 1
Number of Live Market-Sized Oysters per Bushel	30 ± 14	21 ± 3
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%) (Average ± Standard Error)	19.7 ± 13.5	12.8 ± 2.4

A patent tong population survey was conducted in 2012 (Figures A.05-4). No such population surveys were conducted prior to the establishment of the sanctuary. The average density of live oysters was 0.08 ± 0.05 oysters m^{-2} (mean ± standard error, n= 36). Only three small-sized oysters were collected. The percentage of samples having no live oysters or boxes was 92%. Although cultch was present, very few oysters were found. This suggests that recruitment is not limited by cultch availability (Figure A.05.5).

Oyster Size Structure

The Fall Survey has not consistently measured oyster shell heights in this area since 1990. Shell heights were measured during the patent tong population survey (Figure A.05-6). Only three oysters were collected; all of which were small-sized.

Biomass

The Fall Survey has not calculated biomass in this area since 1990.

Recruitment (Spatfall)

Based on the Fall Survey spat data, only three years since 1990 received a spat set: 1995, 2002, and 2010 (Figure A.05-4). The spat count ranged between two and three spat per bushel. This area generally has little natural recruitment.

No spat were collected during the 2012 patent tong population survey.

Mortality

Based on Fall Survey box counts, average annual mortality has decreased since the establishment of the sanctuary (Table A.05-2; Figure A.05-7). The highest mortality (57%) occurred in 1994, prior to the area becoming a sanctuary. Due to low salinity, disease is unlikely to be a cause of mortality in the sanctuary. Freshets may contribute to mortality, however.

Disease

The Fall Survey has not measured disease prevalence and intensity in this area since 1990.

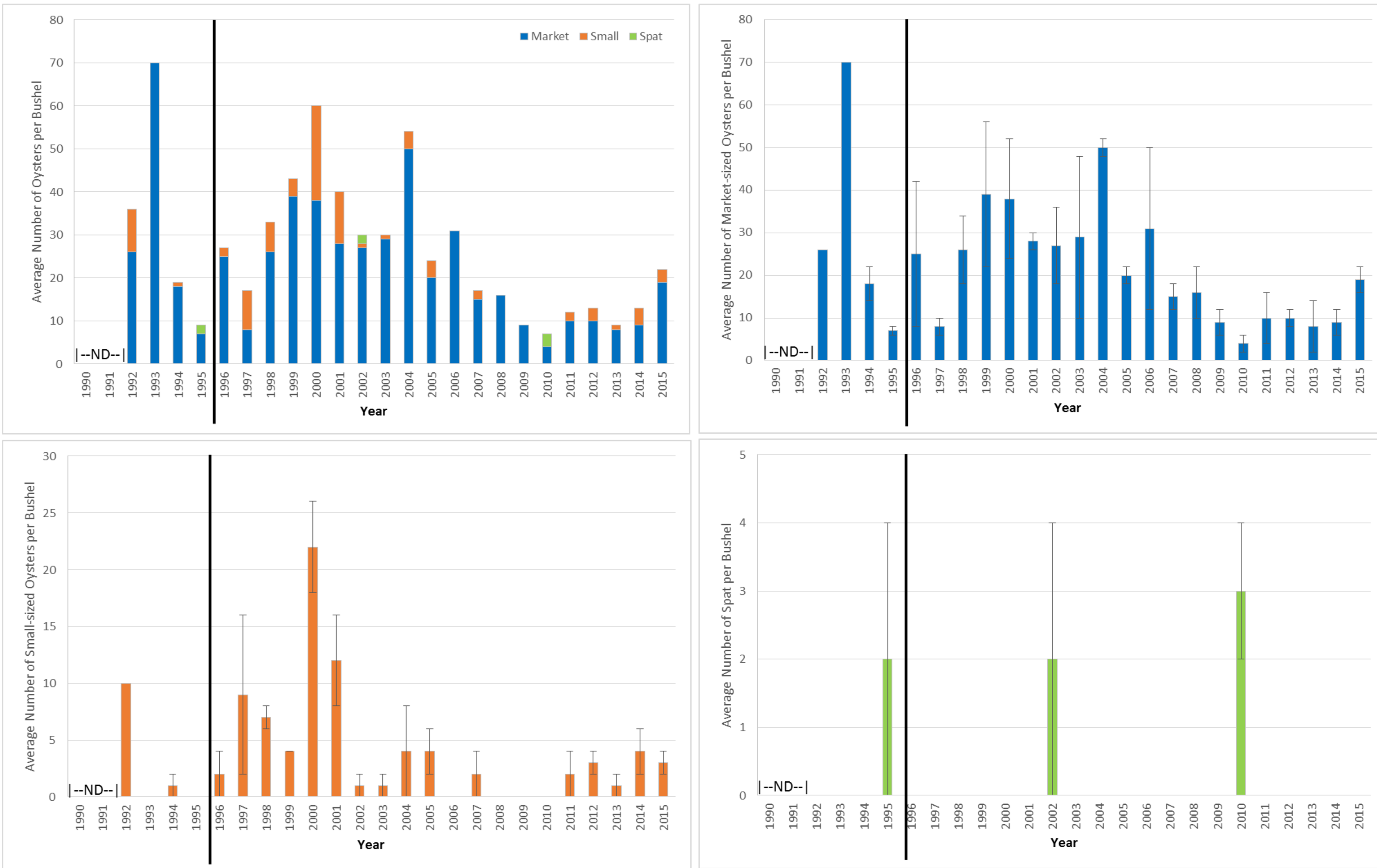


Figure A.05-3. Average number of live oysters per bushel of material by size class in the Chester River ORA Zone A Sanctuary. The area was not sampled in 1990 or 1991. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data.

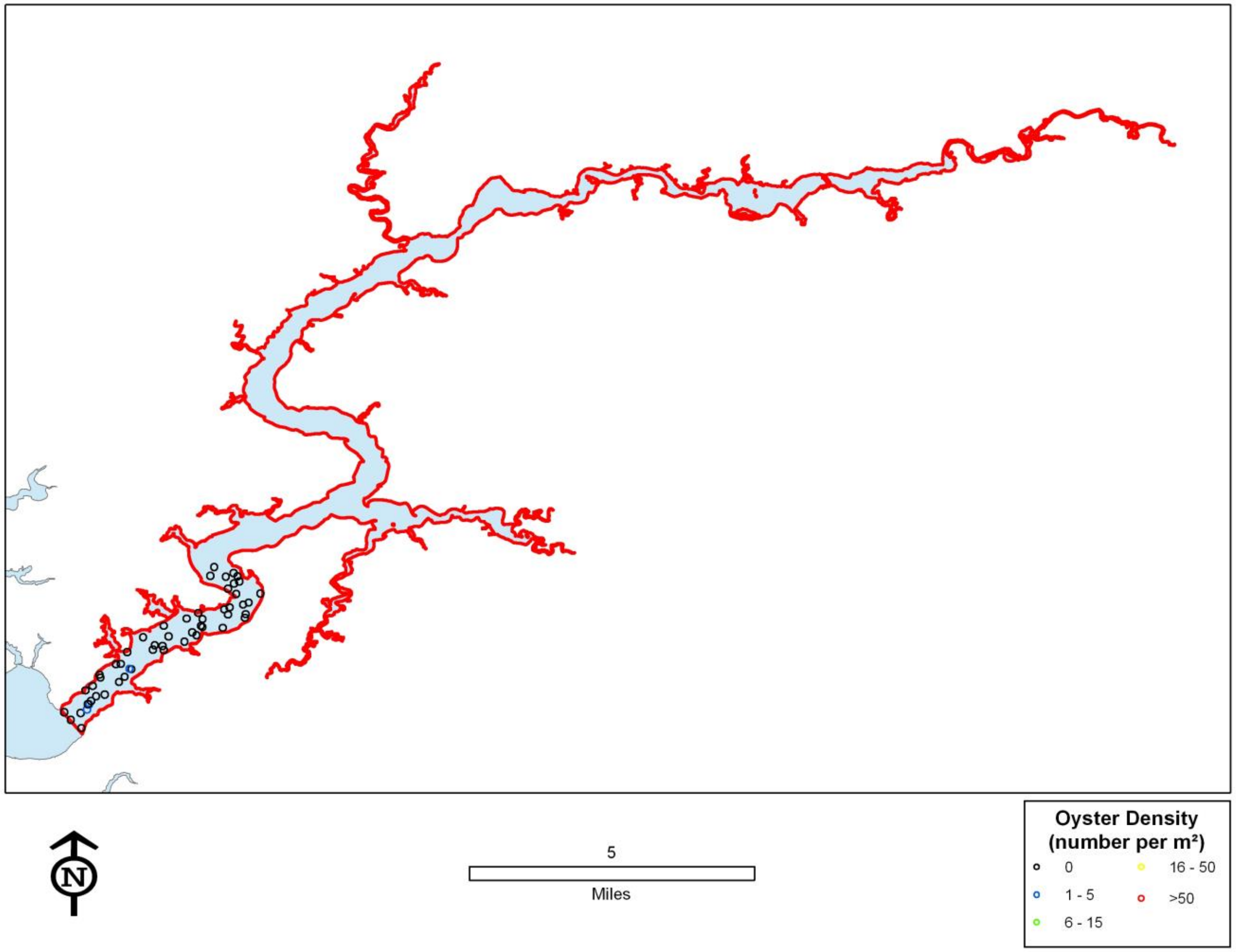


Figure A.05-4. Map of 2012 oyster density in the Chester River ORA Zone A Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

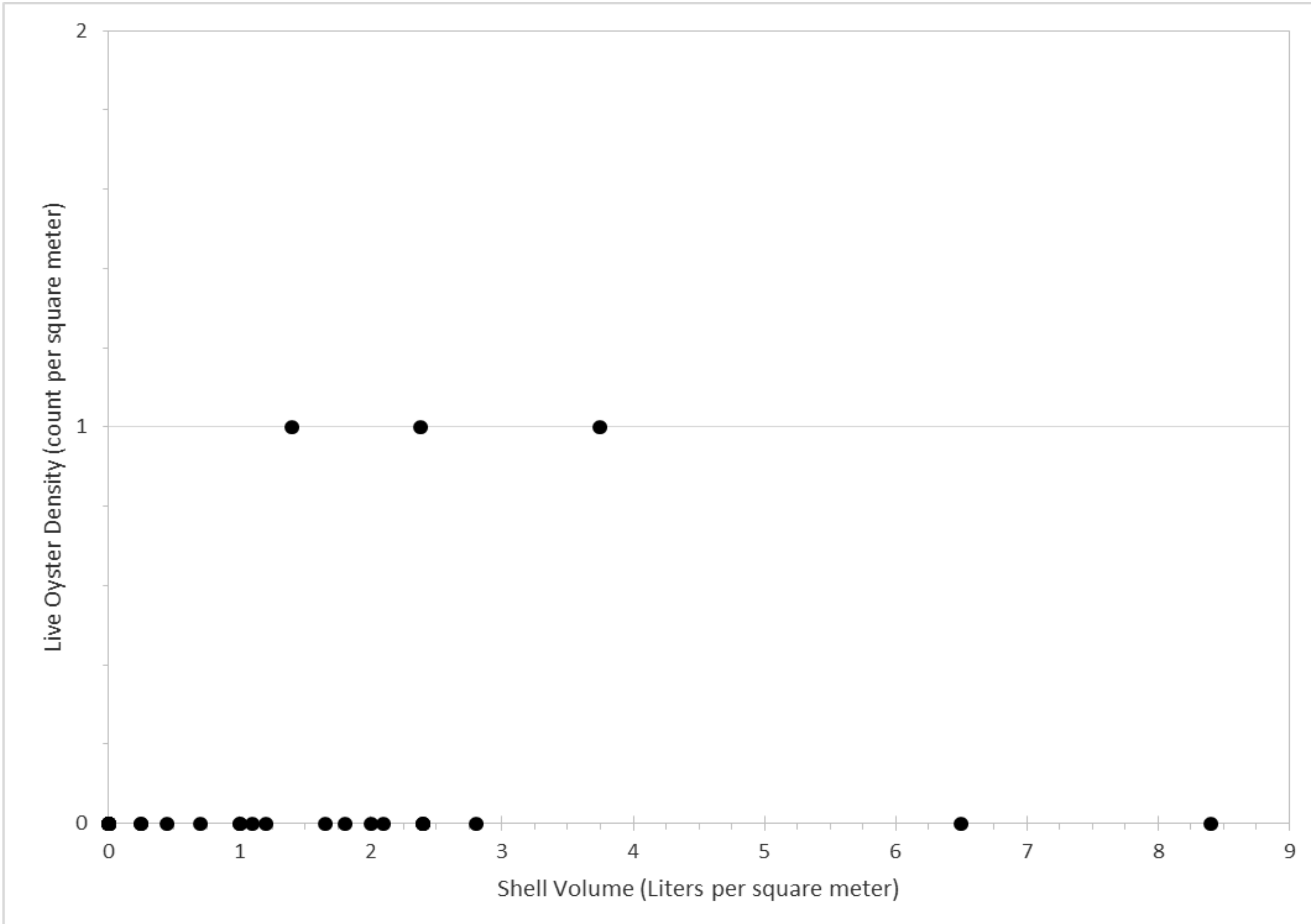


Figure A.05-5. 2012 live oyster density vs. shell volume in the Chester River ORA Zone A Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

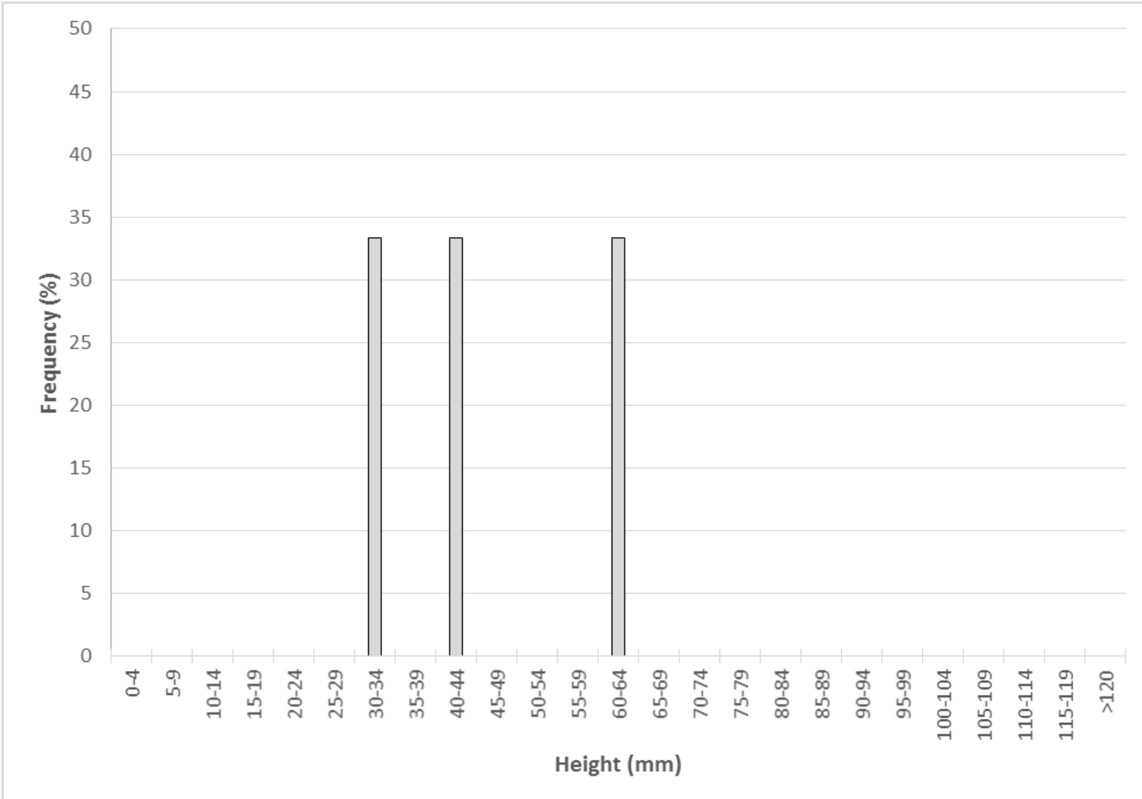


Figure A.05-6. Live oyster height distribution in the Chester River ORA Zone A Sanctuary in 2012. Data from Maryland Department of Natural Resources Population Patent Tong Survey.

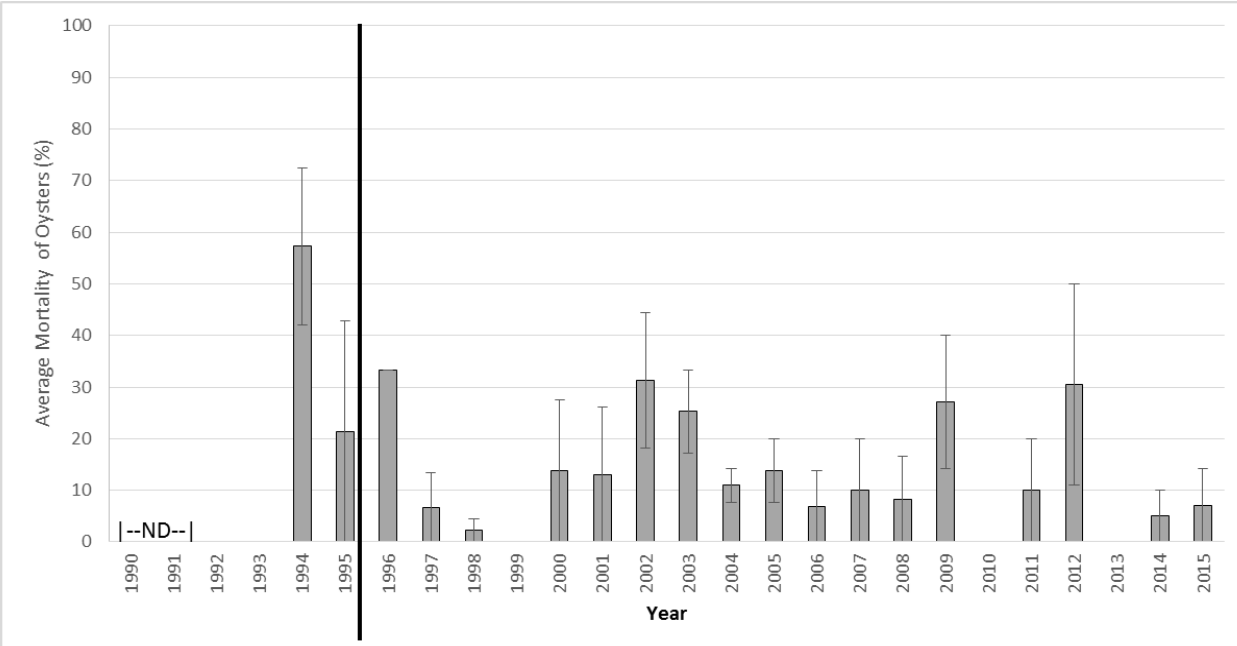


Figure A.05-7. Average annual mortality of market-sized and small-sized since 1992 in Chester River ORA Zone A Sanctuary (the area was not sampled in 1990 or 1992). Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error. ND = No Data.

Harvest

The sanctuary oyster bottom encompasses approximately 86% of the 7,204 acres in NOAA Code 331. The sanctuary was established prior to the collection oyster harvester reports; therefore, no harvester reports are available to assess catch before the creation of the sanctuary. In 2010, the entire area of NOAA Code 331 became a sanctuary (combination of Chester River ORA Zone A Sanctuary and Upper Chester River Sanctuary) and no harvest was allowed. Harvest totals, as reported from seafood dealer buy tickets, ranged from 0 (several seasons) to 2300 bushels (1991-1992 season) per season (Figure A.05-8).

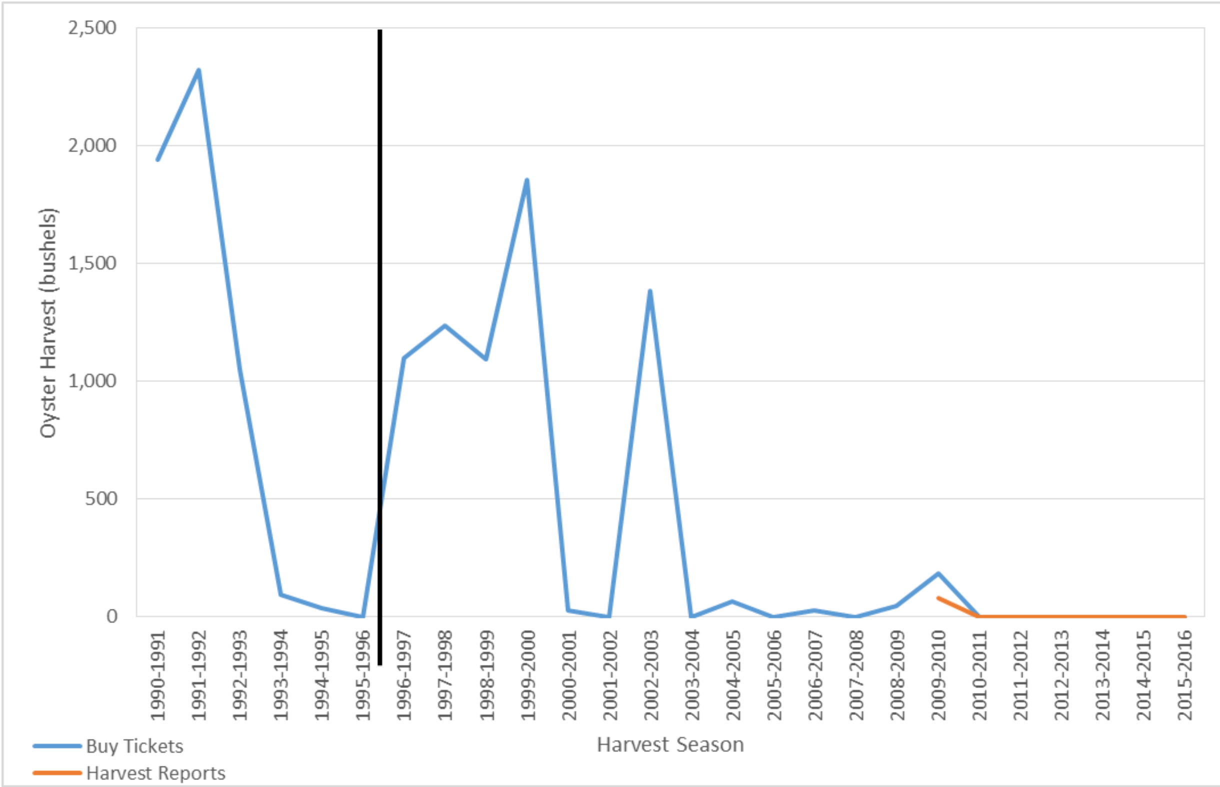


Figure A.05-8. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 331 (Chester River Upper). Black line denotes the date the sanctuary was established (1996). The Chester River ORA Zone A encompasses 86% of NOAA Code 331.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Data Hub has recorded monthly water quality at station XHH7848 (39.1298, -76.08772) in this area (Table A.05-2). Chlorophyll a, salinity, secchi depth, total nitrogen, total suspended solids, and water temperature were measured only from May to October, 2003. Salinity was low for oysters throughout this period. There is no information about water quality after the establishment of the sanctuary.

We are unaware of any studies explicitly examining oyster ecosystem services in the sanctuary.

Table A.05-2. Surface water quality values from station XHH7848 (39.1298, -76.08772) in the Chester River ORA Zone A Sanctuary.						
Sample Date	Chlorophyll a (ug/L)	Salinity (ppt)	Secchi Depth (ft)	Total Nitrogen (mg/L)	Total Suspended Solids (mg.L)	Water Temperature (Celsius)
5/29/2003	6.73	5.57	0.50	1.94	12.00	16.00
6/11/2003	10.96	4.88	0.30	1.74	29.00	21.00
7/30/2003	26.66	4.75	0.60	1.12	9.00	27.10
8/20/2003	9.16	3.83	0.50	1.11	8.75	28.30
9/10/2003	19.44	5.57	0.70	0.97	10.75	23.90
10/30/2003	5.98	6.43	0.90	0.98	4.85	14.20

Section A.06: Choptank River ORA Zone A Sanctuary

The Choptank River ORA Zone A Sanctuary is located in the upper Choptank River, a low salinity (less than 12 ppt) region of Maryland (Figure A.06-1). The sanctuary was created in 1996 to evaluate methods for oyster restoration, culture, and production as recommended by the Maryland Oyster Roundtable in 1993. The sanctuary encompasses 8,962 acres of which 236 (3%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 11 historic oyster bars within the sanctuary[14]. In 2009, the entire sanctuary is classified by the Maryland Department of the Environment as restricted area due to potential contamination with fecal coliforms and other bacteria. Therefore, no shellfish harvest would be allowed if the area was not a sanctuary.

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.02-2). Of the 1,413 acres surveyed within the sanctuary, 978 (69%) were classified as oyster reef habitat. In 2008 Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 1,302 acres surveyed in 2008, which largely overlap with the Bay Bottom Survey, only 142 acres (11%) were classified as oyster reef habitat, indicating a substantial loss of oyster habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

Dredged shell was planted in 1994 as a replenishment activity for the wild fishery prior to the area being designated a sanctuary. Hatchery spat-on-shell was planted in 2008 for restoration purposes (Table A.06-1).

Table A.06-1. Replenishment and restoration planting activities occurring since 1990 in the area established as the Choptank River ORA Zone A Sanctuary in 1996. S = planting occurring after the area was established as a sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1994	Dredged Shell	11.18	10.44	-
2008 (S)	Hatchery Spat-on-Shell	20.23	-	15.99

[14] See chart 21 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

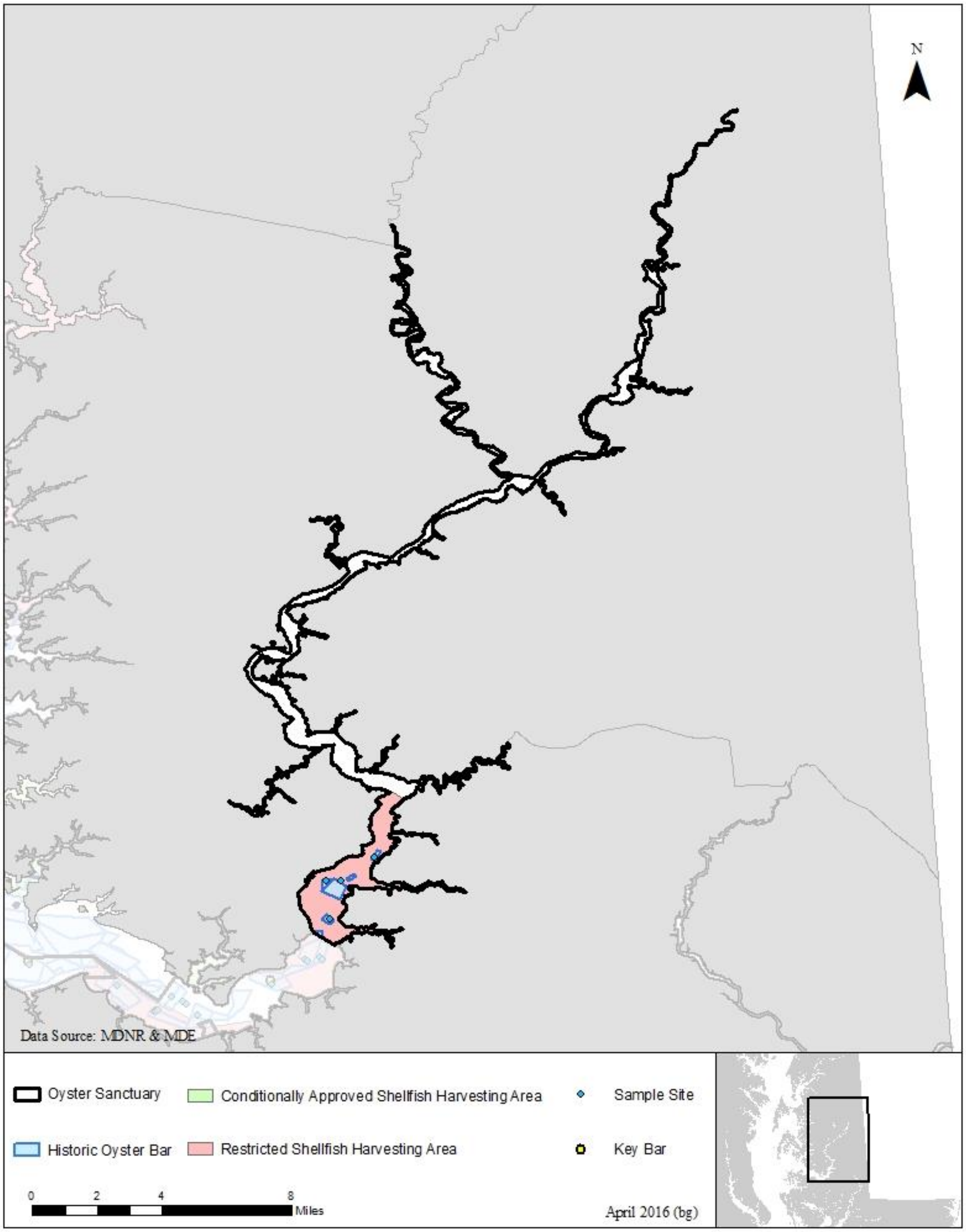
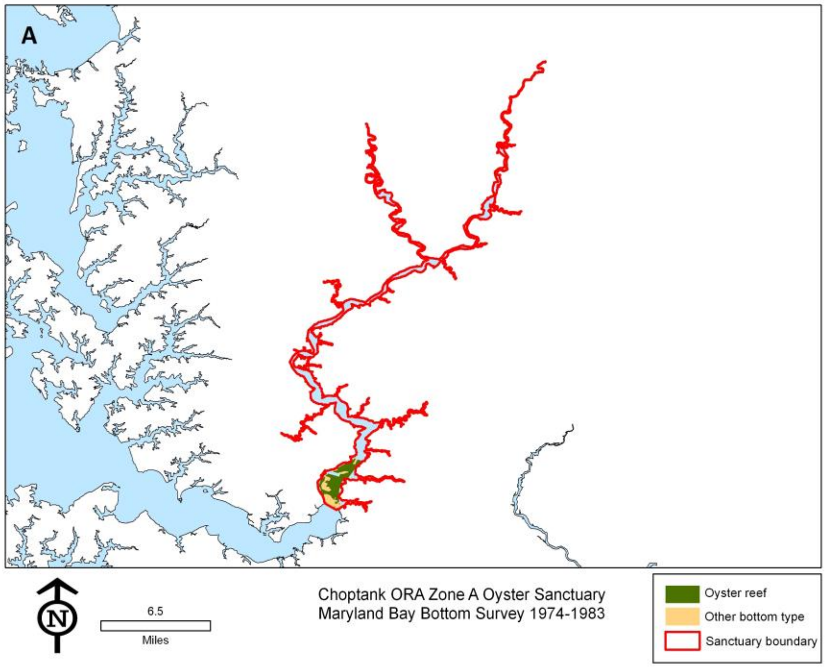


Figure A.06 -1. Choptank River ORA Zone A Sanctuary.



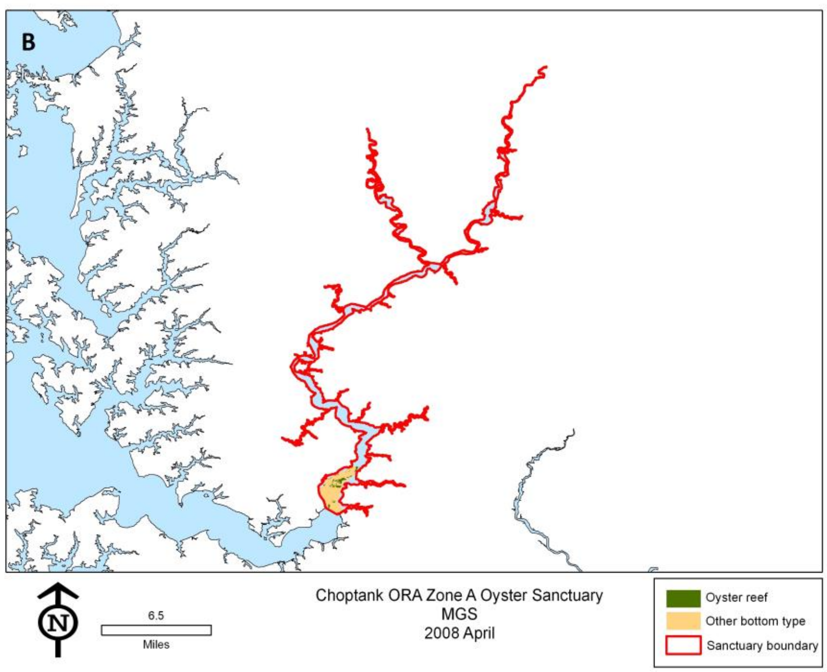


Figure A.05 -2. Choptank River ORA Zone A Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2008. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled 3 to 4 oyster bars in this area since 1990 with an average of 3 oyster bars sampled annually. The number of live oysters per bushel (market, small, and spat) has fluctuated over the years, but decreased after sanctuary establishment (Table A.06.2; Figure A.06-3). The same pattern of decrease was observed when small- and market-sized oysters were considered separately.

Table A.06-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Choptank River ORA Zone A Sanctuary in 1996. ND = No Data. Values are given as means ± standard error.

	1990-1995	**1996-2015**
Number of Years Sampled / Number of Samples	6 / 19	20 / 68
Number of Live Oysters per Bushel	150 ±2 0	46 ± 8
Number of Live Small-Sized Oysters per Bushel	93 ± 10	25 ± 5
Number of Live Market-Sized Oysters per Bushel	54 ± 11	21 ± 4
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	14.8 ± 4.7	11.6 ± 2.9

A patent tong population survey was conducted in 2015 (Figures A.06-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 11.49 ± 2.99 oysters m^{-2} (mean ± standard error, number of samples collected was 143). Density of small oysters (8.57 ± 2.65 individuals m^{-2}) was greater than that of market-sized oysters (2.92 ± 0.84 individuals m^{-2}). Of the 37 samples collected, 41% had no live oysters or boxes. Oyster density generally increased with shell volume (Figure A.06-5).

Oyster Size Structure

The Fall Survey has not consistently measured oyster shell heights in this area since 1990. Heights of oysters collected during the patent tong population survey ranged from 31-110 mm with the most frequent size being between 65 and 69 mm (Figure A.06-6).

Biomass

The Fall Survey has not calculated biomass in this area since 1990.

Recruitment (Spatfall)

From 1990 to 2015, spat count per bushel ranged from 0 to 17 (Figure A.06-3). The highest number of spat collected was in 1992 (17 ± 6 per bushel, mean ± standard error). Spatfall occurred infrequently over the time period.

No spat were collected during the 2015 patent tong population survey.

Mortality

Based on Fall Survey box counts, average mortality was similar before and after sanctuary establishment (Table A.06-2; Figure A.06-7).

Disease

No Fall Survey disease samples have been taken within this area since 1990.

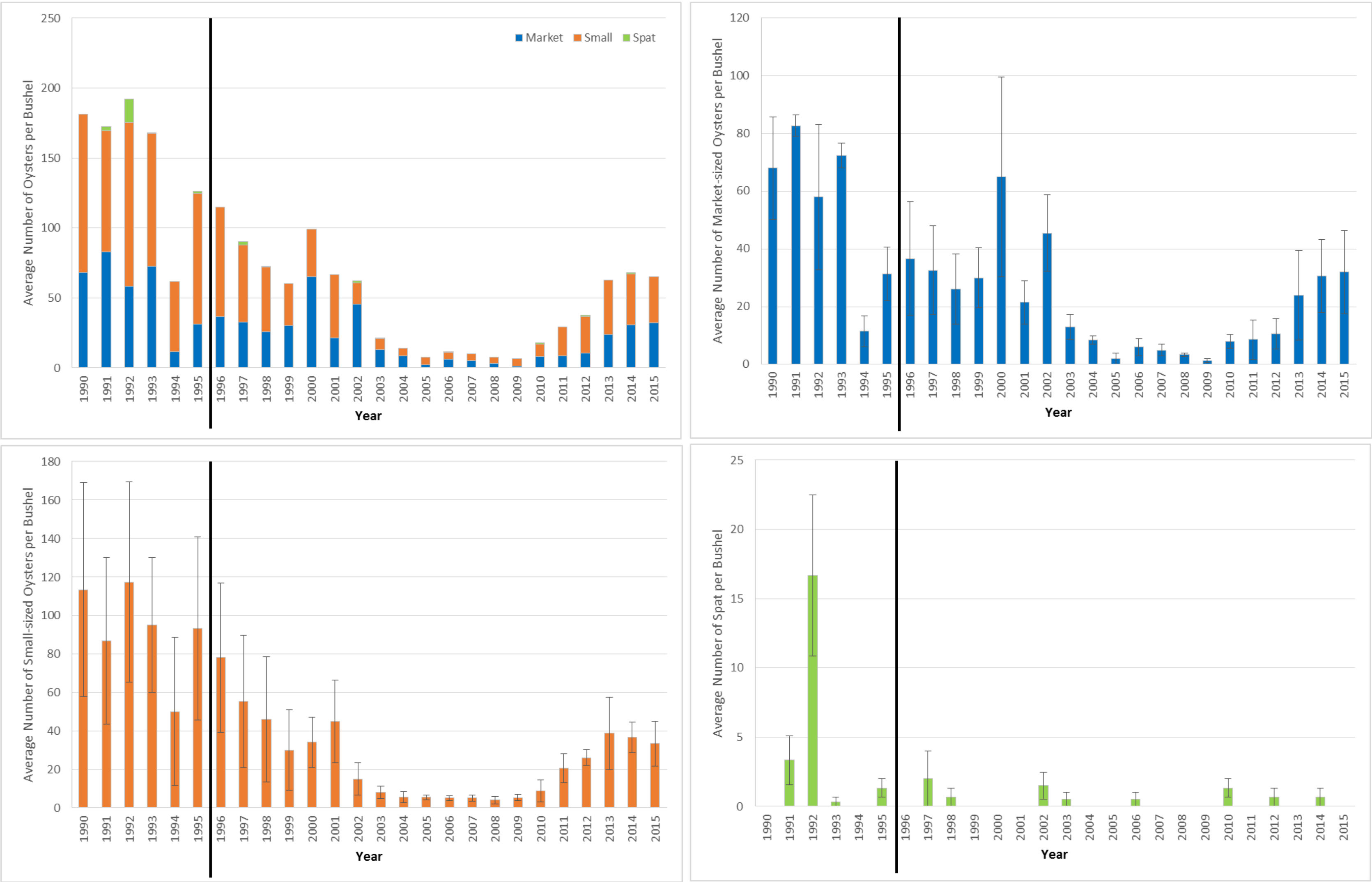


Figure A.06-3. Average number of live oysters per bushel of material by size class in the Choptank River ORA Zone A Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

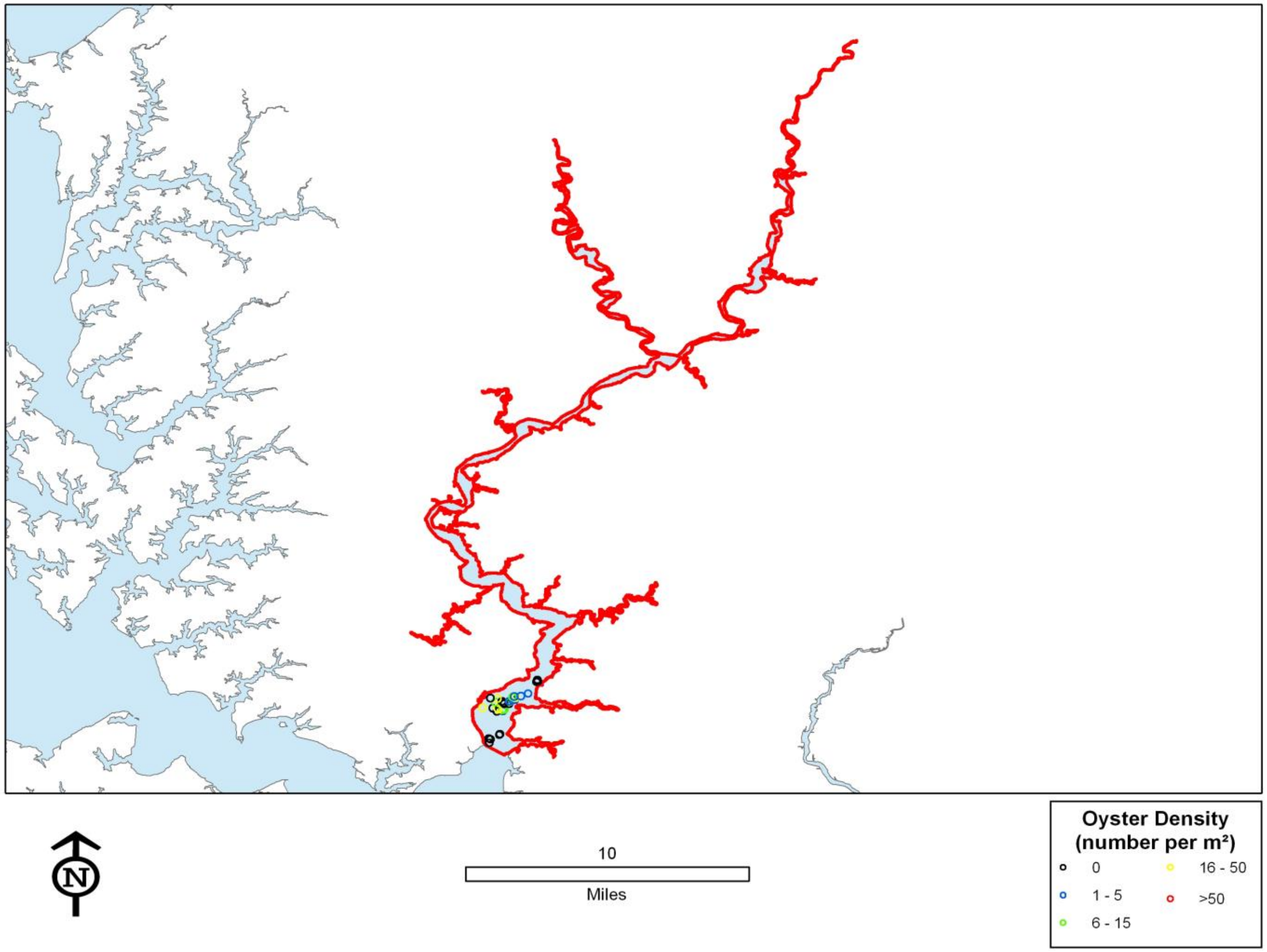


Figure A.06-4. Map of 2012 oyster density in the Choptank ORA Zone A Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

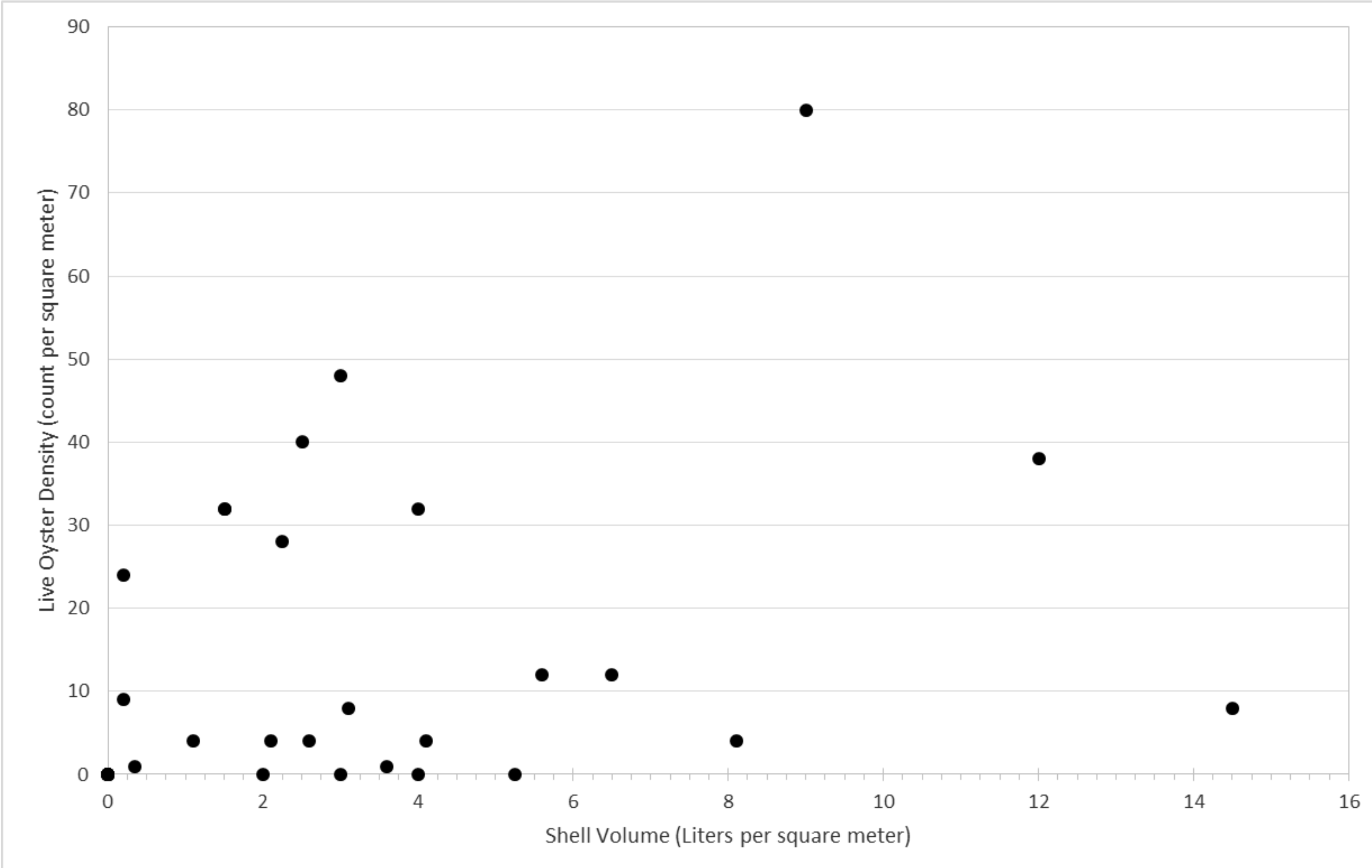


Figure A.06-5. 2012 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Choptank River ORA Zone A Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

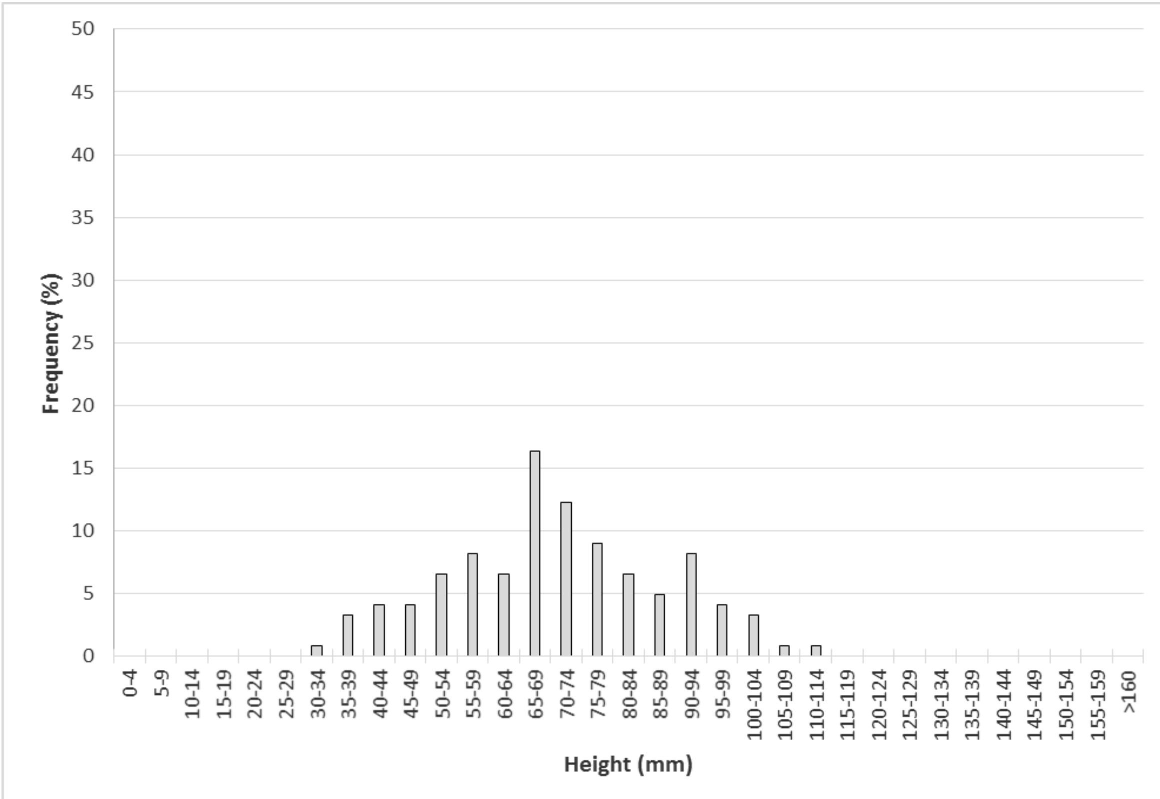


Figure A.06-6. Live oyster height distribution frequency in the Choptank River ORA Zone A Sanctuary in 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

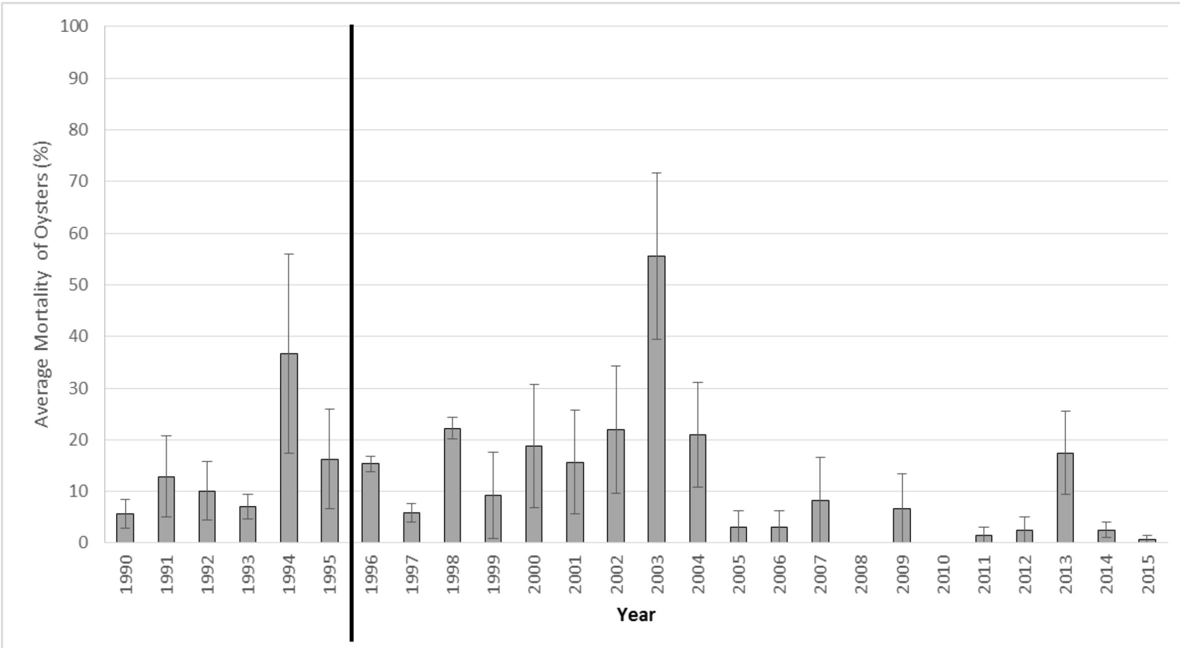


Figure A.06-7. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Choptank River ORA Zone A Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

Harvest

The sanctuary encompasses approximately 84% of the 14,142 acres in NOAA Code. The sanctuary was established prior to the collection of oyster harvester reports; therefore, no harvester reports are available to assess catch before the creation of the sanctuary. According to seafood dealer buy tickets, approximately 42,000 bushels were harvested during the 1990-1991 season. In 2010, the entire area of the NOAA Code became a sanctuary (combination of Choptank River ORA Zone A Sanctuary and Upper Choptank River Sanctuary) and no further harvest was allowed (Figure A.06-8).

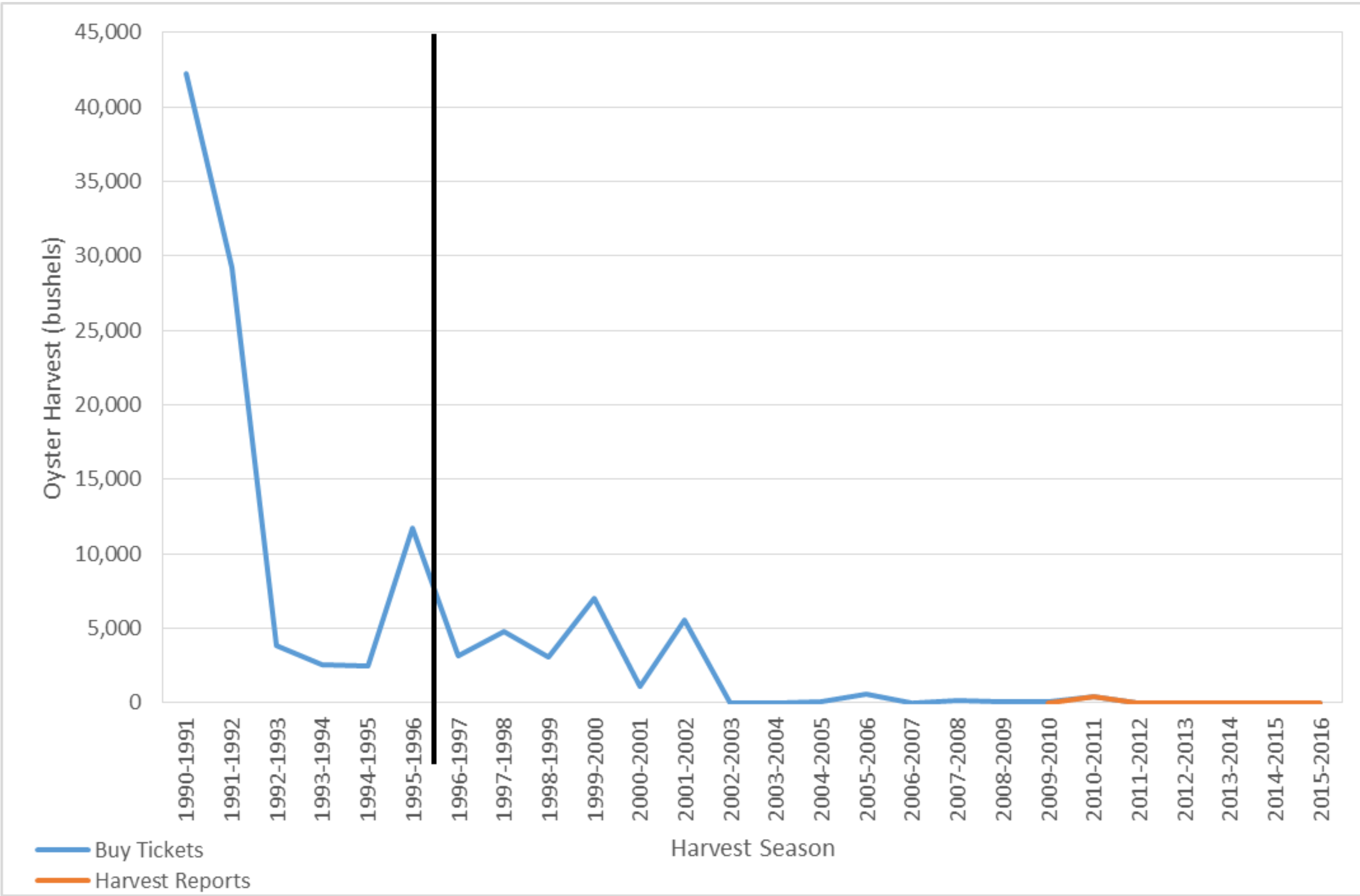


Figure A.06-8. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 337 (Choptank River Upper). Black line denotes the date the sanctuary was established (1996). The Choptank River ORA Zone A Sanctuary encompasses 84% of NOAA Code 337.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.07: Cook Point Sanctuary

The Cook Point Sanctuary is located in lower Choptank River in a medium salinity (12 to 14 ppt) region (Figure A.07-1). The sanctuary was originally established in 2001 with an area of 17 acres to accommodate an Environmental Protection Agency project examining three-dimensional oyster habitat. In 2010, the sanctuary was expanded to 814 acres of which 781 acres (96%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are two historic oyster bars within the sanctuary: Cook Point, 78% of which is within the sanctuary, and Todd Point Addition, of which 3% is within the sanctuary.

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.07-2). Of the 814 acres surveyed, 474 acres (58%) were classified as oyster reef habitat. In 2013 Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 814 acres surveyed in 2013, 256 acres (31%) were classified as oyster reef habitat, indicating a substantial loss of oyster habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

This area has received both replenishment and restoration efforts since 1990, both inside and outside the original 17 acre area (Table A.07-1). Several different techniques have been used to enhance oyster habitat including piles of shell, flat shell plantings, crushed granite reefs, granite reefs topped with shell, and reef balls (concrete spheres with holes). Spitznagel et al. (2015)[15] examined the shell and granite areas and found higher oyster density on shell and granite restored areas compared with unrestored areas.

[15] Matthew Spitznagel, Anne Handschy, Kennedy Paynter. 2015. 2014 Cook Point Oyster Sanctuary Survey. Paynter Lab, University of Maryland. http://www.life.umd.edu/biology/paynterlab/labpub/2014%20USACE%20Report%20Final%2020150902.pdf

Table A.07-1. Replenishment and restoration planting activities occurring since 1990 in the area established as the Cook Point Sanctuary (established in 2001 and expanded in 2010). S = a planting activity occurring after the area was established as a sanctuary				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Oysters Planted (millions)
1990	Dredged Shell	11.54	75.52	-
1997	Hatchery Spat-on-Shell	0.81	-	0.5
1997-1998	Dredged Shell, Mounds And Flat Planting	0.81	25.89	-
1998	Wild Seed	0.28	0.42	-
2006 (S)	Dredged Shell, Flat Planting	11.18	196.5	-
2008 (S)	Reefballs With Oysters	0.57	-	0.57
2008 (S)	Hatchery Spat-on-Shell	1.42	-	1.42
2009 (S)	Reefballs With Oysters	0.2	-	0.2
2009 (S)	Hatchery Spat-on-Shell	5.2	-	5.2
2010 (S)	Reefballs With Oysters	0.5	-	0.5
2010 (S)	Hatchery Spat-on-Shell	33.58	-	41.07
2011 (S)	Hatchery Spat-on-Shell	24.03	-	93.12
2011 (S)	Granite And Shell Reef Construction	8.5	309	-
2012 (S)	Reefballs With Oysters	0.32	-	0.32
2012 (S)	Hatchery Spat-on-Shell	11.79	-	11.79
2013 (S)	Hatchery Spat-on-Shell	7.03	-	7.03

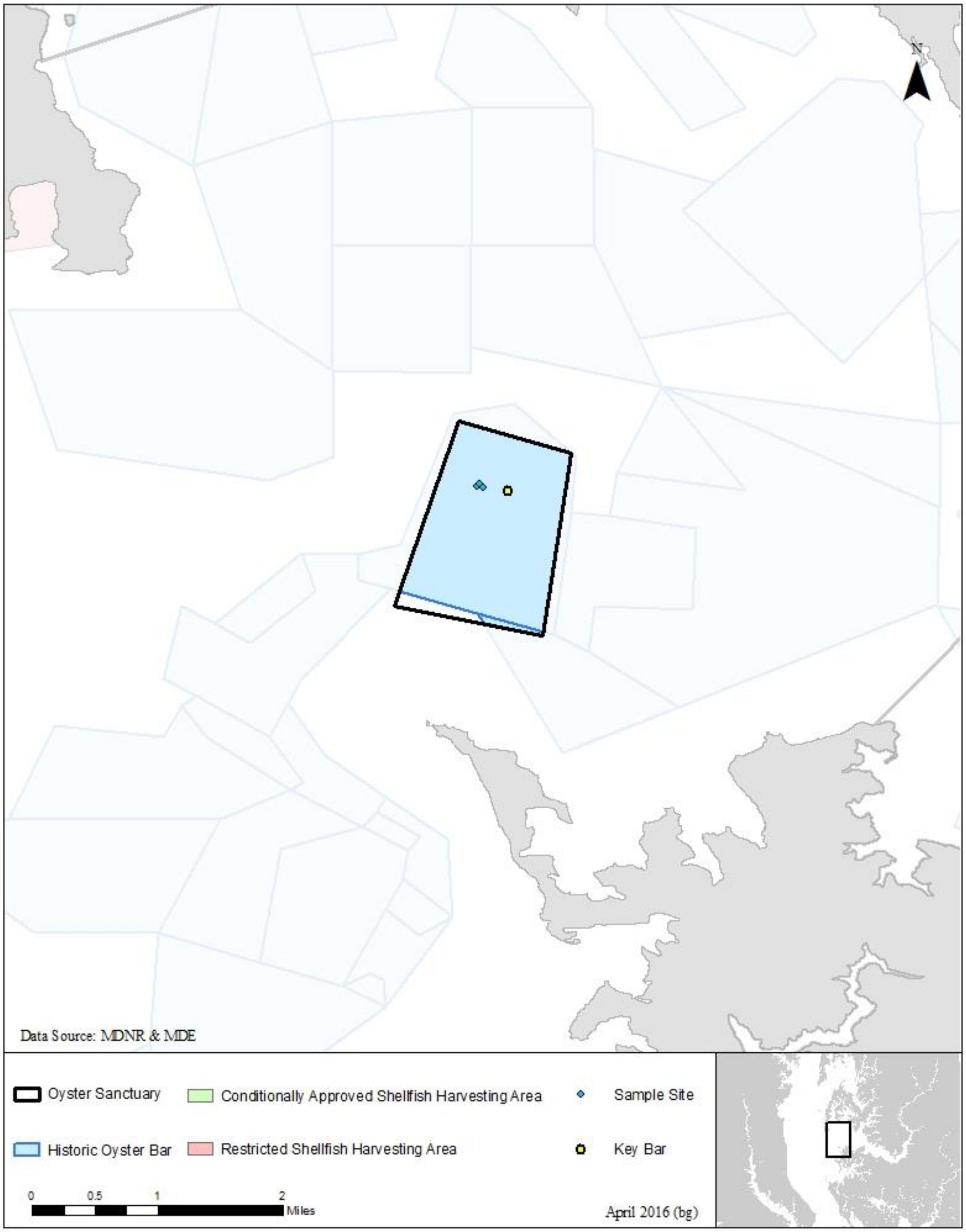


Figure A.07-1. Cook Point Sanctuary.

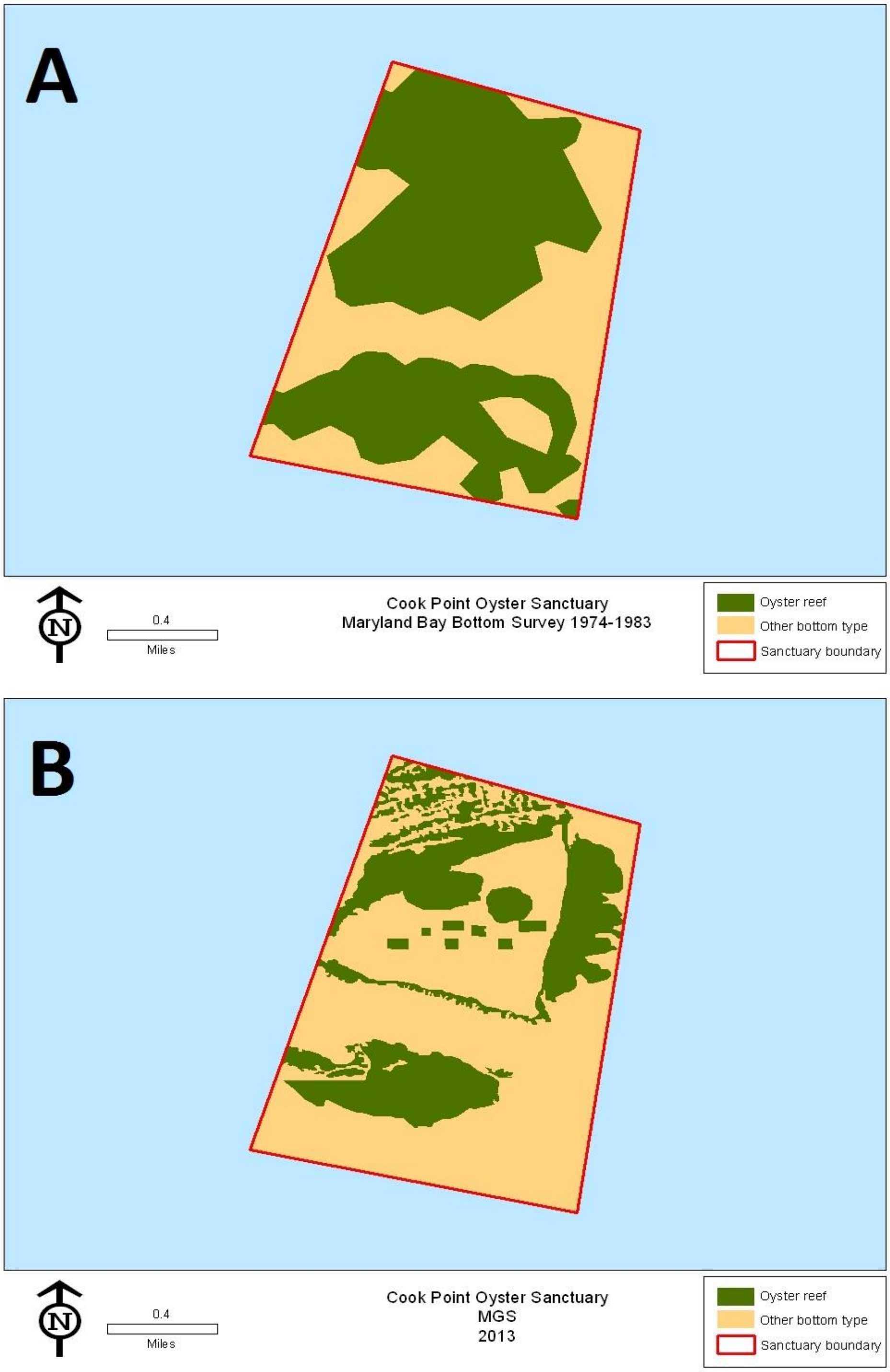


Figure A.07-2. Cook Point Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2013. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled a single bar (Cook Point oyster bar) in this area annually since 1990. Since 2005, two samples have been taken on the bar. The average number of total live oysters per bushel (market, small, and spat) has increased since the sanctuary was established (Table A.07-2; Figure A.07-3). This was primarily due to strong spat sets in 2010 and 2012 and hatchery seed plantings in 2010 and 2011. The average number of all live oysters from 2001-2015 was 106 ± 40 per bushel of material (mean ± standard error). Excluding hatchery spat-on-shell, the average number of oysters per bushel of material from 2001 to 2015 was 75 ± 19. The number of both small- and market-sized oysters per bushel of material increased after the establishment of the sanctuary, with the number of market sized oysters in 2013-2015 the highest observed since 1990 (average 103-108 oysters per bushel of material

Table A.07-2. Oyster population characteristics based on Fall Survey data collected before and after the establishment of the Cook Point Sanctuary in 2001. Values are given as means ± standard error.

	1990-2000	**2001-2015**
Number of Years Sampled / Number of Samples	11 / 11	15 / 27
Number of Live Oysters per Bushel	46 ± 18	106 ± 40
Number of Live Small-Sized Oysters per Bushel	14 ± 4	30 ± 9
Number of Live Market-Sized Oysters per Bushel (	11 ± 3	33 ± 12
Live Oyster Biomass (g Dry Weight per Bushel)	24.6 ± 8.3	91.7 ± 29.7
Mortality (%)	37.9 ± 9.7	17.4 ± 6.2

Patent tong population surveys by the Department have not been conducted to date on sanctuary since 1990.

Spitznagel et al. (2015)[16] examined oyster density on natural and artificial substrates in the sanctuary. Densities on three year old-plantings ranged from 6 oysters m^{-2} on sand to 130 oysters m^{-2} on a flat shell planting.

Oyster Size Structure

The Fall Survey has measured oyster shell heights at Cook Point bar since 1990 (Figure A.07-4). Shell heights of oysters collected at Cook Point has increased between 2012 and 2015, with a notable increase in the proportion of market-sized oysters. This increase is likely due to good spat sets in 2010 and 2012 coupled with absence of harvest.

[16] Matthew Spitznagel, Anne Handschy, Kennedy Paynter. 2015. 2014 Cook Point Oyster Sanctuary Survey. Paynter Lab, University of Maryland. http://www.life.umd.edu/biology/paynterlab/labpub/2014%20USACE%20Report%20Final%2020150902.pdf

Spitznagel et al. (2015)[17] examined oyster size on natural and artificial substrates in the sanctuary. Average shell height on three year-old plantings ranged from 70 mm on shell to 95 mm on granite.

Biomass

Biomass of oysters from Cook Point bar collected by the Fall Survey increased steadily since 2007, with the highest biomass of 334 grams dry weight per bushel occurring in 2015 (Table A.07-2; Figure A.07-5). This increase is due to both the increasing number of and size of oysters.

Spitznagel et al. (2015)[18] examined oyster biomass on natural and artificial substrates in the sanctuary. Average biomass on three year-old plantings ranged from 7.9 g m^{-2} on sand to 209 g m^{-2} mm on shell mounds.

Recruitment (Spatfall)

From 1990 to 2015, spat count ranged from 0 to 171 per bushel excluding the spat from the hatchery seed plantings (Figure A.07.6). The maximum number including the hatchery seed planting was 537 spat per bushel (Figure A.07-3). The longest period of consecutive spatfall was from 2006 to 2015.

Mortality

Based on Fall Survey box counts, average mortality after the establishment of the sanctuary was lower than in the period before (Table A.07-2; Figure A.07-7).

Disease

Dermo disease prevalence fluctuated greatly between 1990 and 2015 ranging from 0% to 97% (Figure A.07-8), with several periods of high (greater than80%) prevalence. Dermo intensity ranged from 0.7 to 4.2 (scale of 0 to 7 with values higher than 5 indicating lethal infections) from 1990 to 2015, with intensity level following the same trend as prevalence. Dermo intensity has not reached lethal levels in the sanctuary. Spitznagel et al. (2015)[19] surveyed oyster plantings on the sanctuary for dermo disease in 2012 and 2014. They found dermo prevalence ranged from 14% to 90% in 2012 and 93% to 100% in 2014. Dermo intensity was low in 2012 and moderate in 2014.

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[17] Matthew Spitznagel, Anne Handschy, Kennedy Paynter. 2015. 2014 Cook Point Oyster Sanctuary Survey. Paynter Lab, University of Maryland. http://www.life.umd.edu/biology/paynterlab/labpub/2014%20USACE%20Report%20Final%2020150902.pdf
[18] IBID
[19] IBID

MSX prevalence ranged from 0% to 73% from 1990 to 2015. Extended periods of high MSX prevalence occurred from 1999 to 2001 and 2008 to 2010.

Spitznagel et al. (2015)[20] examined dermo on natural and artificial substrates in the sanctuary. Dermo prevalence was similar across substrates, ranging from 93-100%.

[20] Matthew Spitznagel, Anne Handschy, Kennedy Paynter. 2015. 2014 Cook Point Oyster Sanctuary Survey. Paynter Lab, University of Maryland. http://www.life.umd.edu/biology/paynterlab/labpub/2014%20USACE%20Report%20Final%2020150902.pdf

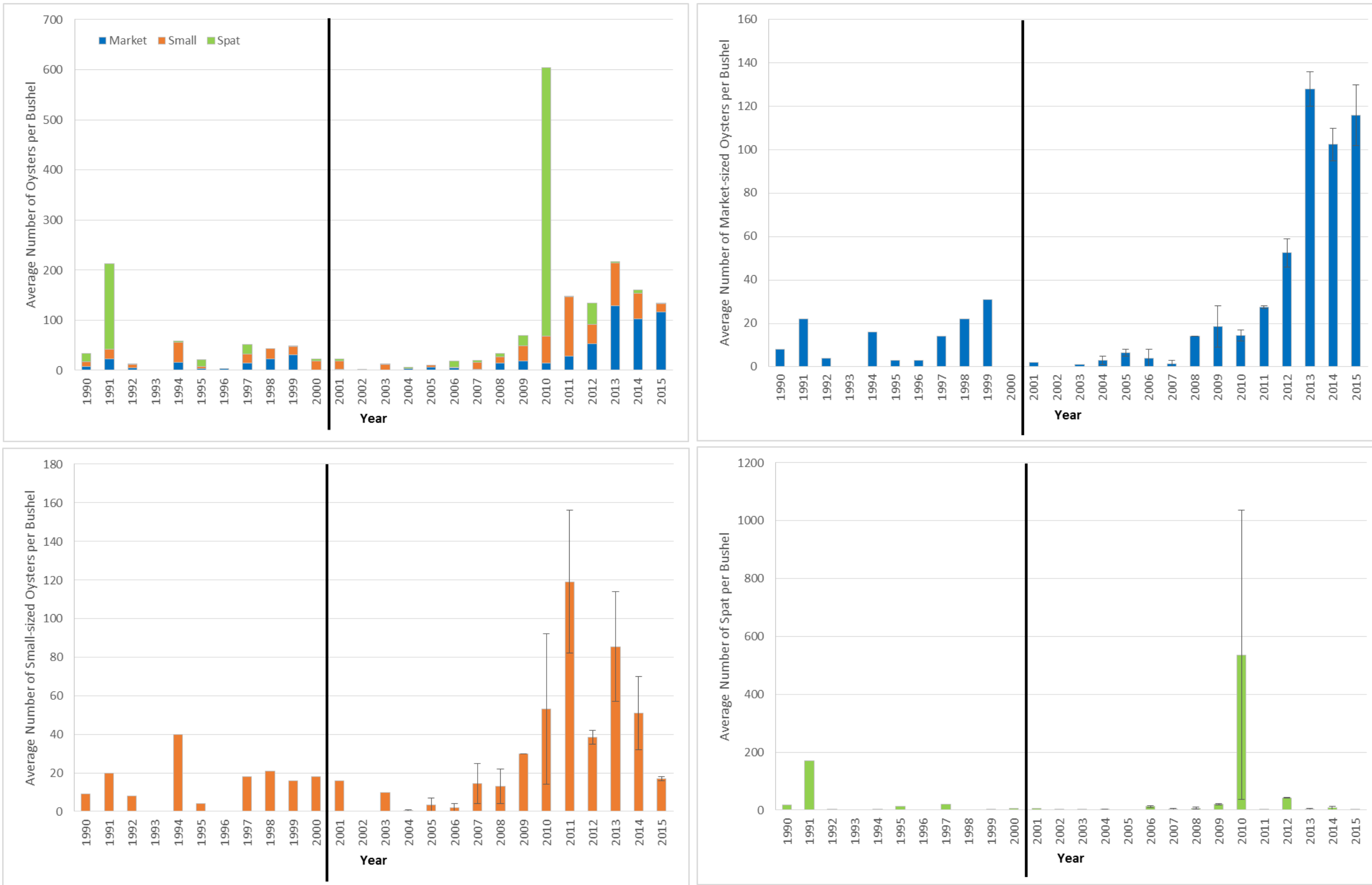


Figure A.07-3. Average number of live oysters per bushel of material by size class in the Cook Point Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

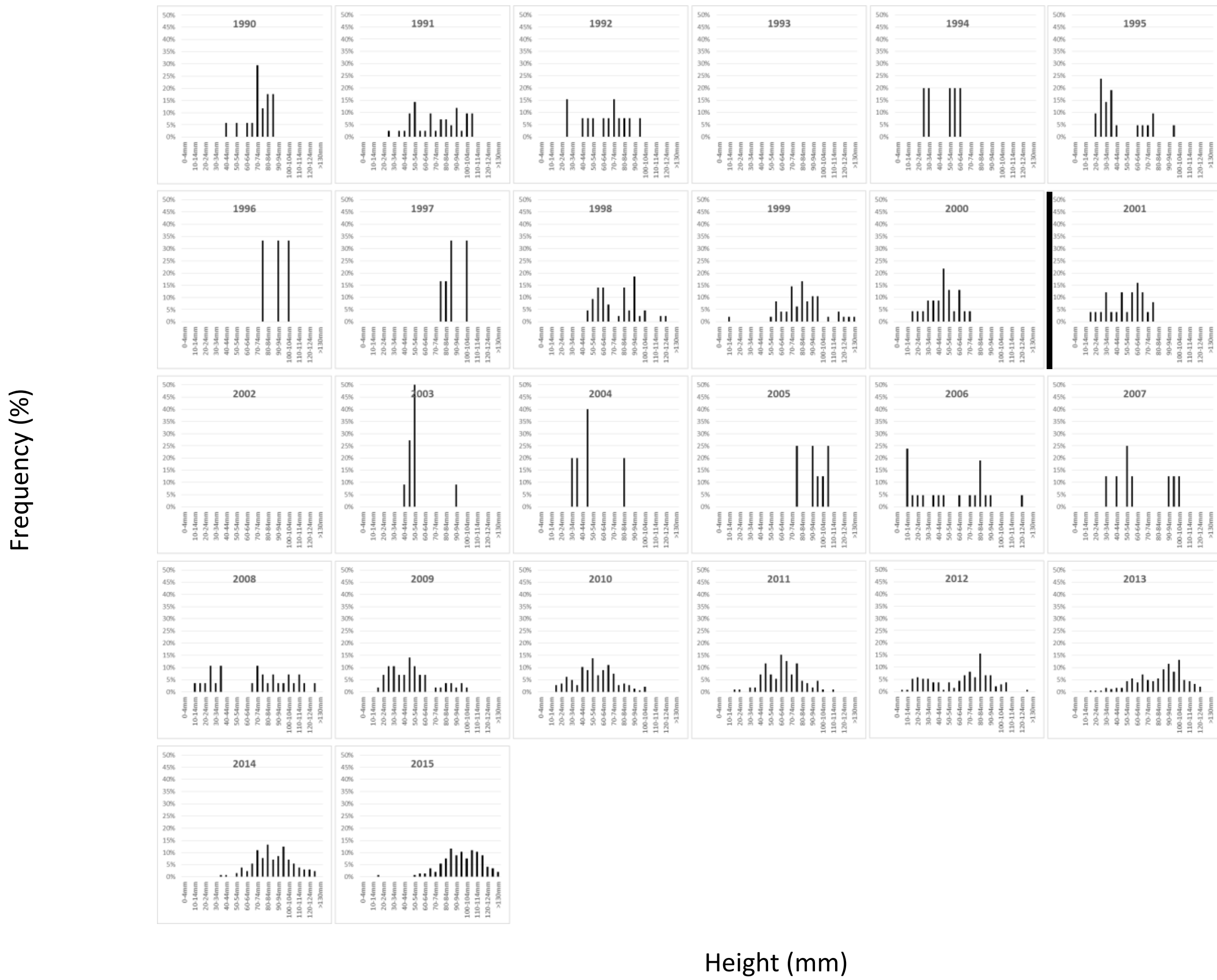


Figure A.07-4. Shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the Cook Point Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Cook Point bar. The black line denotes the year the sanctuary was established. No oysters were found in 1993 and 2002. Oyster sizes less than 37mm were not recorded in 2003.

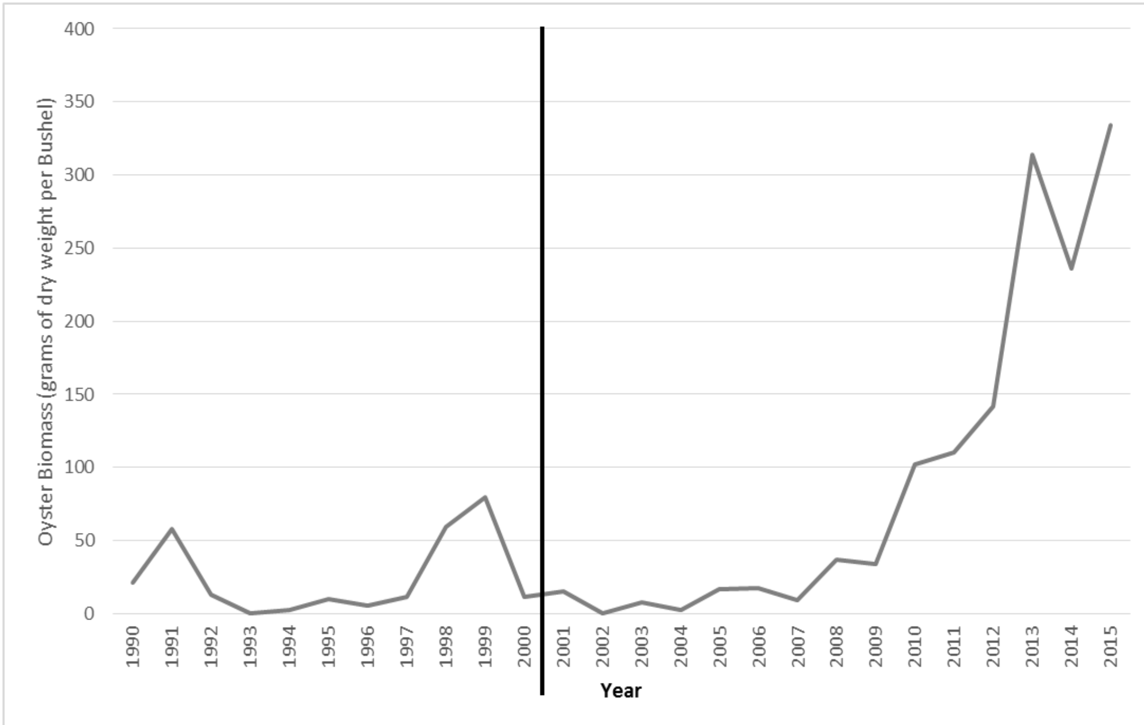


Figure A.07-5. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Cook Point Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Cook Point bar. Black line indicates the date the sanctuary was established.

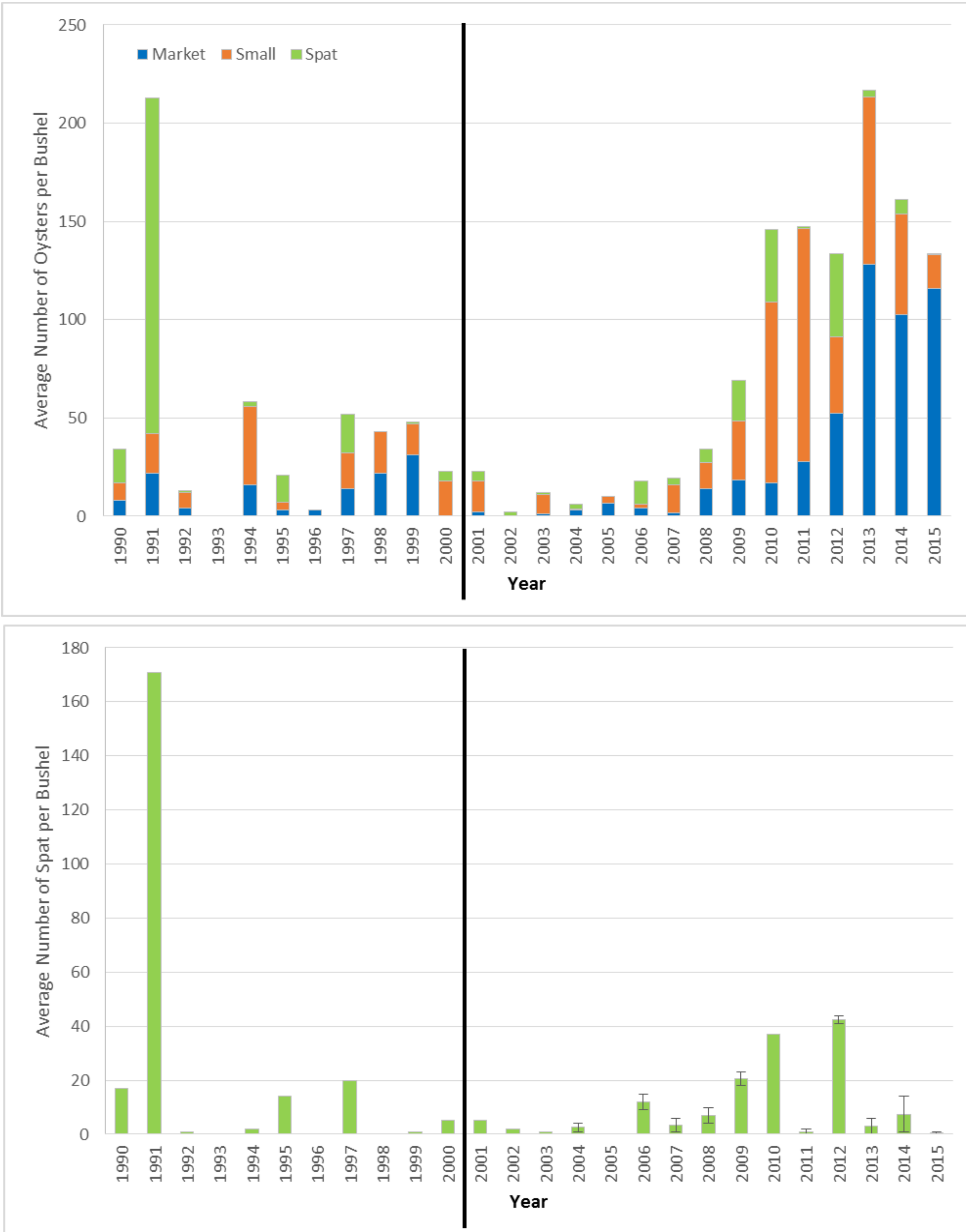


Figure A.07-6. Average number of live oysters per bushel of material by size class in the Cook Point Sanctuary excluding Fall Survey samples taken on hatchery seed plantings. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

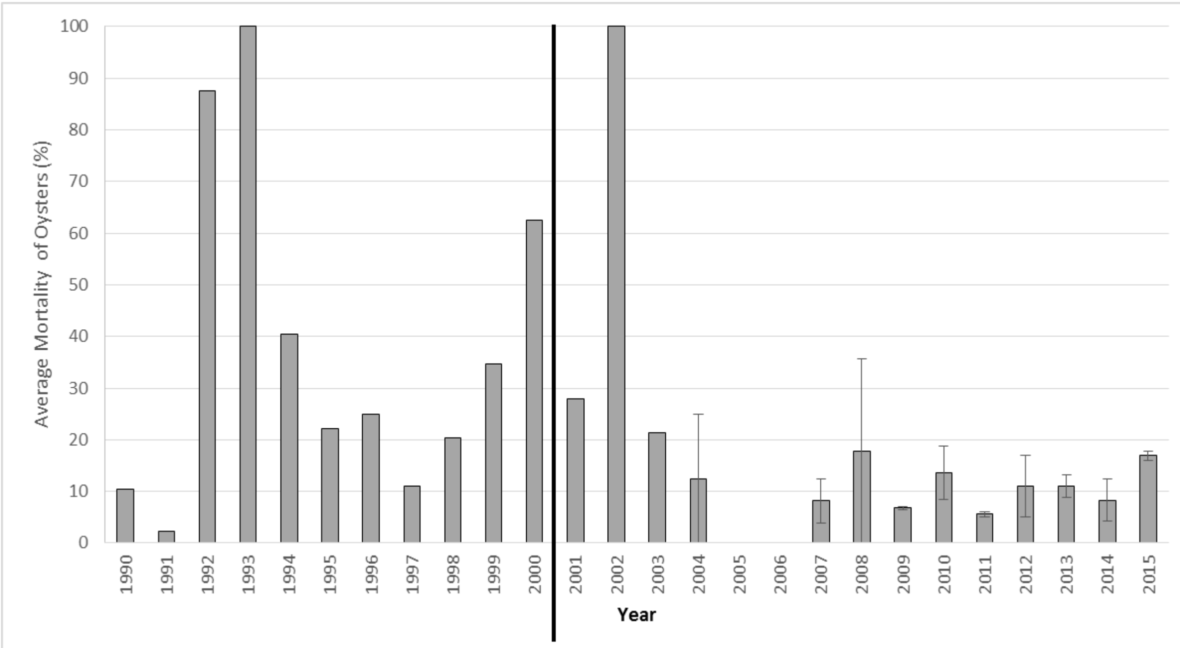


Figure A.07-7. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Cook Point Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

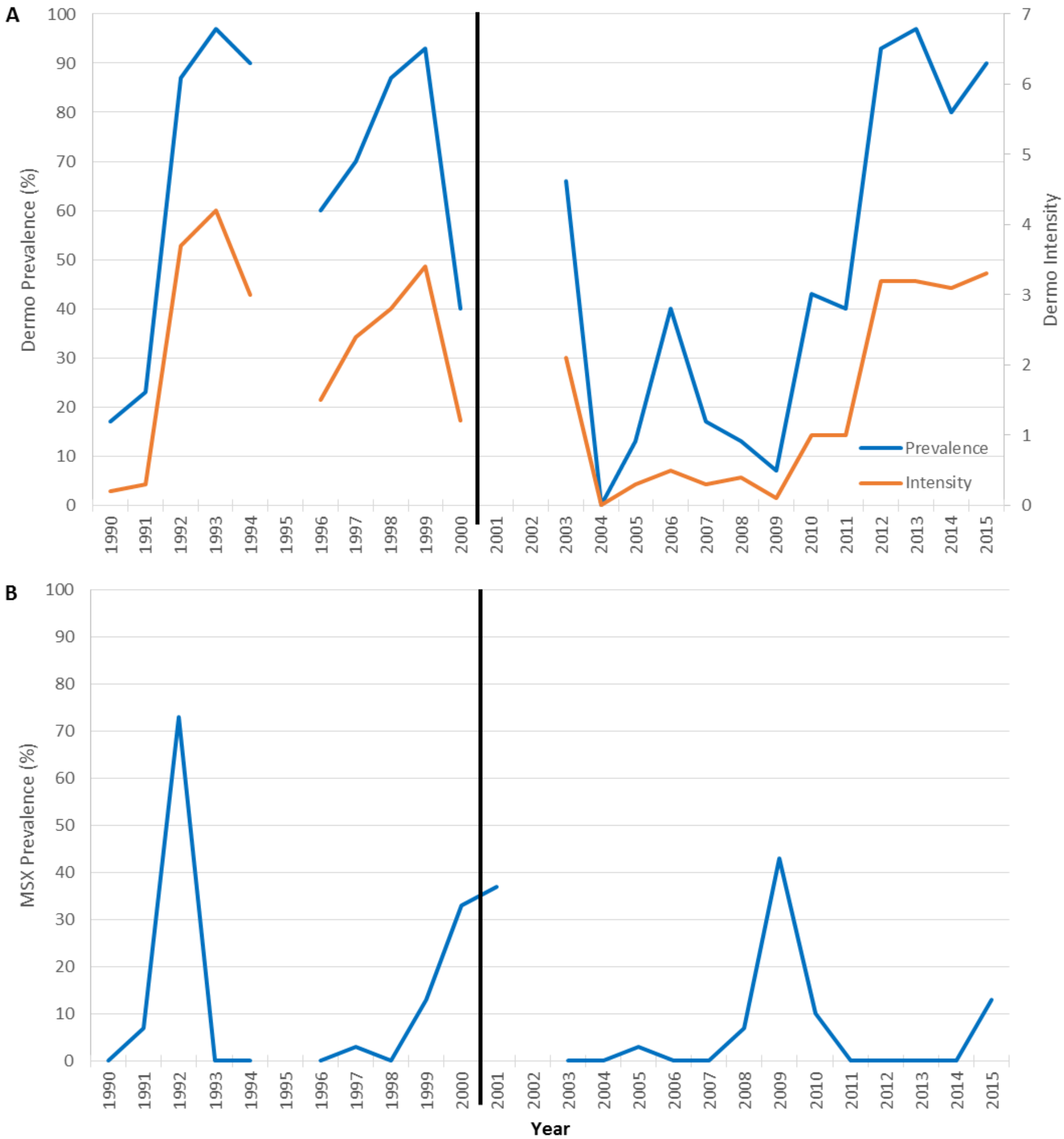


Figure A.07-8. Oyster disease prevalence and intensity from 1990 to 2015 in the Cook Point Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Cook Point bar. Disease data was not collected in 1995.

Harvest

The sanctuary encompasses 2.3% of the 35,040 acres in NOAA Code 137. Because harvest for NOAA code 137 may have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. Oyster harvester reports show no harvest from Cook Point in 2009-2010, the season immediately prior to the sanctuary expansion.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.08: Cox Creek Sanctuary

The Cox Creek Sanctuary is located in a tributary of Eastern Bay, a low salinity (less than 12 ppt) region (Figure A.08-1). The sanctuary was created in 2010 and encompasses 2,112 acres of which 939 acres (45%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are nine historic oyster bars within the sanctuary, one of which (Ringgold Middleground) is located only partially within the sanctuary[21].

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.08-2). Of the 964 acres surveyed, 692 acres (72%) were classified as oyster reef habitat. In 2011, Maryland Geological Survey conducted a side scan sonar survey of essentially the same area. Of the 901 acres surveyed in 2011, 103 acres (11%) were classified as oyster reef habitat, indicating a substantial loss of oyster habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

No active restoration efforts have been made in the sanctuary since it was established in 2010; however, replenishment efforts occurred prior to 2010 when the area was not a sanctuary (Table A.08-1). Between 1990 and 1999, 16.01 acres were planted with 95,400 bushels of fresh shell. Wild seed was transplanted into Cox Creek in 1995. No dredged shell or hatchery spat-on-shell has been planted since 1990.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 20 cages and planted approximately 60,000 oysters.

Table A.08-1. Replenishment planting activities occurring since 1990 in the area established as Cox Creek Sanctuary in 2010.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1991	Fresh Shell	3.15	12.60	-
1995	Wild Seed	3.21	0.95	-
1996	Fresh Shell	3.72	19.20	-
1999	Fresh Shell	9.13	63.60	-

[21] See chart 11 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

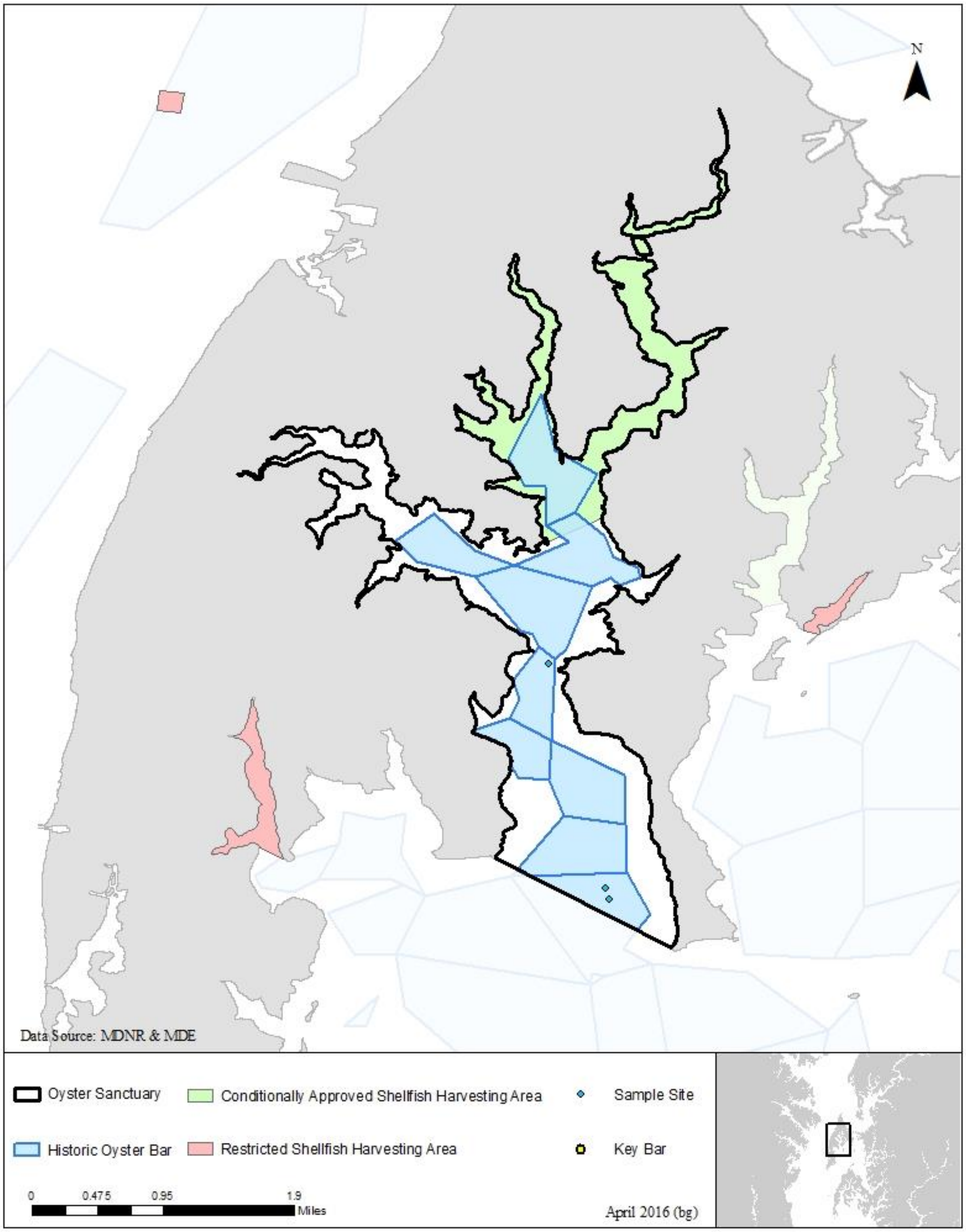
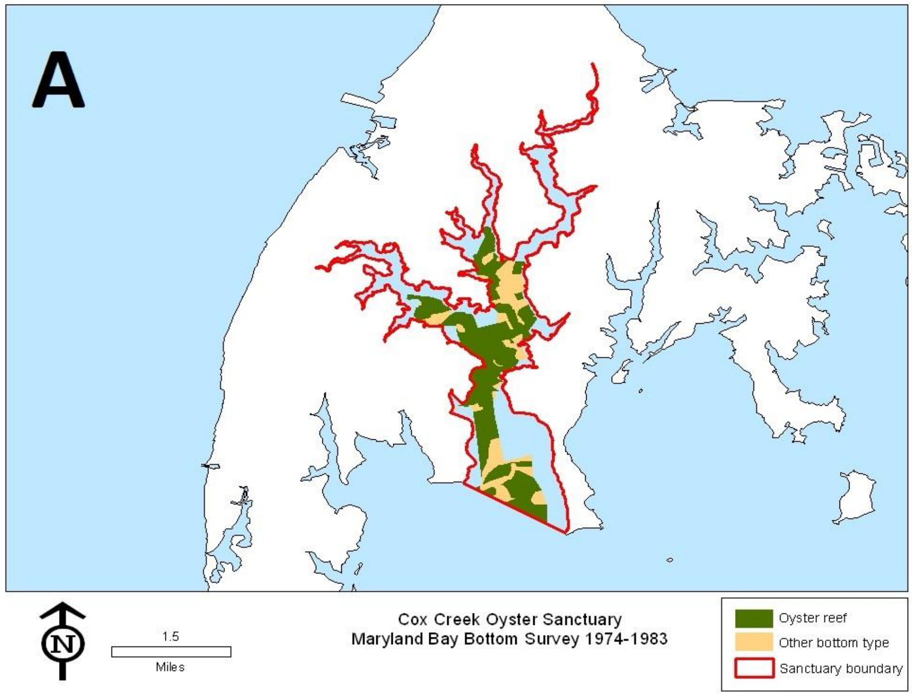


Figure A.08-1. Cox Creek Sanctuary.



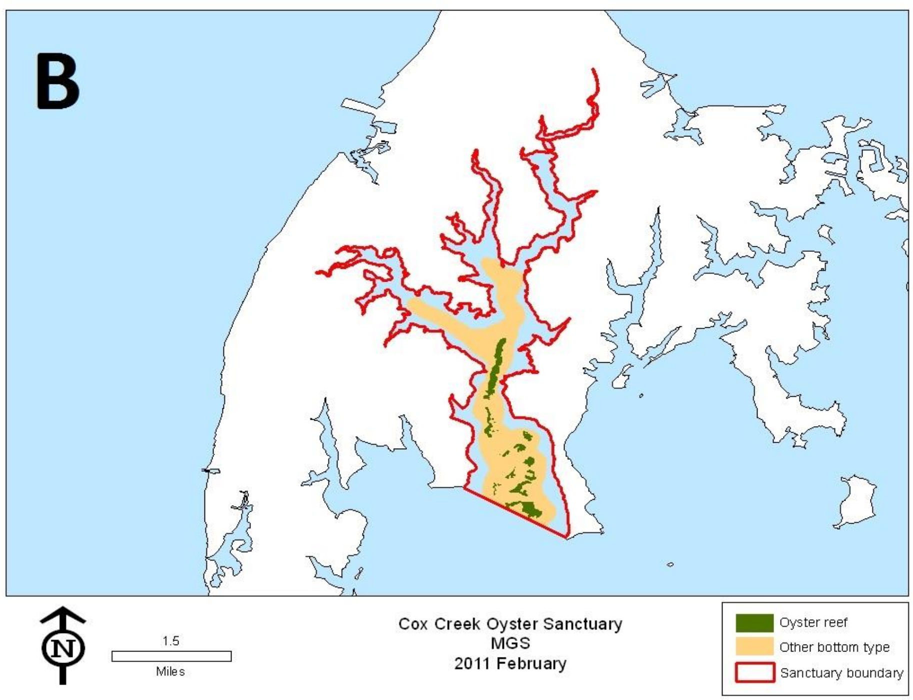


Figure A.08 -2. Cox Creek Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2011. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled one to two oyster bars in the area now established as the sanctuary since 1990, with an average of one oyster bar sampled annually. The area was not sampled from 2001 to 2004 and from 2007 to 2015; no samples were collected after the sanctuary was established (Table A.08-2; Figure A.08-3). The average number of live oysters (spat, small, and market) per bushel of material ranged from 32 to 528.

Table A.08-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Cox Creek Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	13 / 16	0 / 0
Number of Live Oysters per Bushel	120 ± 37	ND
Number of Live Small-Sized Oysters per Bushel	47 ± 15	ND
Number of Live Market-Sized Oysters per Bushel	33 ± 3	ND
Live Oyster Biomass (g Dry Weight per Bushel	ND	ND
Mortality (%)	31.4 ± 5.9	ND

A patent tong population survey was conducted in 2014 (Figures A.08-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 0.64 ± 0.13 oysters m^{-2} (mean ± standard error, n=151), with similar densities of small- and market-sized oysters. Eighty percent of the samples had no live oysters or boxes. Live oyster density generally increased with shell volume (Figure A.08.5).

Oyster Size Structure

Shell height data have not been collected from Fall Survey samples taken in Cox Creek since 1990. Shell heights were measured during the patent tong population survey (Figure A.08-6), however. Shell height ranged from 40 to 157 mm, with an average of 86.2 ± 3.6 mm (mean ± standard error). The size distribution appears bimodal suggesting multiple age classes.

Biomass

The Fall Survey has not collected any information on biomass in this area since 1990.

Recruitment (Spatfall)

During the years sampled from 1990 to 2015, the average spat per bushel ranged from 0 to 416 with the maximum spatfall occurring in 1997 (Figure A.08-3). No spat were found during the 2014 patent tong survey.

Mortality

Based on Fall Survey box counts, mortality ranged from 9% to 52% with the average mortality being 31.4% ± 5.9 (mean ± standard error) (Table A.08-2; Figure A.08-7).

Disease

The Fall Survey has not collected any information on disease in this area since 1990.

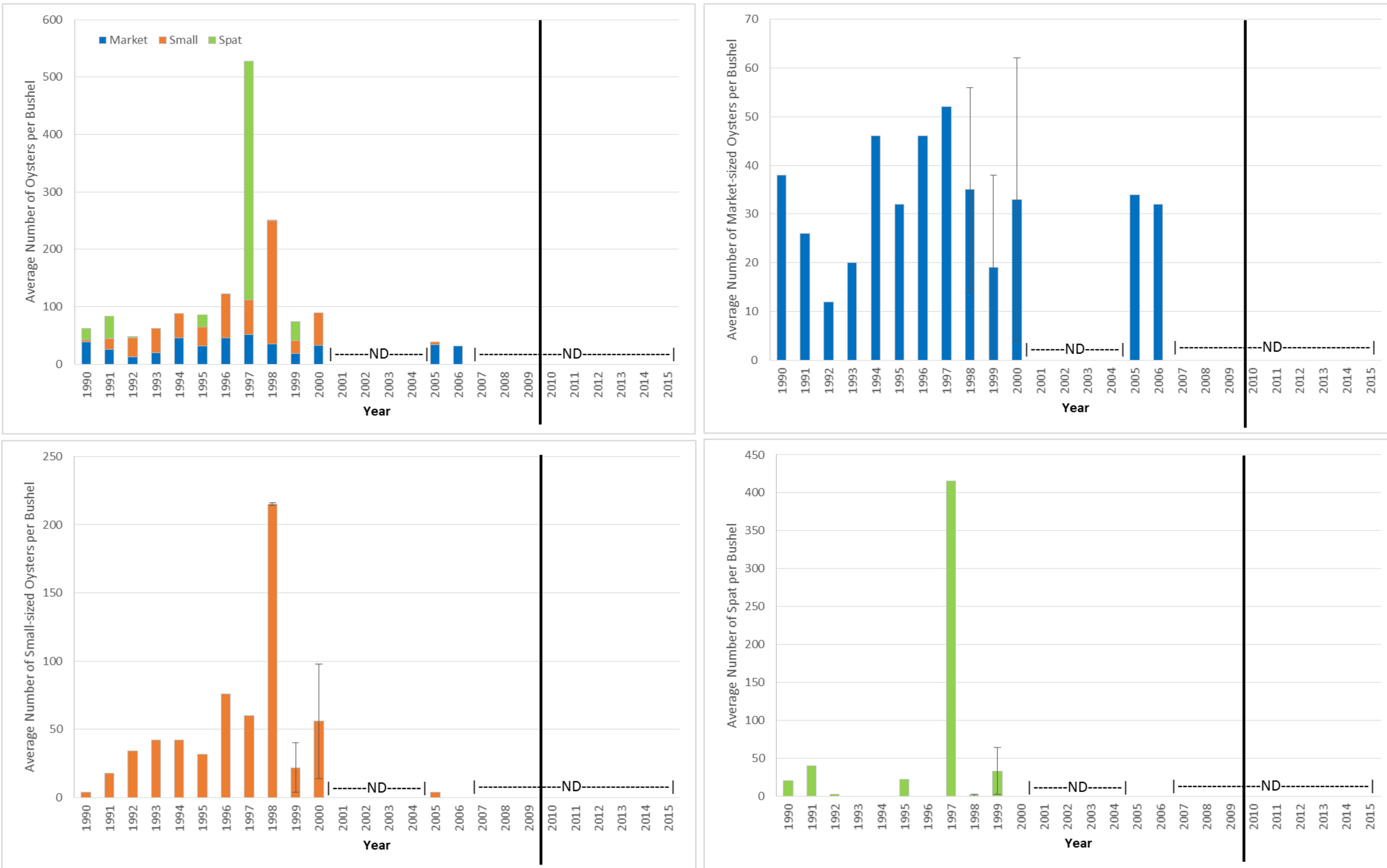


Figure A.08-3. Average number of live oysters per bushel of material by size class in the Cox Creek Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data.

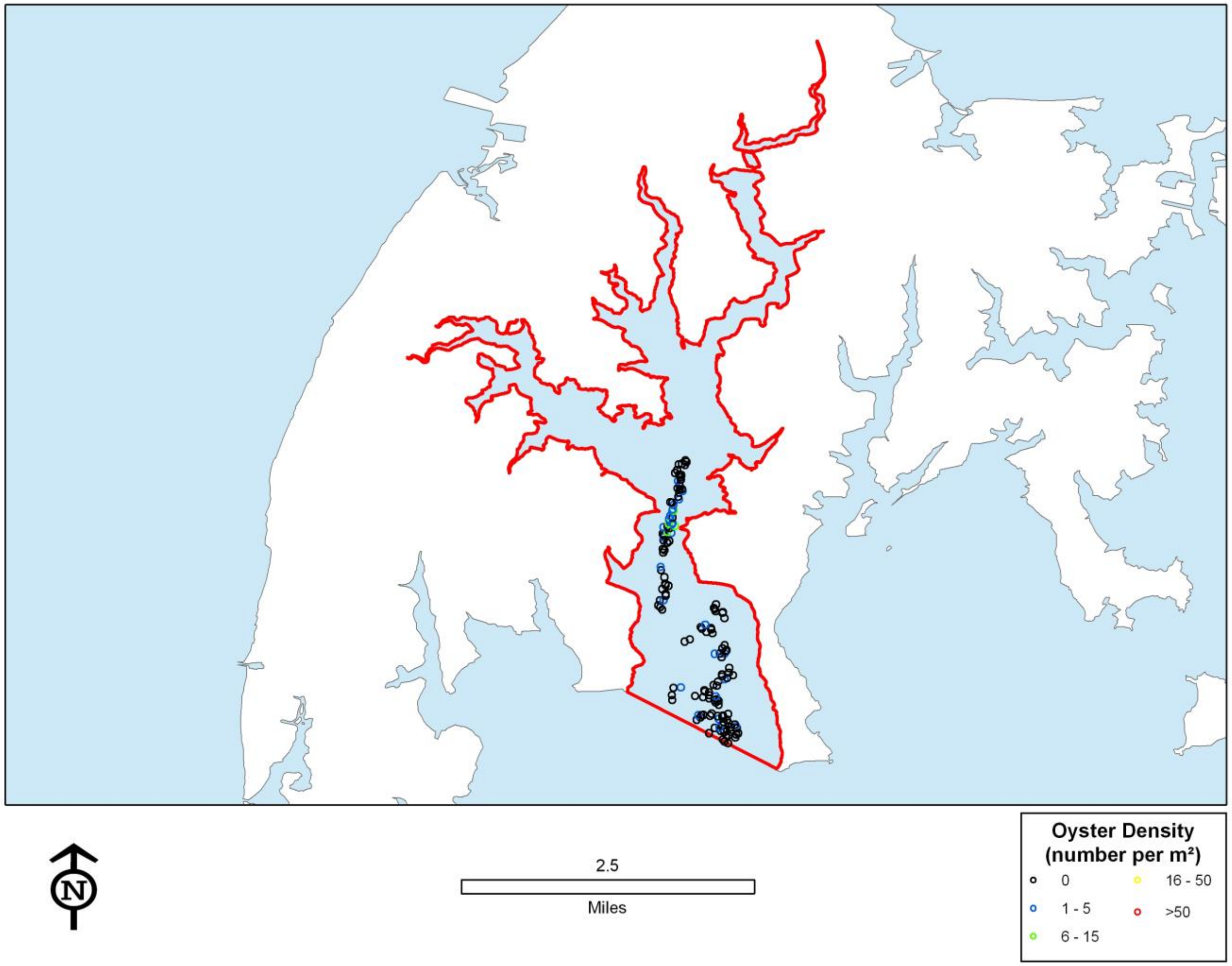


Figure A.08-4. Map of 2014 oyster density in the Cox Creek Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

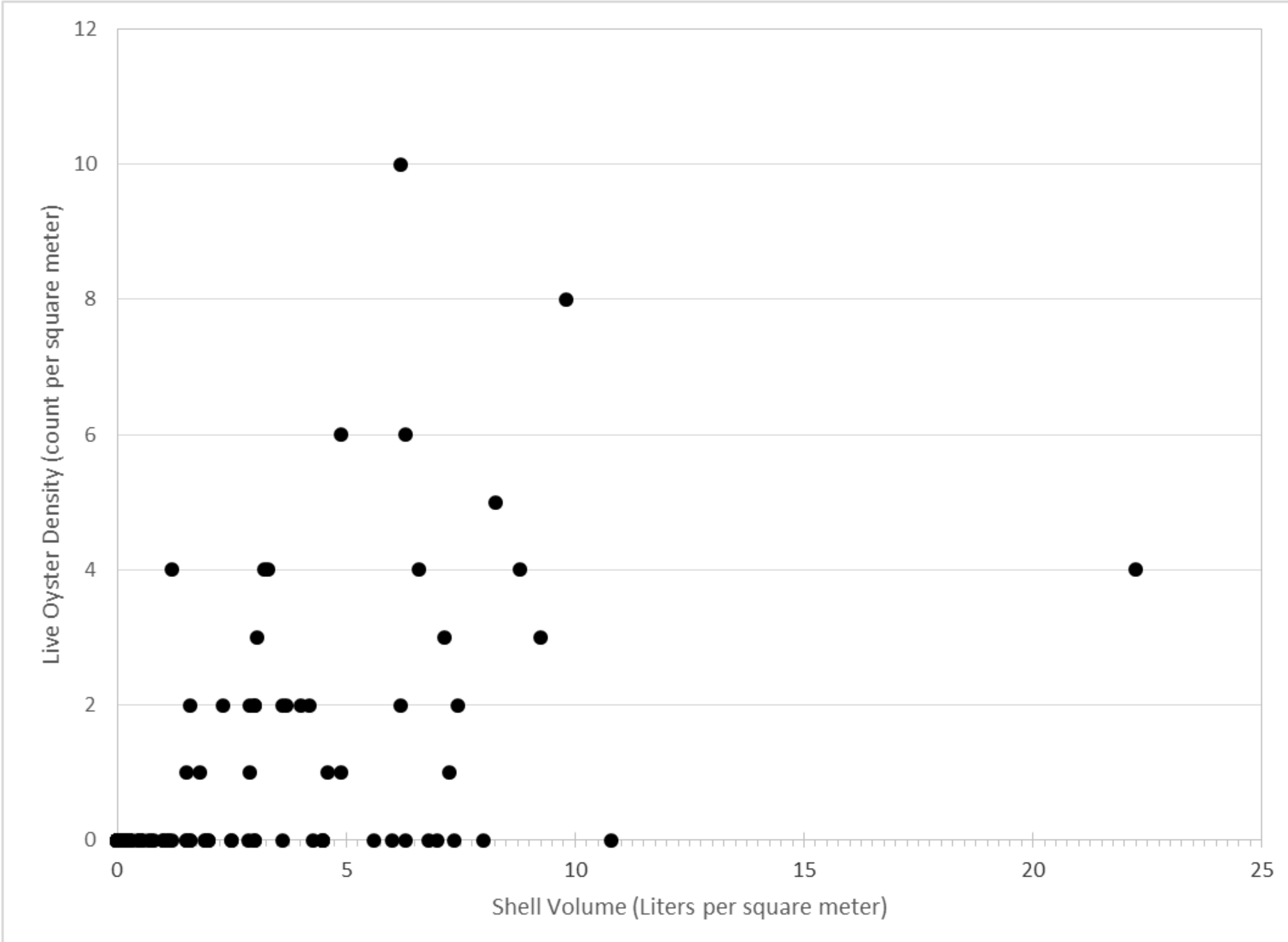


Figure A.08-5. 2014 live oyster density and shell volume (liters of live oysters, boxes, and surface shell) in the Cox Creek Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

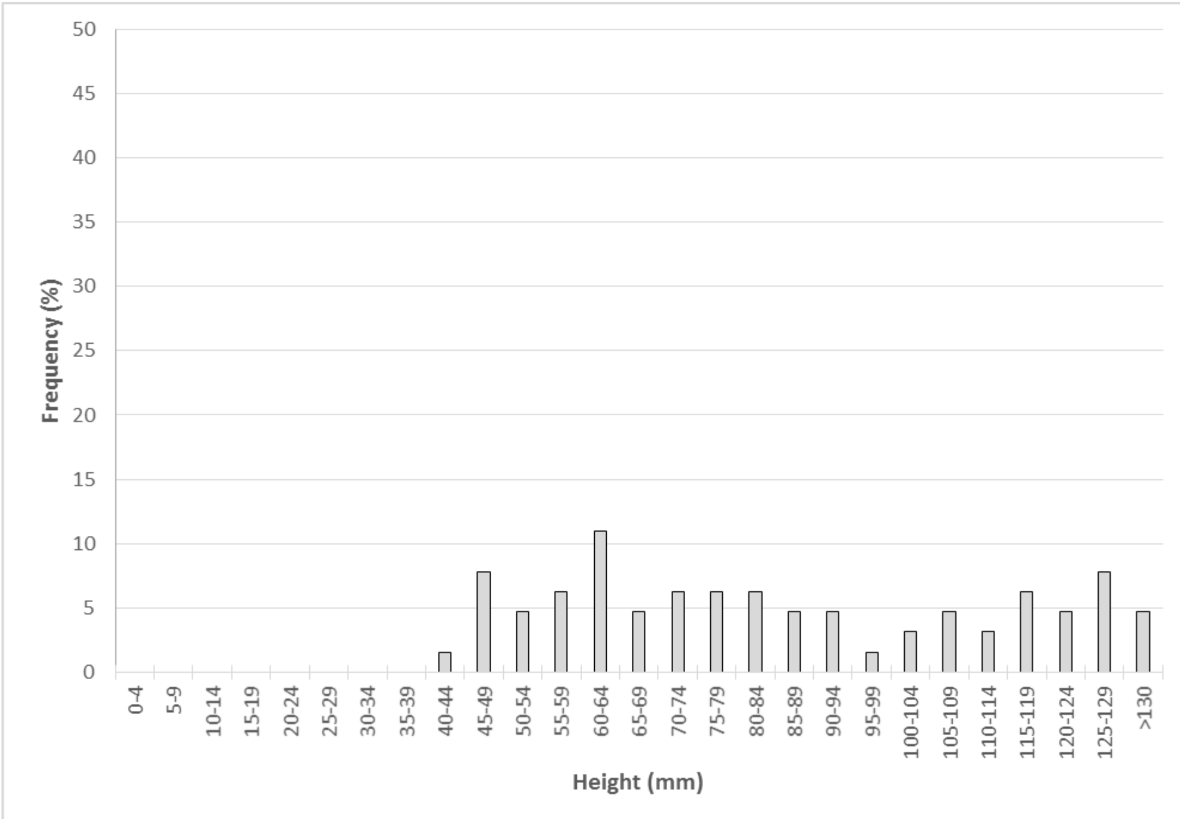


Figure A.08-6. Live oyster height distribution frequency in the Cox Creek Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

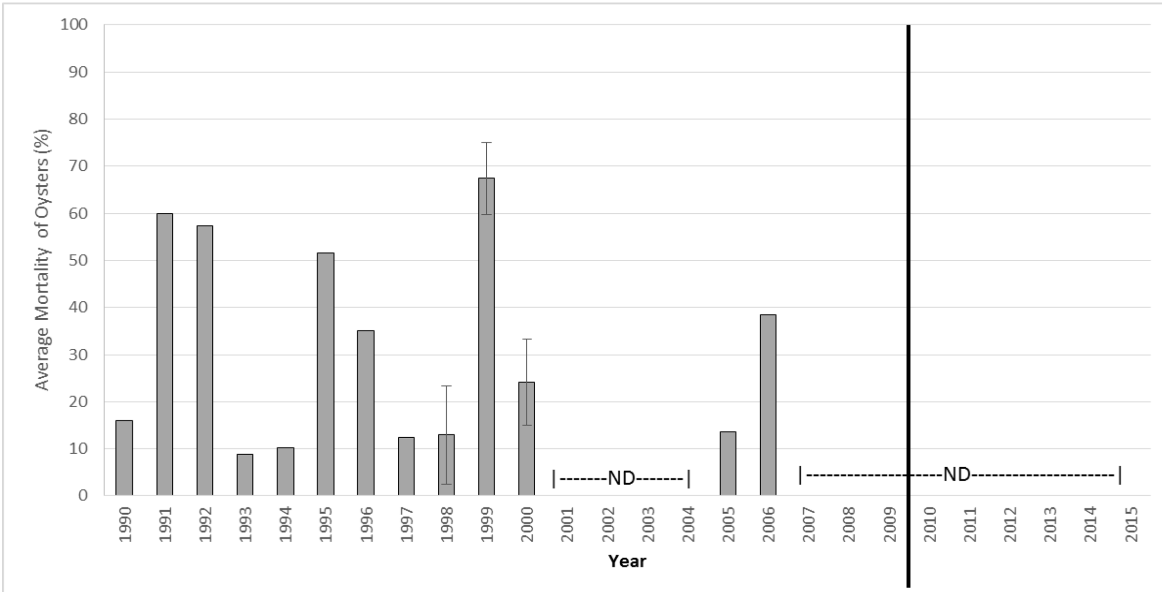


Figure A.08-7. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Cox Creek Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error. ND = No Data.

Harvest

The sanctuary encompasses 6% of the 33,334 acres in NOAA Code 039. Because harvest for NOAA code 039 may have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. Oyster harvester reports show no harvest from bars located in Cox Creek in 2009-2010, the season immediately prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program recorded monthly water quality at station XGG5115 (38.9191, -76.3073) in this area from 2004-2006 (Figure A.08-8). Chlorophyll a, salinity, secchi depth, total nitrogen, total suspended solids, and water temperature were measured. Water quality was favorable for oysters during this time period. No water quality data have been collected since the establishment of the sanctuary.

We are unaware of any studies explicitly examining oyster ecosystem services in the sanctuary.

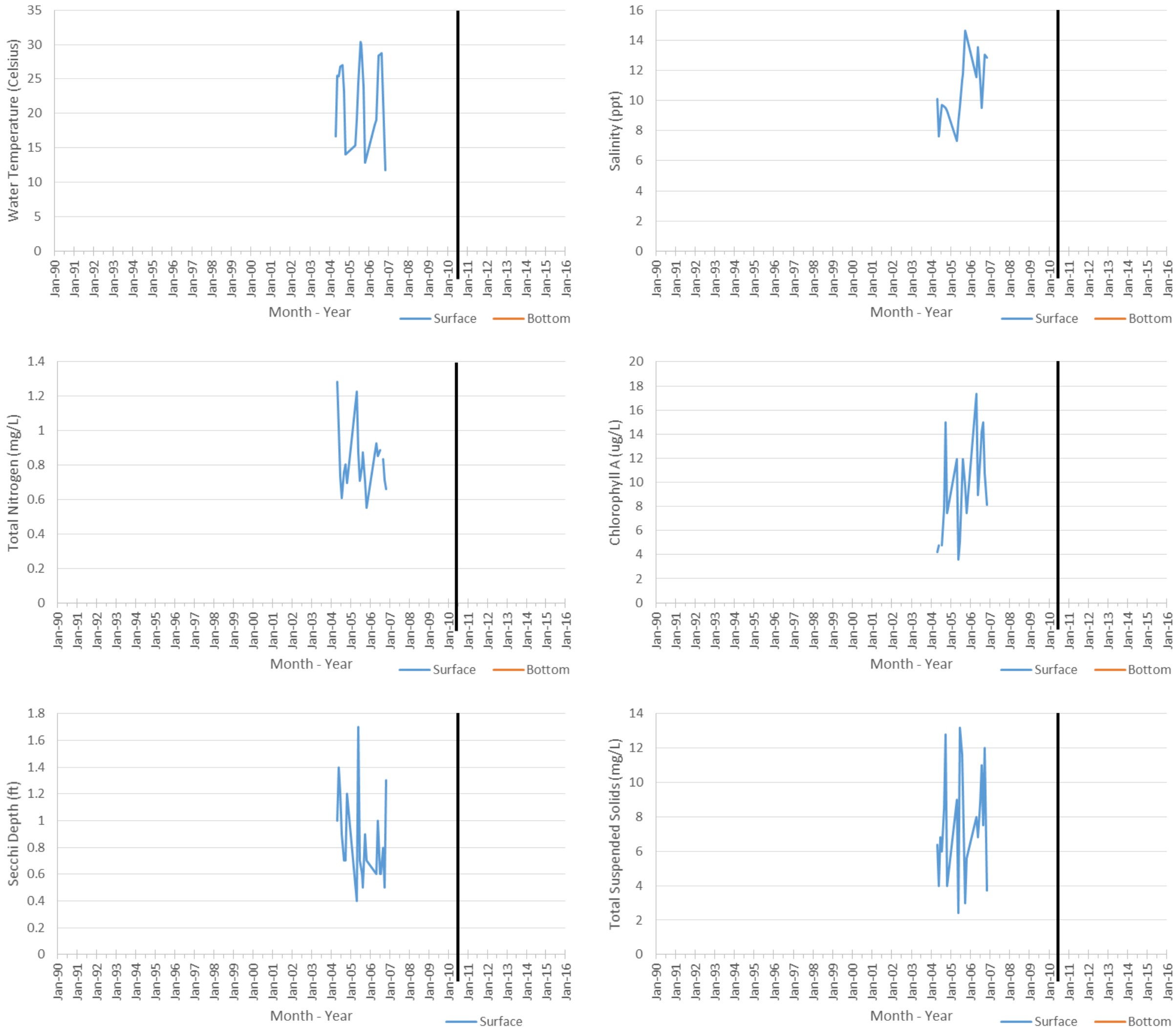


Figure A.08-8. Water quality data collected at Station XGG5115 within the area now established as Cox Creek Sanctuary from 2004 to 2006. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.

Section A.09: Eastern Bay Sanctuary

The Eastern Bay Sanctuary is located along the southern shore of Eastern Bay, a low salinity (less than 12 ppt) region (Figure A.09-1). The sanctuary was created in 2010 and encompasses 4,521 acres of which 939 acres (21%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 7 historic oyster bars within the sanctuary[22].

Bottom Habitat Characteristics

The area that is now the Eastern Bay Sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.09-2), however, the chart covering this entire area has been lost[23]. Of the 512 acres surveyed within the sanctuary from the charts that were not lost, 86 (17%) were classified as oyster reef habitat. In 2011 Maryland Geological Survey conducted a more thorough side scan sonar survey of the area. Of the 3,193 acres surveyed in 2011, 245 acres (8%) were classified as oyster reef habitat. The far greater coverage of the Maryland Geological survey's side scan sonar work precludes comparison of the two surveys.

Restoration and Replenishment Activities

No replenishment or restoration planting activities have occurred in this area since 1990.

Oyster Population Characteristics

The Fall Survey sampled one oyster bar in this area from annually 1990 to 1999. No Fall Survey samples were collected after 2000. The average number of total live oysters (market, small, and spat) per bushel of material ranged from 24 to 880 (Table A.09-1; Figure A.09-3), with an average of 172.

[22] See chart 11 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

[23] Smith, G.F., K.N. Greenhawk, D.G. Bruce, E.B. Roach, and S.J. Jordan. 2001. A digital presentation of the Maryland oyster habitat and associated bottom types in the Chesapeake Bay (1974–1983). Journal of Shellfish Research 20:192–206.

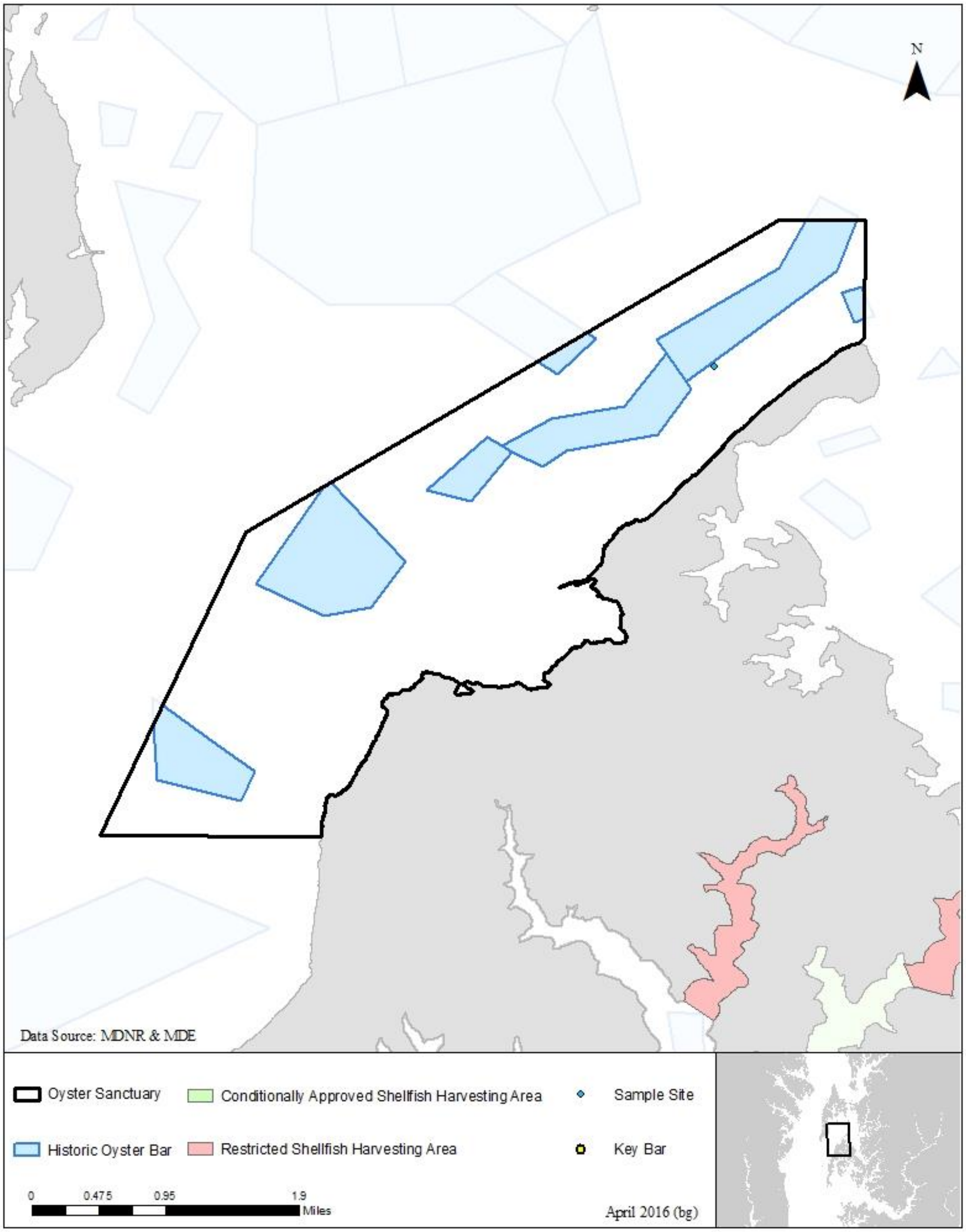


Figure A.09-1. Eastern Bay Sanctuary.

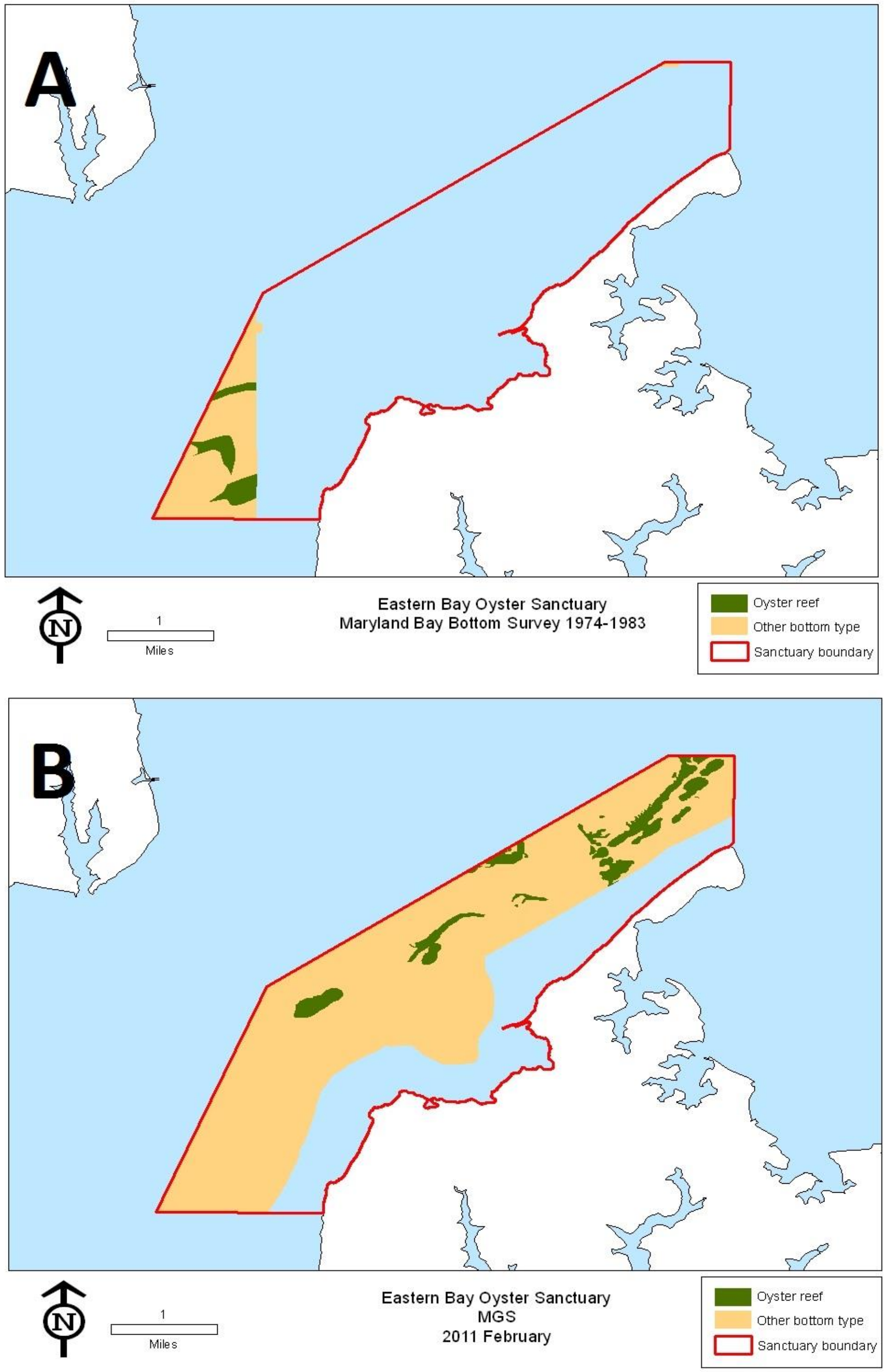


Figure A.09-2. Eastern Bay Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2011. Tan and green colored areas depict areas examined during the surveys.

Table A.09-1. Oyster population characteristics based on the Fall Survey before and after the establishment of the Eastern Bay Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.		
	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	10 / 10	0 / 0
Number of Live Oysters per Bushel	172 ± 81	ND
Number of Live Small-Sized Oysters per Bushel	42 ± 14	ND
Number of Live Market-Sized Oysters per Bushel	15 ± 5	ND
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	25.8 ± 4.2	ND

A patent tong population survey was conducted in 2014 (Figures A.09-4). No patent tong survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 0.53 ± 0.15 oysters m^{-2} (mean ± standard error, n=143), with the density of small oysters greater than that of market oyster (0.32 ± 0.10 and 0.15 ± 0.07 oyster m^{-2}, respectively). Eighty-two percent of the samples had no live oysters or boxes. Oyster density generally increased with volume of shell, although several samples contained cultch but few oysters, suggesting factors other than cultch are influencing density (Figure A.09.5).

Oyster Size Structure

Shell height data were not collected from Fall Survey samples taken in this area since 1990. Shell heights were measured during the patent tong population survey, however (Figure A.09-6). Shell height ranged from 18 to 137 mm, with an average of 64.1 ± 2.8 (mean ± standard error).

Biomass

The Fall Survey has not collect oyster biomass information in this area since 1990.

Recruitment (Spatfall)

From 1990 to 1997, the average number spat per bushel of material ranged from 0 to 860, with an average of 116 ± 84 (mean ± standard error) (Figure A.09-3). Excluding the unusually high spatfall of 1997, the average number spat per bushel was 34 ± 18. The density of spat found in the 2014 patent tong population survey was 0.06 ± 0.02 m^{-2}.

Mortality

Based on Fall Survey box counts, mortality from 1990 to 1999 ranged from 0% to 47.8% with an average of 25.8% ± 4.2% (mean ± standard error) (Figure A.09.7). No more recent mortality data are available.

Disease

The Fall Survey has not collect oyster disease information in this area since 1990.

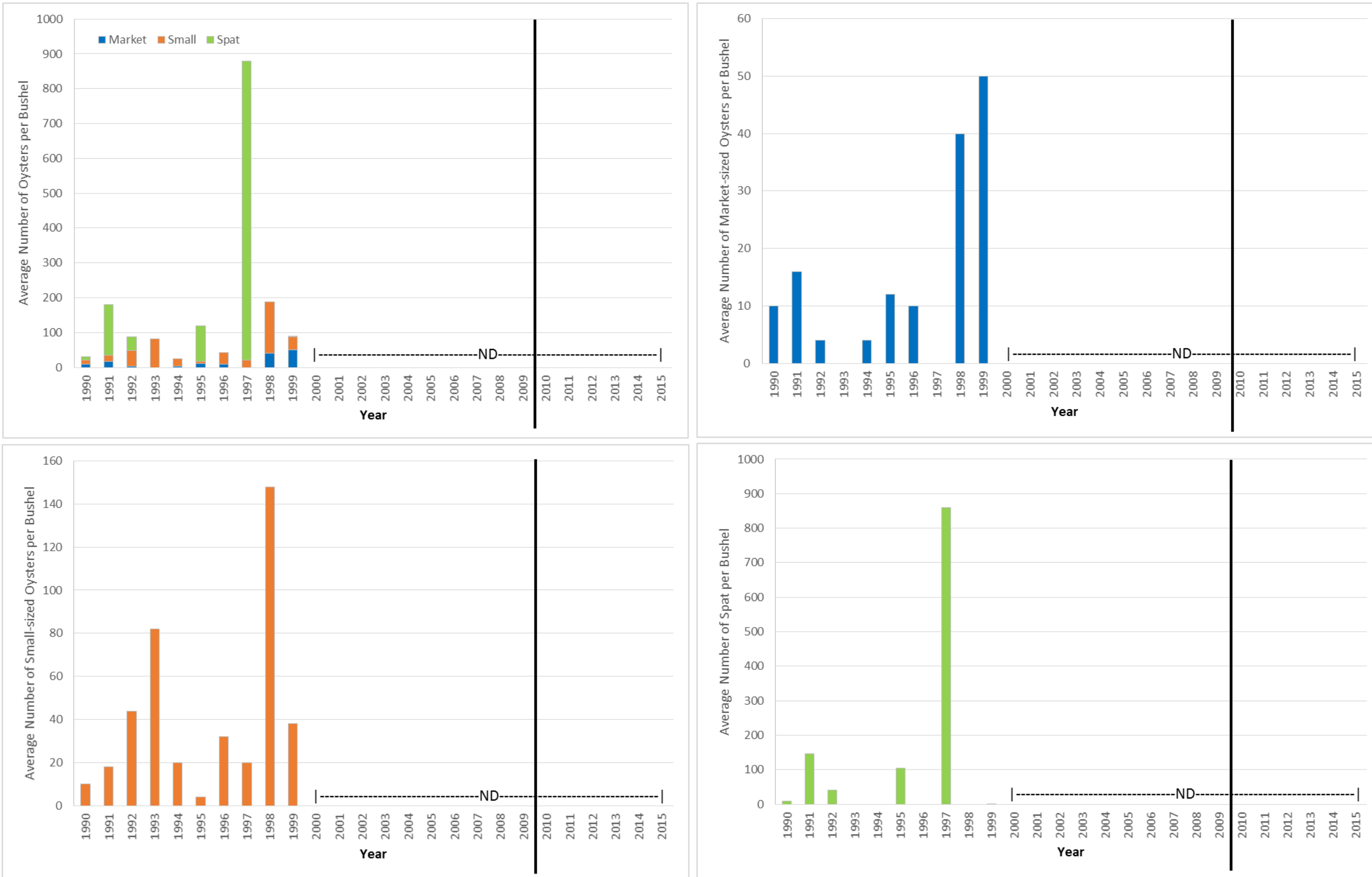


Figure A.09-3. Average number of live oysters per bushel of material by size class in the Eastern Bay Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data

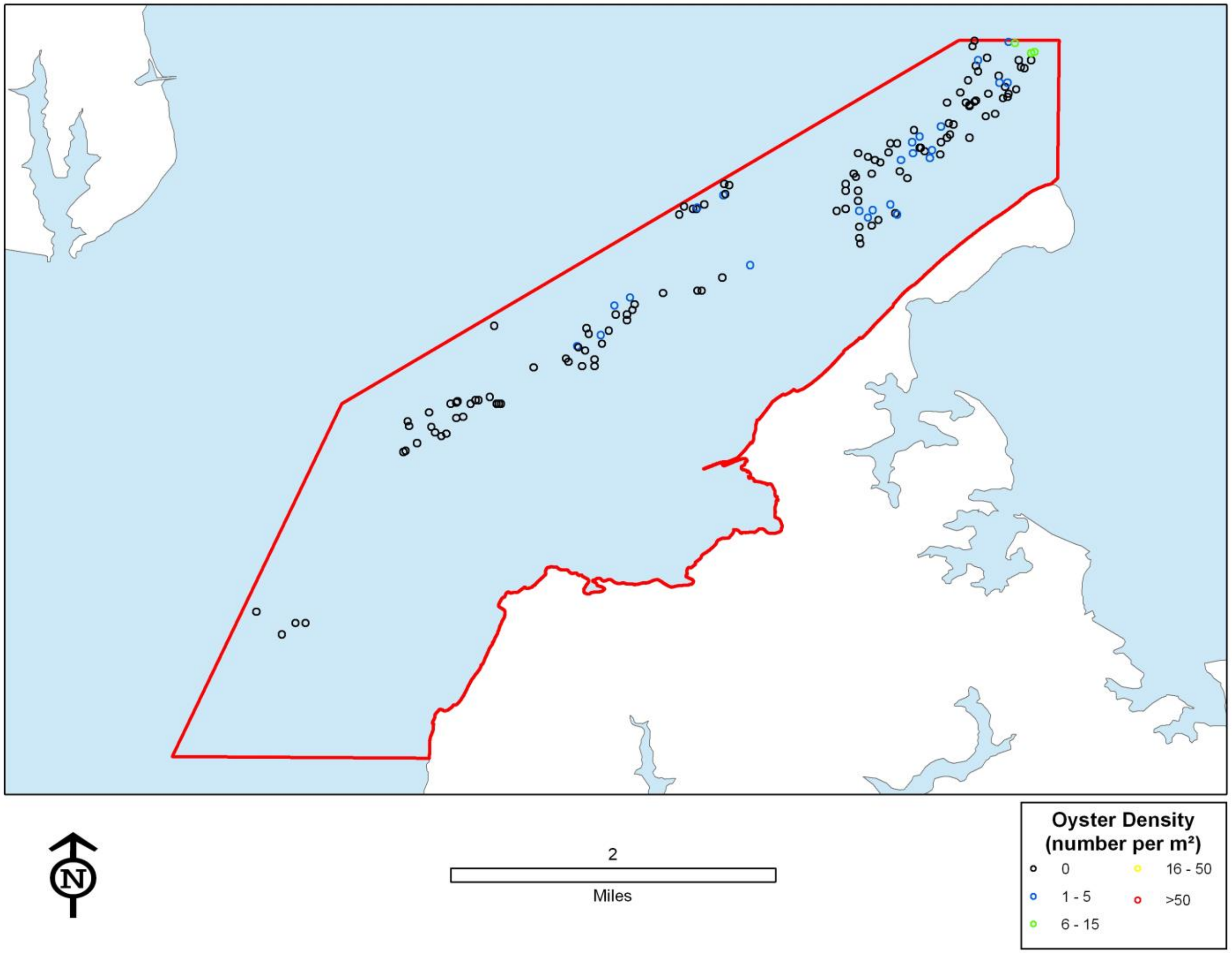


Figure A.09-4. Map of 2014 oyster density in the Eastern Bay Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

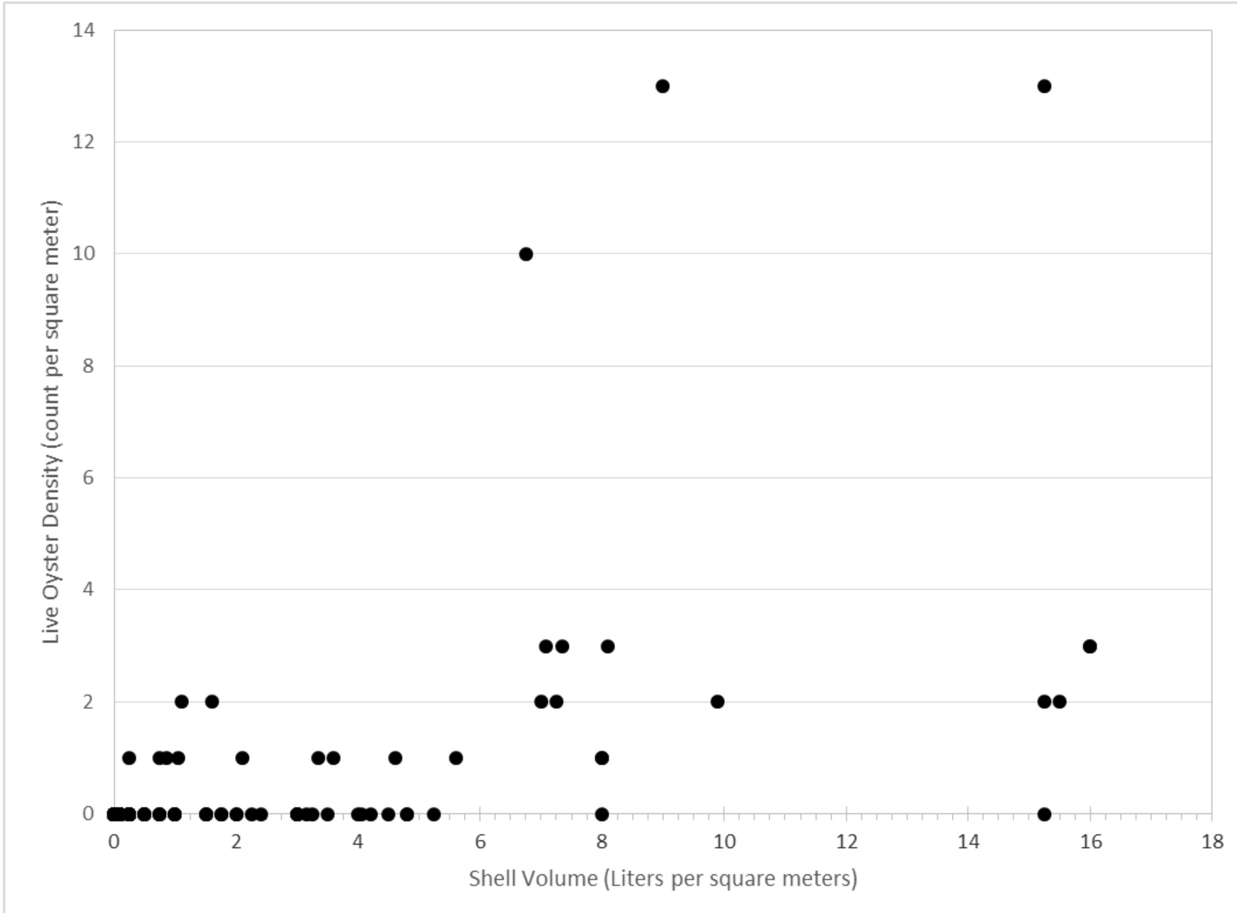


Figure A.09-5. 2014 live oyster density and shell volume (liters of live oysters, boxes, and surface shell) in the Eastern Bay Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

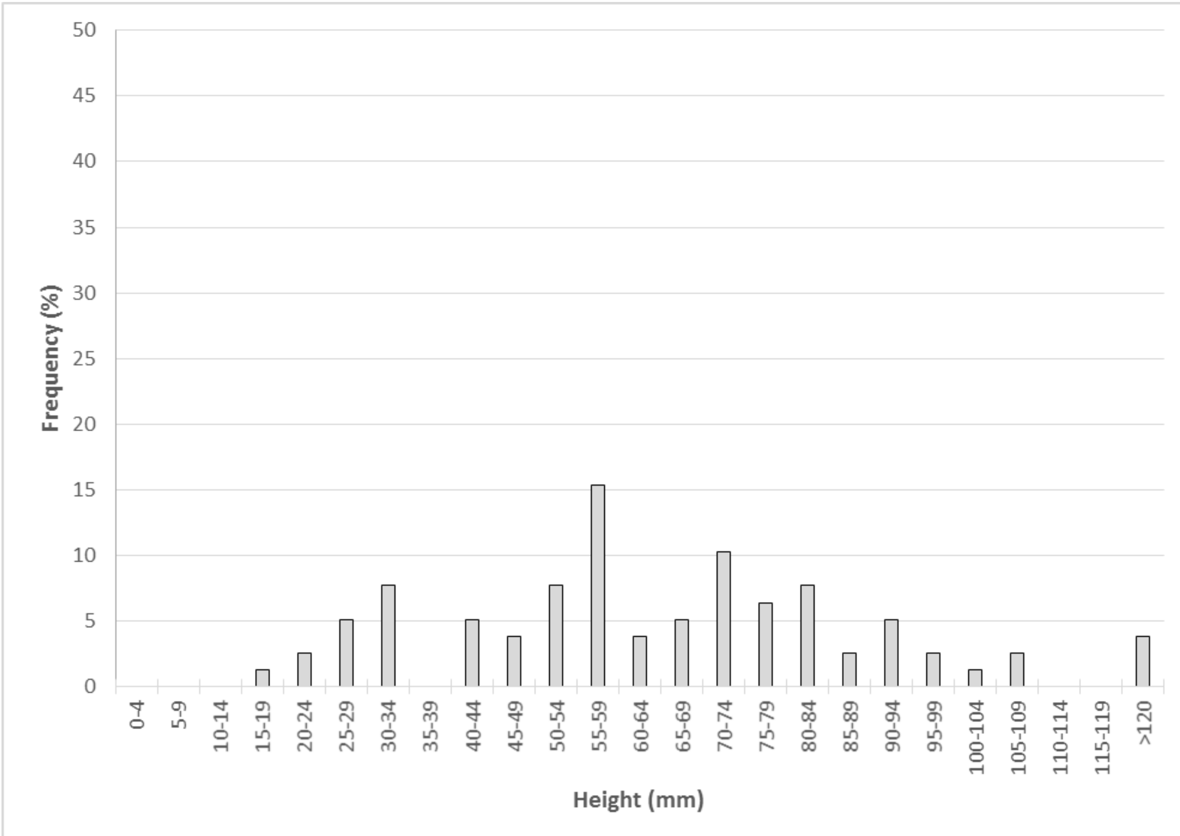


Figure A.09-6. Live oyster height distribution in the Eastern Bay Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

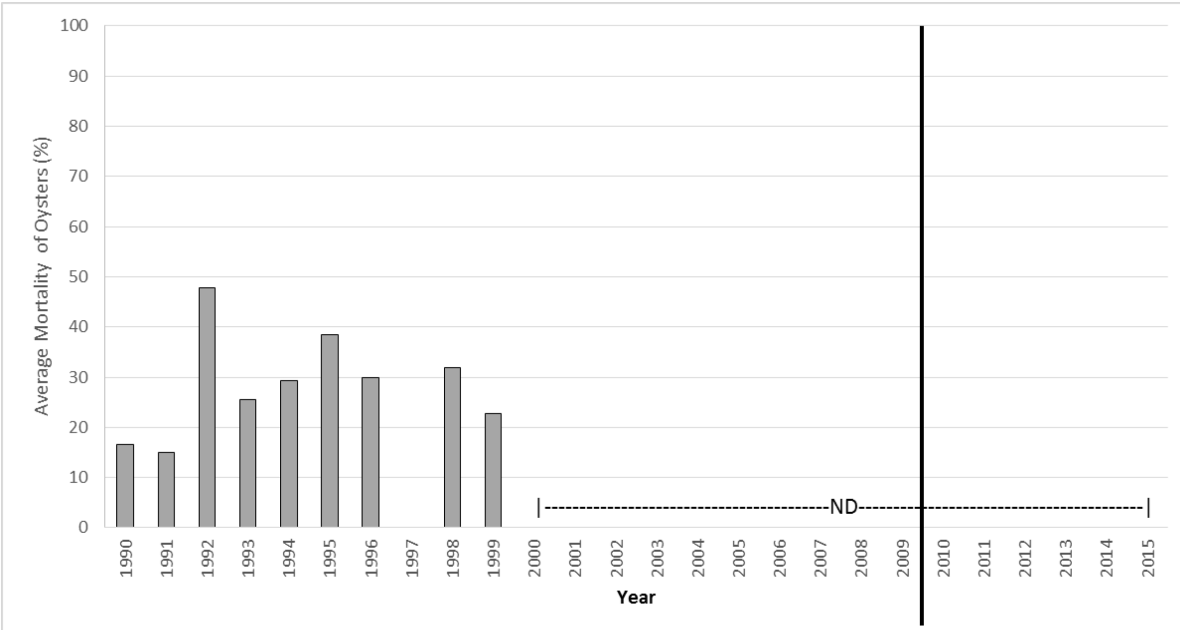


Figure A.09-7. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Eastern Bay Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error. ND = No Data.

Harvest

The Eastern Bay Sanctuary encompasses 14% of the 33,334 acres in NOAA Code 039. Because harvest for NOAA code 039 may have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. Oyster harvester reports show no harvest from bars located in Eastern Bay in 2009-2010, the season immediately prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program recorded monthly water quality at station XFG9210 (38.82, -76.316) in this area from 2004-2006 (Figure A.09-9). Chlorophyll a, salinity, secchi depth, total nitrogen, total suspended solids, and water temperature were measured. Water quality was suitable for oysters during this timer interval except for periods of low salinity in the spring of 2004 and 2005. No water quality data have been collected since the establishment of the sanctuary.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

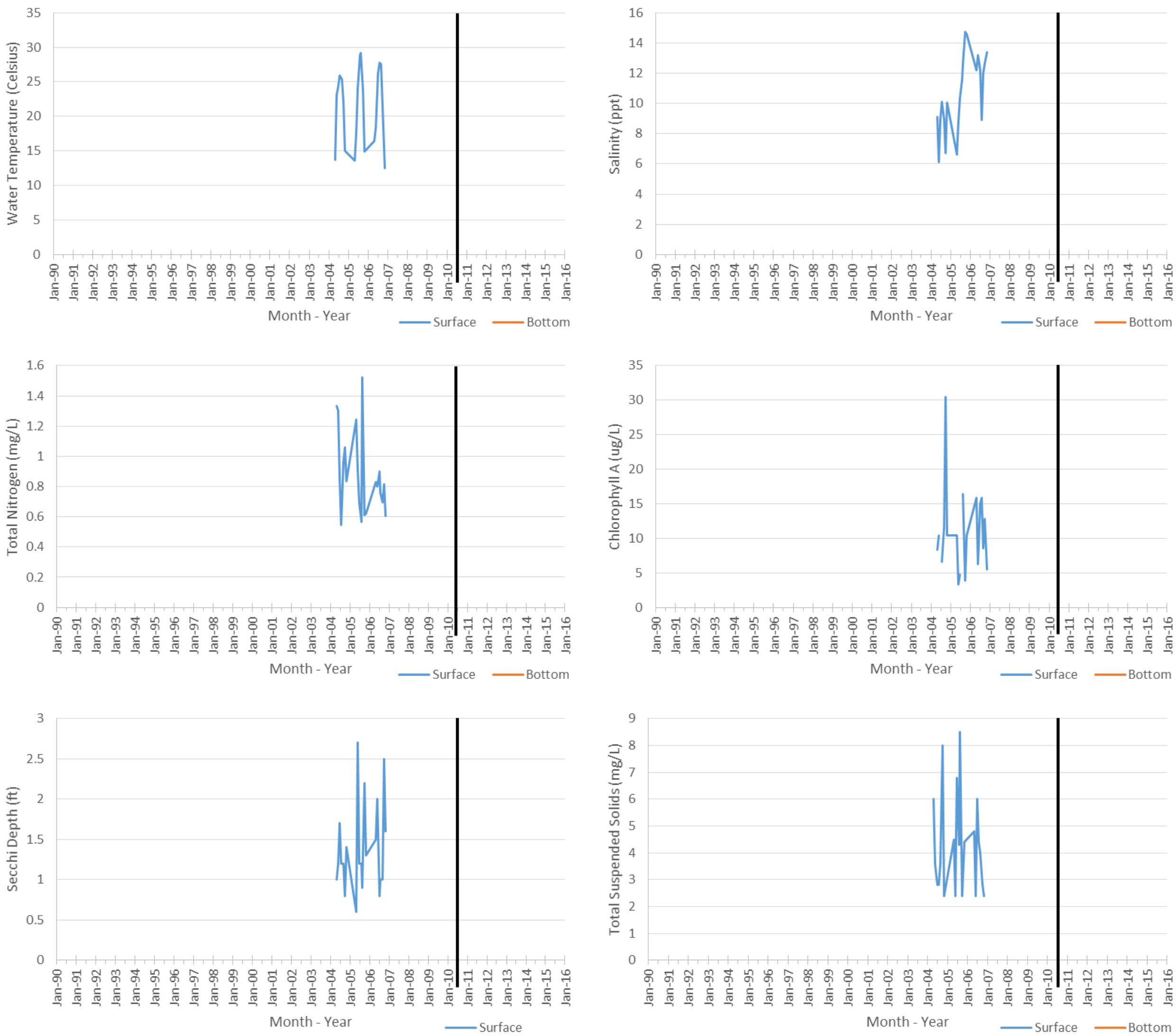


Figure A.09-9. Water quality data collected at Station XFG9210 within the area now established as Eastern Bay Sanctuary from 2004 to 2006. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.

Section A.10: Fort Carroll Sanctuary

The Fort Carroll Sanctuary is located in the Patapsco River, a low salinity (less than 12 ppt) region (Figure A.10-1). The sanctuary was created in 1995 and encompasses 30 acres. There is no historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments) in the sanctuary. Fort Carroll Sanctuary was established for educational programs run by the Living Classrooms Foundation.

Bottom Habitat Characteristics

No bottom habitat mapping has been conducted to date in this area.

Restoration and Replenishment Activities

The Living Classrooms Foundation has planted over 590,000 spat in the sanctuary since 1995.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 248 cages and planted approximately 72,000 oysters.

Oyster Population Characteristics

The Fall Survey has no sampling stations within this area since 1990.

The Department has not conducted any patent tong surveys conducted in sanctuary.

Harvest

No oyster harvest has been recorded from this area prior to the area becoming a sanctuary in 1995. The Fort Carroll Sanctuary is encompassed by the 164,314 acres in NOAA Code 025.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental condition (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

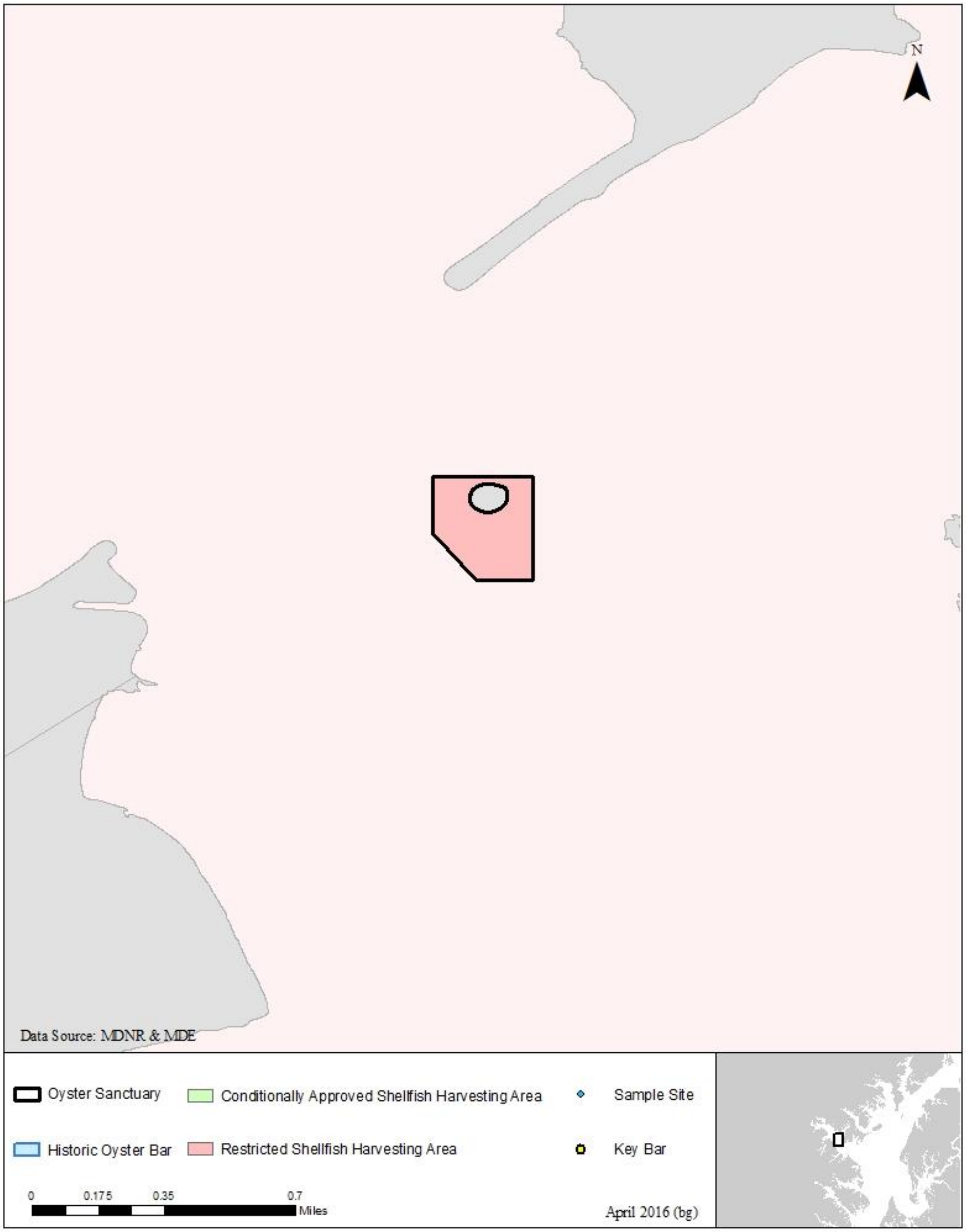


Figure A.10 -1. Fort Carroll Sanctuary. The grey circle within the sanctuary is a lighthouse.

Section A.11: Harris Creek Sanctuary

The Harris Creek Sanctuary is located in a low salinity (less than 12 ppt) tributary of the Choptank River (Figure A.11-1). The sanctuary was created in 2010 and encompasses 4,647 acres of which 1,998 acres (43%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments) oyster bottom. There are 15 historic oyster bars within the sanctuary[24]. This sanctuary has been selected for large-scale oyster restoration under the 2014 Chesapeake Bay Watershed Agreement.

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.11-2A). Of the 1,230 acres surveyed within the sanctuary, 1,033 (84%) were classified as oyster reef habitat. In 2010 Maryland Geological Survey conducted a more thorough side scan sonar survey of the area. Of the 1,939 acres surveyed in 2010, 420 acres (22%) were classified as oyster reef habitat. Comparing the area investigated by both surveys, there appears to be a substantial loss of oyster habitat between when the Bay Bottom Survey was conducted and the side scan sonar survey. After initial large-scale restoration efforts were completed in 2015, NOAA conducted a multi-beam sonar survey of the restored areas (Figure A.11-2B). This survey showed 531 acres of oyster reef habitat, an increase of 111 acres since the 2010 survey.

Restoration and Replenishment Activities

The area of the sanctuary has received both replenishment and restoration activities since 1990 (Table S.11-1). Prior to the establishment of the sanctuary, dredged shell, fresh shell, and wild seed were planted to enhance the public oyster fishery.

After the creation of the sanctuary areas in 2010, Harris Creek was chosen as the first tributary for large-scale oyster restoration under the Chesapeake Bay Agreement. Due to a shortage of fresh oyster shell, reefs were restored using stone, dredged oyster shell, oyster shell reclaimed from previous plantings, fossil oyster shell, clam shell, and mixed shell (clam and whelk). Over two billion hatchery spat-on-shell were placed in the sanctuary from 2011-2015 on 390.5 acres of restored oyster bottom. Several organizations participated in the restoration work including MDNR, U.S. Army Corps of Engineers, NOAA, Oyster Recovery Partnership, National Fish and Wildlife Foundation, Chesapeake Bay Foundation, The Nature Conservancy, and CSX Railroad.

Marylanders Grow Oysters, a public outreach program, has planted oysters since 2012 at one site in the sanctuary. In 2016, growers tended 590 cages and planted approximately 213,000 oysters.

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[24] See chart 15 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

The Phillips Wharf Environmental Center estimated planting a total of 549,700 oysters in the sanctuary since 2012 by Marylanders Grow Oysters.

Table A.11-1. Replenishment and restoration planting activities occurring since 1990 in Harris Creek Sanctuary. S = Planting activity occurring after the area became a sanctuary in 2010. ND = No Data.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Dredged Shell	13.59	100.10	-
1990	Fresh Shell	8	29.51	-
1991	Fresh Shell	2.99	11.03	-
1995	Fresh Shell	4	14.76	-
1996	Dredged Shell	19.31	118.89	-
1998	Dredged Shell	9.27	43.24	-
1999	Dredged Shell	49.97	137.77	-
2000	Dredged Shell	18.21	118.68	-
2001	Dredged Shell	16.47	165.20	-
2001	Wild Seed	32.93	20.78	-
2002	Dredged Shell	10.73	69.69	-
2002	Wild Seed	7.41	9.00	-
2004	Wild Seed	21.53	10.03	-
2007	Wild Seed	11.81	20.84	-
2011 (S)	Dredged Shell, Reclaimed Shell, Clam Shell	1.5	48	-
2011 (S)	Hatchery Spat-on-Shell	10.3	-	55.63
2012 (S)	Stone, Mixed Shell	22	586	-
2012 (S)	Hatchery Spat-on-Shell	97	-	450
2013 (S)	Stone, Mixed Shell	34	916	-
2013 (S)	Hatchery Spat-on-Shell	67.6	-	723.1
2014 (S)	Stone, Mixed Shell, Fossil Shell	85	1,797	-
2014(S)	Hatchery Spat-on-Shell	69.6	-	444.3
2015 (S)	Stone, Mixed Shell	55.4	1,472	-
2015 (S)	Hatchery Spat-on-Shell	93.41	-	389.54

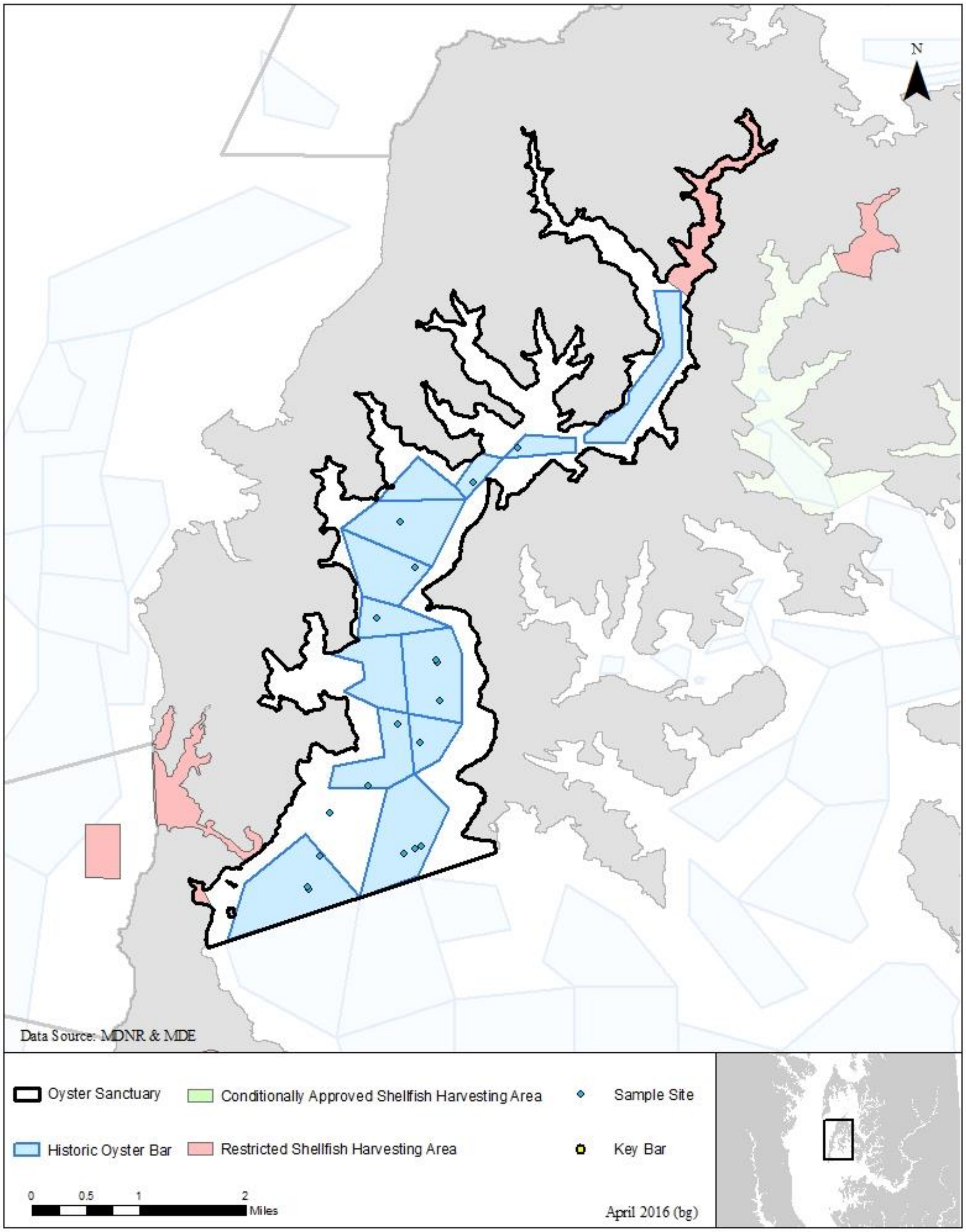

Figure A.11 -1. Harris Creek Sanctuary.

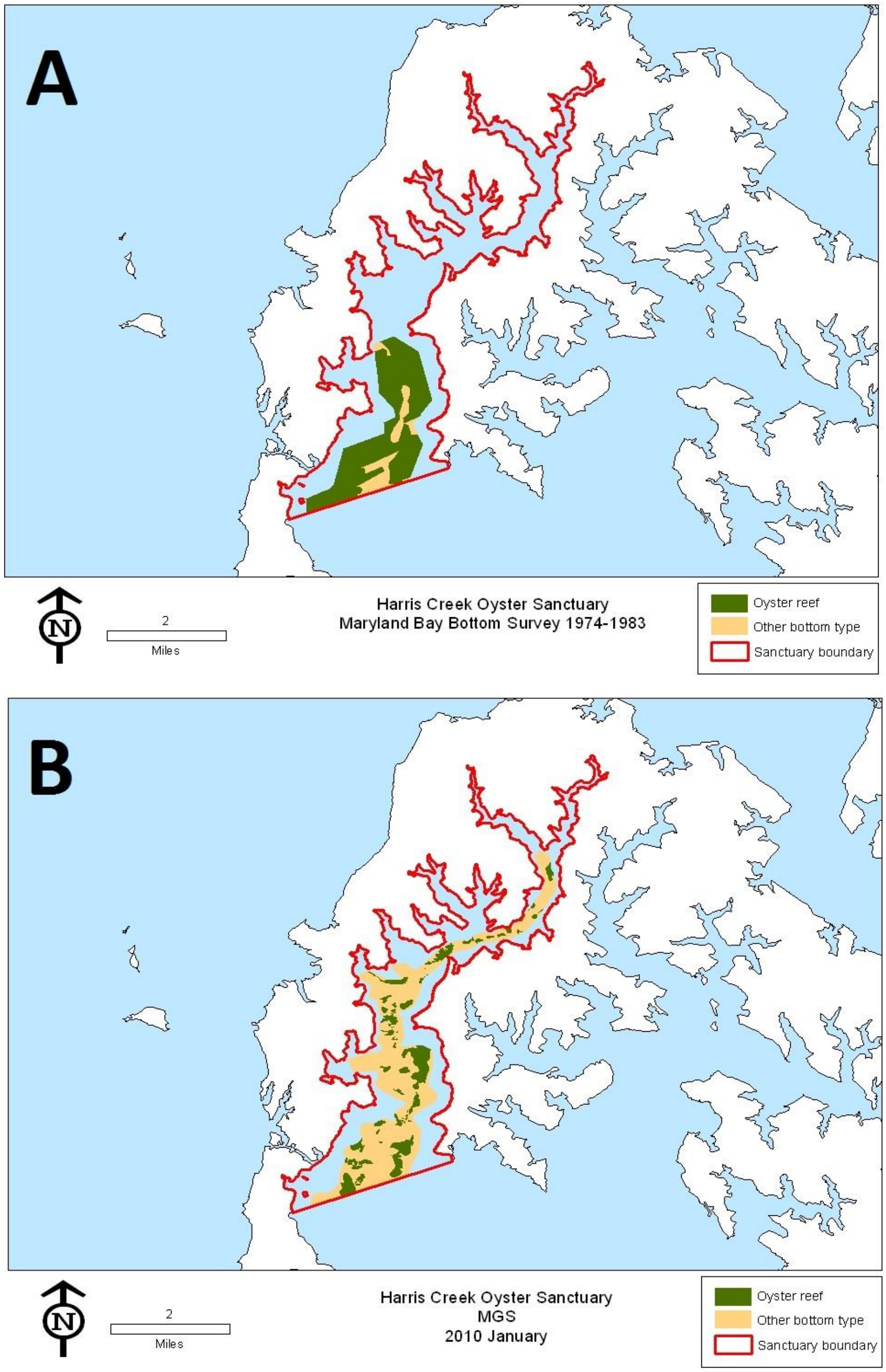

Figure A.11 -2A. Harris Creek Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2010. Tan and green colored areas depict areas examined during the surveys.

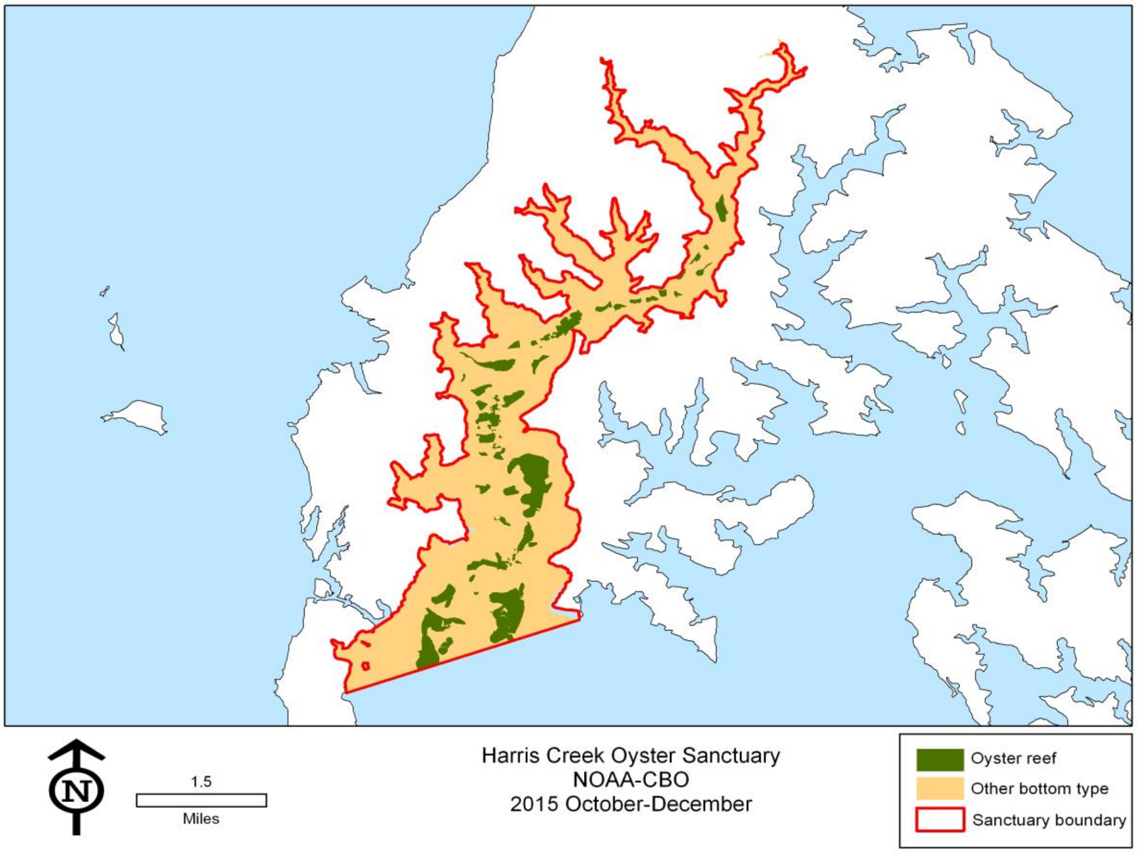

Figure A.11 -2B. Harris Creek Sanctuary bottom types, 2015. Tan and green colored areas depict the areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled four to seven oyster bars in this area since 1990 with an average of five oyster bars sampled annually. In 2012, three Fall Survey samples were collected on hatchery spat-on-shell restoration planting areas. In 2013, two more samples were collected on hatchery spat-on-shell restoration planting areas. After 2013, all samples (seven) were collected on hatchery spat-on-shell restoration planting areas. An additional sample location visited in 2012, 2014, and 2015 is located on a Marylanders Grow Oysters planting site.

The average number of total live oysters per bushel of material (market, small, and spat) from 1990-2009 was lower than the average from 2010-2015 (Table A.11-2; Figure A.11-3). Oyster abundance was high from 1990-1999, low from 2000-2011, and high again from 2012-2015 (Fig. A.11-3). The average number of small and market-sized oysters per bushel of material was greater after the creation of the sanctuary than before. The average number of market-sized oysters in 2013, 2014, and 2015 was the highest since 1990.

Patent tong population surveys were conducted in Harris Creek by Dr. Kennedy Paynter's lab in the fall of 2011 (Paynter et al. 2012)[25] and by Versar in winter of 2012 (Versar 2012)[26]. Paynter et al. found high densities of oysters (24.9 ± 3.1 m^{-2}) on planted sites, but oyster density was much lower (1.7 ± 0.3 oysters m^{-2}) on shell bottom that had not been planted with spat-on-shell. The highest oyster density found by Versar in 2012 was (6.83 ± 8.79 oysters m^{-2}).

As part of the monitoring to determine whether the large-scale restoration project is meeting the goals specified by the Oyster Metrics Workgroup (2011)[27], oyster plantings from 2012 were sampled by Dr. Kennedy Paynter's lab in 2015 three years after the areas were restored (NOAA 2016)[28]. Before these areas were planted in 2012, none of them met the Oyster Metrics Workgroup threshold density of 15 oysters m^{-2} over 30% of the bottom. In 2015, all of these sites met this criterion, and six of them met the target density of 50 oysters m^{-2} over 30% of the bottom.[5]

Reference sites were established to gauge the effectiveness of restoration treatments in the Paynter lab survey of 2016. The reference sites were areas that were suitable for restoration with seed or substrate and seed, but left unrestored. These areas were not true controls in that they were not exact replicates of the treated sites (exact replicates are not possible given variation in flow, salinity, and bottom type). Furthermore, it is not possible to isolate the reference sites from the treated sites, and restoration on treated sites may affect reference sites. For example, as oysters grow on treated sites, they may provide larvae to adjacent reference sites. With these caveats in mind, two reference sites met the threshold density of 15 oysters m^{-2} over 30% of the

[25] Paynter, K.T., A. Michaelis, and H. Lane. 2012. Oyster population and habitat assessment, Harris Creek and the Little Choptank River. Report to NOAA Chesapeake Bay Office. 81 pp. http://oysterrecovery.org/oyster-reef-monitoring/

[26] Versar. 2012. An assessment of oyster resources in Harris Creek and Little Choptank River, Chesapeake Bay. Report to NOAA Chesapeake Bay Office. 33 pp. http://oysterrecovery.org/oyster-reef-monitoring/

[27] Oyster Metrics Workgroup. 2011. Restoration goals, quantitative metrics and assessment protocols for evaluating success on restored oyster reef sanctuaries. Report to the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program. 32pp.. http://chesapeakebay.noaa.gov/images/stories/fisheries/keyFishSpecies/oystermetricsreportfinal.pdf

[28] NOAA. 2016. Initial analysis of fall 2015 Harris Creek oyster density. Available online at http://www.chesapeakebay.noaa.gov/images/stories/hottopics/hc3yrcheckinprelimdata.pdf

bottom, a result of natural spat set.[5] We cannot discern whether the spat were produced by wild or hatchery-reared oysters.

Table A.11-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Harris Creek Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.		
	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 102	6 / 35
Number of Live Oysters per Bushel	197 ± 43	302 ± 73
Number of Live Small-Sized Oysters per Bushel	81 ± 15	164 ± 60
Number of Live Market-Sized Oysters per Bushel	36 ± 6	88 ± 27
Live Oyster Biomass (g Dry Weight per Bushel)	ND	136 ± 32
Mortality (%)	20.5 ± 4.5	4.6 ± 1.3

Oyster Size Structure

The Fall Survey has measured oyster shell heights in this area at Mill Point bar since 2010 (Figure A.11-4). In 2010, the largest oyster was 100-104 mm, however, after 2012 the largest oysters were greater than 130 mm, likely the result of cessation of harvest. 2015 had the largest range of oyster sizes (0 mm to 134 mm), indicating the presence of multiple age classes.

Biomass

Biomass of oysters from Mill Point bar collected by the Fall Survey has been calculated since 2010. From 2010-2013, biomass showed a sharp increase. Biomass then decreased in 2014 and 2015 (Figure A.11-5).

Recruitment (Spatfall)

Based on Fall Survey data from 1990 to 2015, the average number of spat per bushel ranged from 0 to 368 (Figure A.11-3). The average number of spat per bushel of material from 1990-2009 was 81 ± 35 (mean ± standard error), higher than the average after sanctuary creation (49 ± 22). However, the average spat count from 2010 to 2015 was higher than the count from 2000 to 2009 (7 ± 2), the decade immediately preceding establishment of the sanctuary. Versar (2013)[29] conducted a patent tong and diver survey of restored areas to examine spat settlement on oyster shell and alternate substrates including mixed shell, granite, and clam shell. Spat settled on all

[29] Versar. 2013. Harris creek spat survey. Report to the Maryland Department of Natural Resources. 39 pp. http://oysterrecovery.org/oyster-reef-monitoring/

the substrates examined. Average spat density on mixed shell was 2.34 m^{-2} and on granite 33.79 m^{-2}. Average density on clam shell ranged from 1.12 to 36.22 m^{-2}. Spat density on seed plantings ranged from 0.17 to 38.14 m^{-2}, but it is difficult to separate the hatchery-produced seed from natural set.

Mortality

Based on Fall Survey box counts, the average mortality from 2010 to 2015 was lower than the average mortality before the sanctuary was established (Table A.11-2; Figure A.11-6).

Disease

There have only been two disease samples collected by the Fall Survey in 2014 and 2015 within the sanctuary on Mill Point bar. In both 2014 and 2015, dermo prevalence was 93%. Dermo intensity was 3.8 in 2014 and 3.6 in 2015, which is below the potential lethal limit of 5. MSX prevalence was zero in both years.

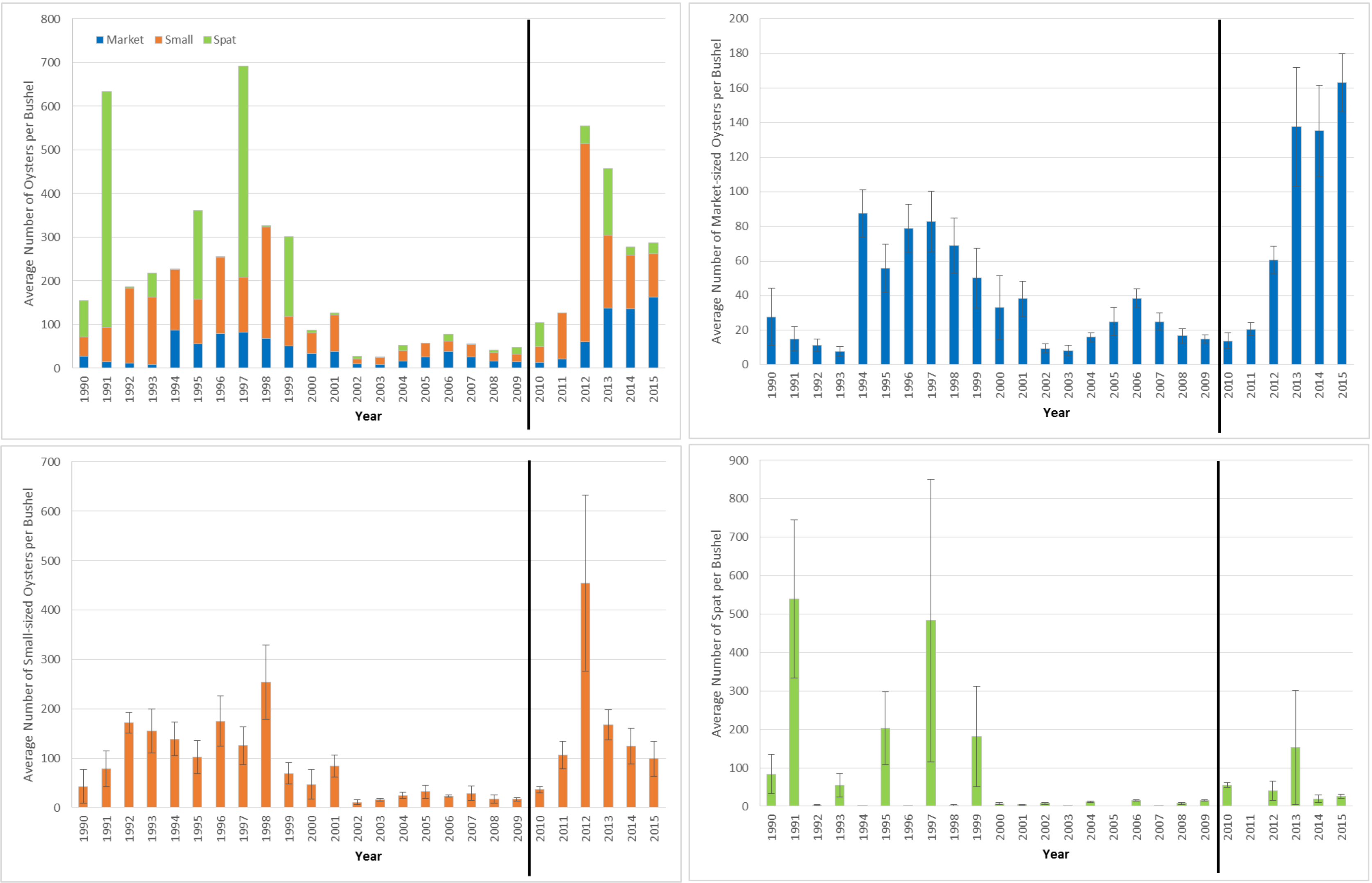

Figure A.11-3. Average number of live oysters per bushel of material by size class in the Harris Creek Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

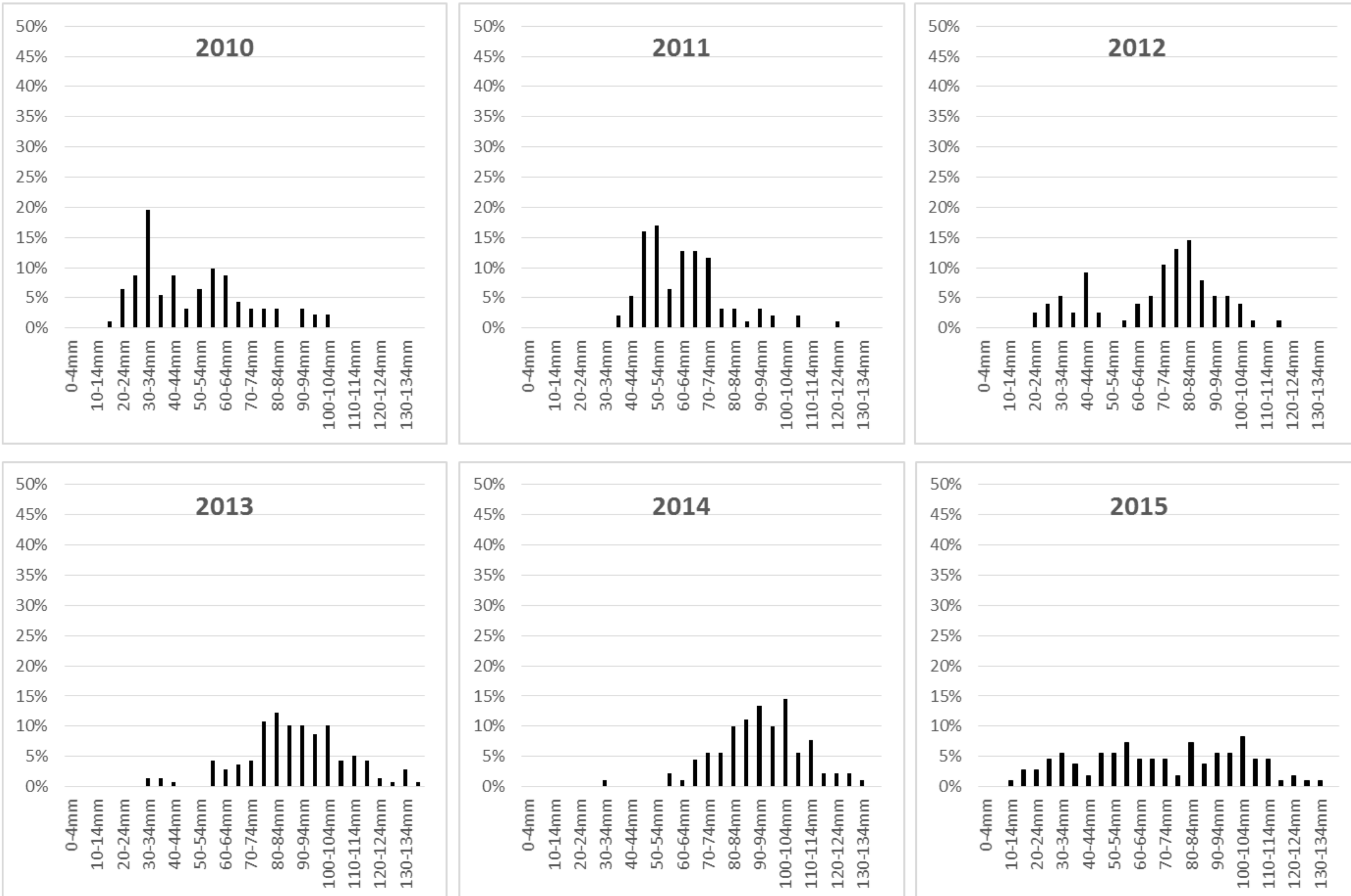

Figure A.11-4. Shell height frequencies of live oysters per bushel of material from 2010 to 2015 in the Harris River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Mill Point bar. Data was not collected prior to 2010.

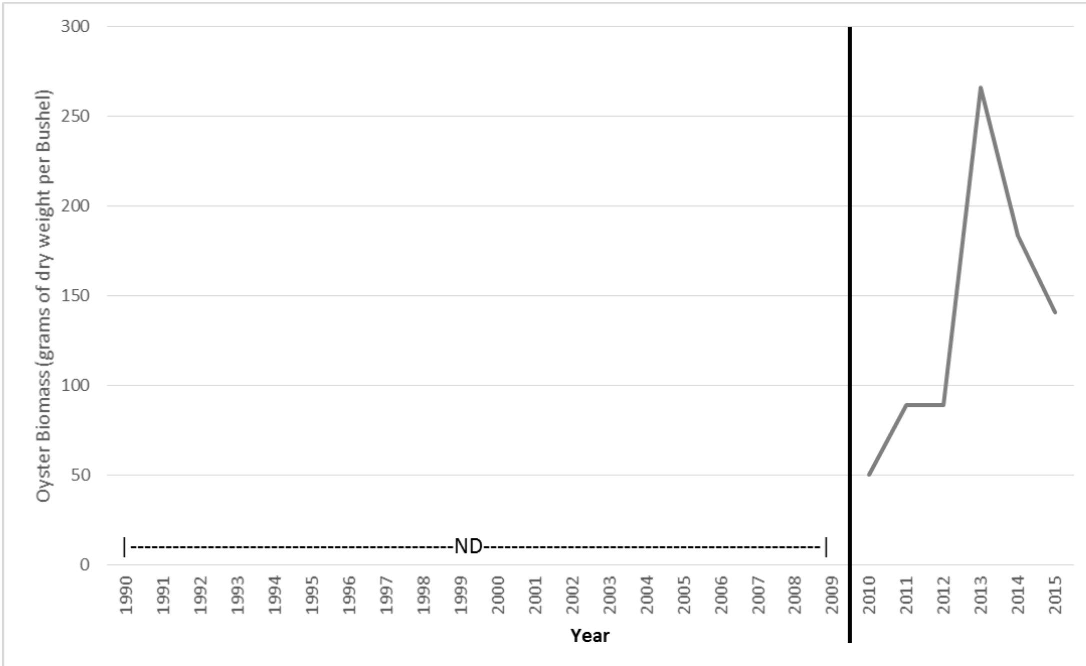

Figure A.11-5. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 on Mill Point bar in the Harris River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line indicates the date the sanctuary was established. ND = No Data.

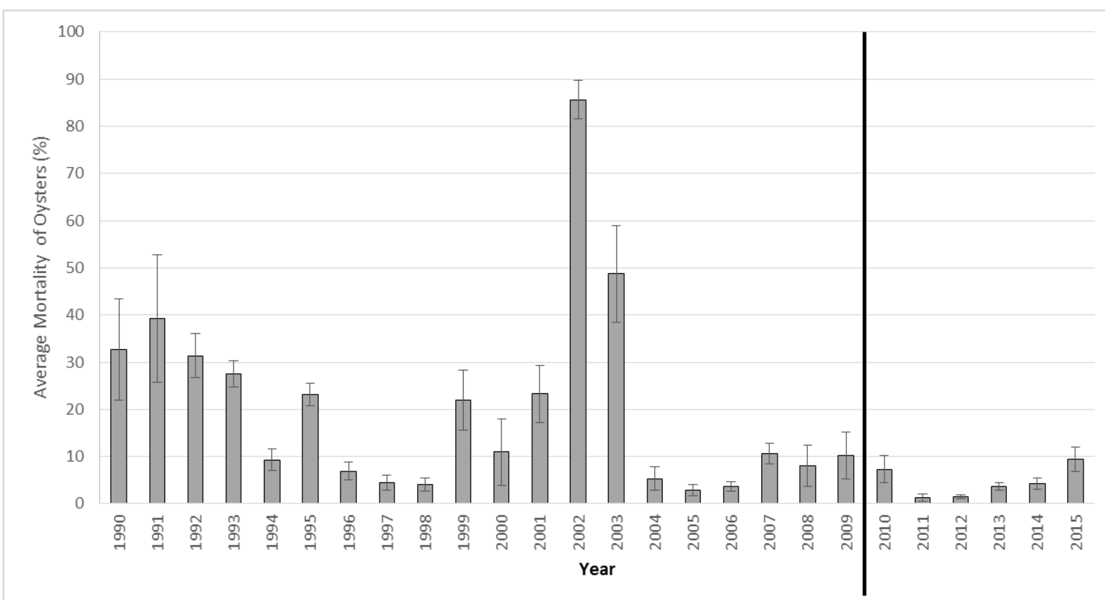

Figure A.11-6. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Harris Creek Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

Harvest

The sanctuary encompasses 64% of the 7,310 acres in NOAA Code 437. Harvest reported by seafood dealers prior to the establishment of the sanctuary peaked in the 1998-1999 season at 66,982 bushels (Figure A.11-7). The average harvest per season from 1990 to 2009 was 9,258 bushels. In the 2009-2010 season, harvester reports showed a catch of 1,253 bushels in Harris Creek.

After the 2009-2010 season, 64% of the NOAA Code area was a sanctuary where harvest is prohibited. In the 2014-2015 season, 8,221 bushels were harvested in the Harris Creek outside the sanctuary. Based on seafood dealer reports, this is the highest harvest since the 2000-2001 season.

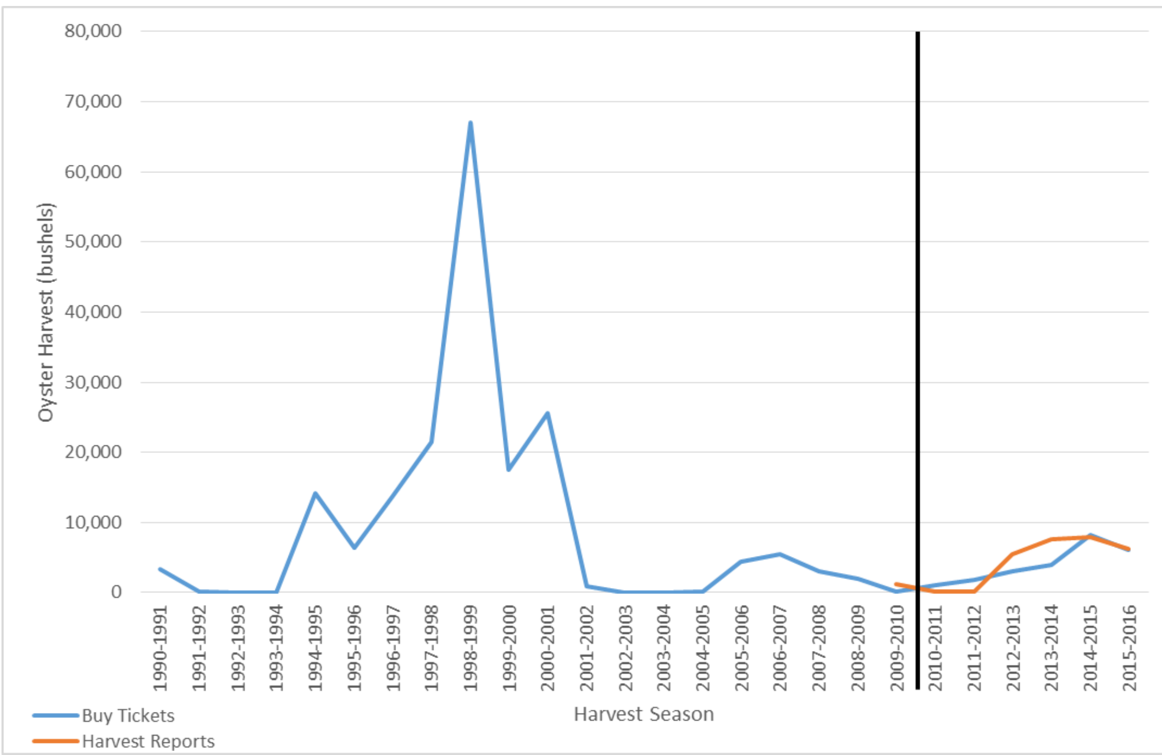

Figure A.11-7. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 437 (Harris Creek). In 2010, 64% of NOAA Code became an oyster sanctuary (denoted by the black line) where harvest is prohibited.

Environmental Conditions and Ecosystem Services

Water quality is measured at three different sites within the sanctuary (Figure A.11-8). Water quality sondes are moored to the bottom at upstream and downstream sites, and a vertical profiler is located mid-stream. Temperature, salinity, dissolved oxygen, pH, turbidity, and total chlorophyll are measured continuously. Additionally, alkalinity is measured bimonthly. Water quality has been favorable for oysters since large-scale restoration began with the exception of a few brief hypoxic periods in the summer of 2015. These short hypoxic periods do not show up in the monthly average graphs as dissolved oxygen levels were higher most of the time.

Harris Creek serves as a laboratory for researchers investigating ecosystem services provided by oysters. Scientists are currently studying the role restored reefs play in water filtration, habitat provisioning, larval supply, and nutrient cycling. Additionally, economists are attempting to estimate the economic value of ecosystem services provided by oysters. A more detailed summary of the ecosystem services research being conducted in Harris Creek may be found in the 2015 Oyster Restoration Ecosystem Services Research Update (NOAA 2015[30]).

Although these studies are still in their early phases, some preliminary results are available. Computer models suggest that oysters from Harris Creek may supply larvae to areas outside the sanctuary that are open for harvest (North et al. 2012[31]). A habitat utilization study in Harris Creek found no clear relationship between oyster biomass density and catch per unit effort, total length or biomass for striped bass or white perch, but gut contents suggest that these fish are foraging on oyster reefs (Kellogg et al 2016[32]). An examination of DNR's water quality data upstream and downstream of restoration areas suggests the restored oysters in Harris Creek may be controlling summer phytoplankton levels (Gedan and Fisher in prep.[9]).

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[30] NOAA. 2015. 2015 Oyster restoration ecosystem services (ORES) research update. Available online at http://chesapeakebay.noaa.gov/images/stories/habitats/2015oresresearchupdate.pdf.

[31] North, E., W. Long, Z. Schlag, S. Suttles. 2012. Native oyster recovery: Hydrodynamic and larval transport modeling in Harris Creek. Report to U.S. Army Corps of Engineers. 37 pp.

[32] Kellogg, M.L., P.G. Ross, M.W. Luckenbach, J.C. Dreyer, M. Pant, A. Birch, S. Fate, E. Smith, and K. Paynter. 2016. Integrated assessment of oyster reef ecosystem services: Fish utilization and trophic linkages. Report to NOAA Chesapeake Bay Office. 20 pp. https://digitalarchive.wm.edu/bitstream/handle/10288/22190/Oyster_reef_ecosystem_services_2016.pdf?sequence=1

[9]. Gedan, K. B. and J.K Fisher. In prep. Water quality impacts of a large-scale oyster restoration.

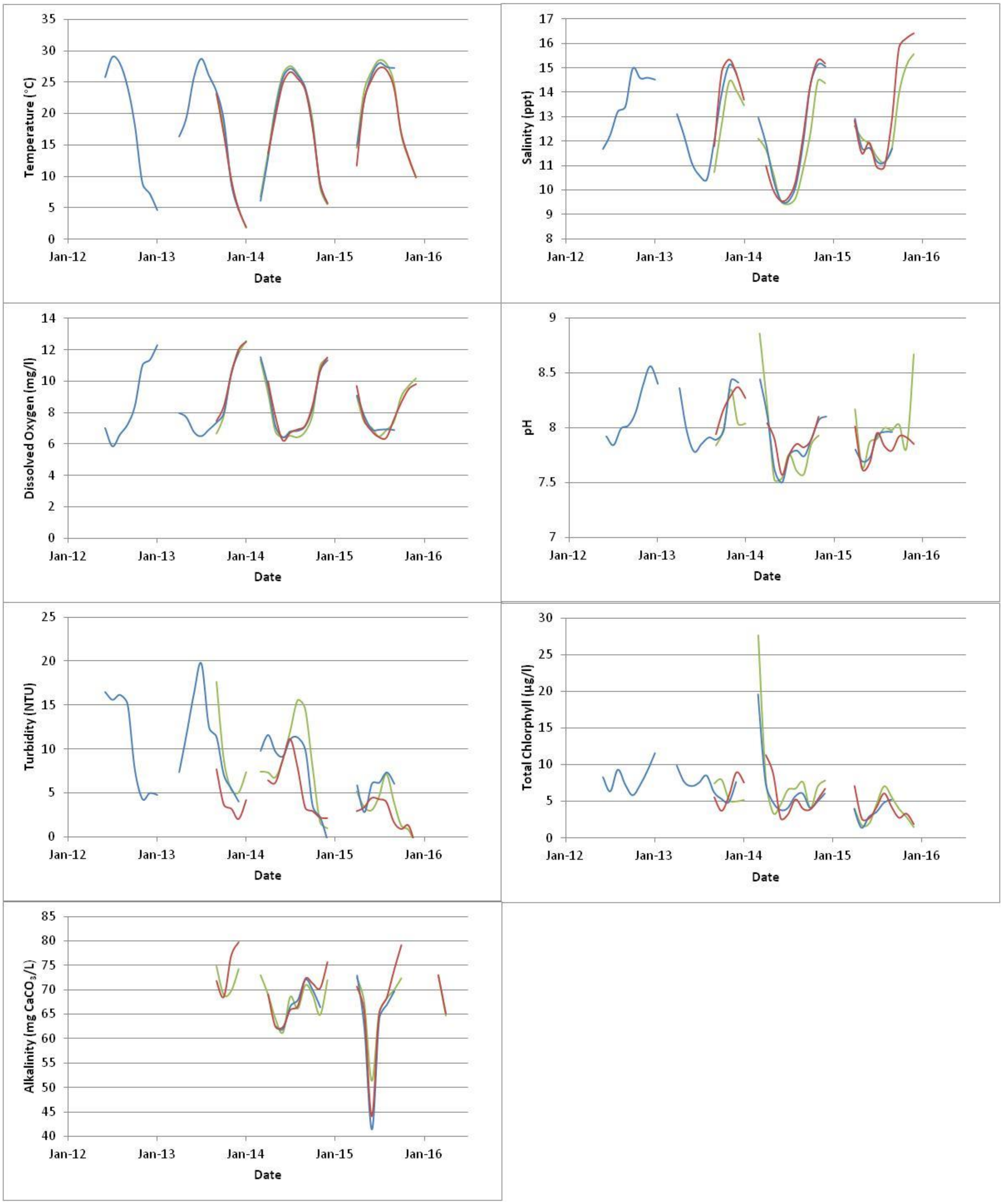

Figure A.11-8. Water quality data collected at three stations in Harris Creek Sanctuary. Monthly averages of bottom measurements are presented. Upstream, Midstream, Downstream

Section A.12: Herring Bay Sanctuary

The Herring Bay Sanctuary is located in a low salinity zone (less than 12 ppt) along the shore of lower Anne Arundel County and upper Calvert County (Figure A.12-1). The sanctuary was created in 2010 and encompasses 16,792 acres of which 7,981 (48%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 8 historic oyster bars within the sanctuary[33].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.12-2). Of the 12,383 acres surveyed within the sanctuary, 5,426 acres (44%) were classified as oyster reef habitat. In 2009, Maryland Geological Survey surveyed a small portion of the Herring Bay Sanctuary using side scan sonar. Of the 1,237 acres surveyed, 795 acres (64%) were classified as oyster reef habitat. The small area examined in 2009 relative to the Bay Bottom Survey precludes comparison of the two surveys.

Restoration and Replenishment Activities

No restoration efforts have occurred in this area since 2010; however, replenishment efforts took place prior to 2010 (Table A.12-1). Since 1990, 35.74 acres were planted with dredged shell and 173.58 acres were planted with wild seed. No hatchery spat-on-shell or fresh shell has been planted since 1990.

Table A.12-1. Replenishment planting activities occurring since 1990 in the area of the established Herring Bay Sanctuary in 2010.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Wild Seed	22.95	10.10	-
1990	Dredged Shell	35.74	256.12	-
1991	Wild Seed	32.33	13.00	-
1992	Wild Seed	94.94	38.54	-
1999	Wild Seed	23.36	11.35	-

[33] See chart 13 and 17 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

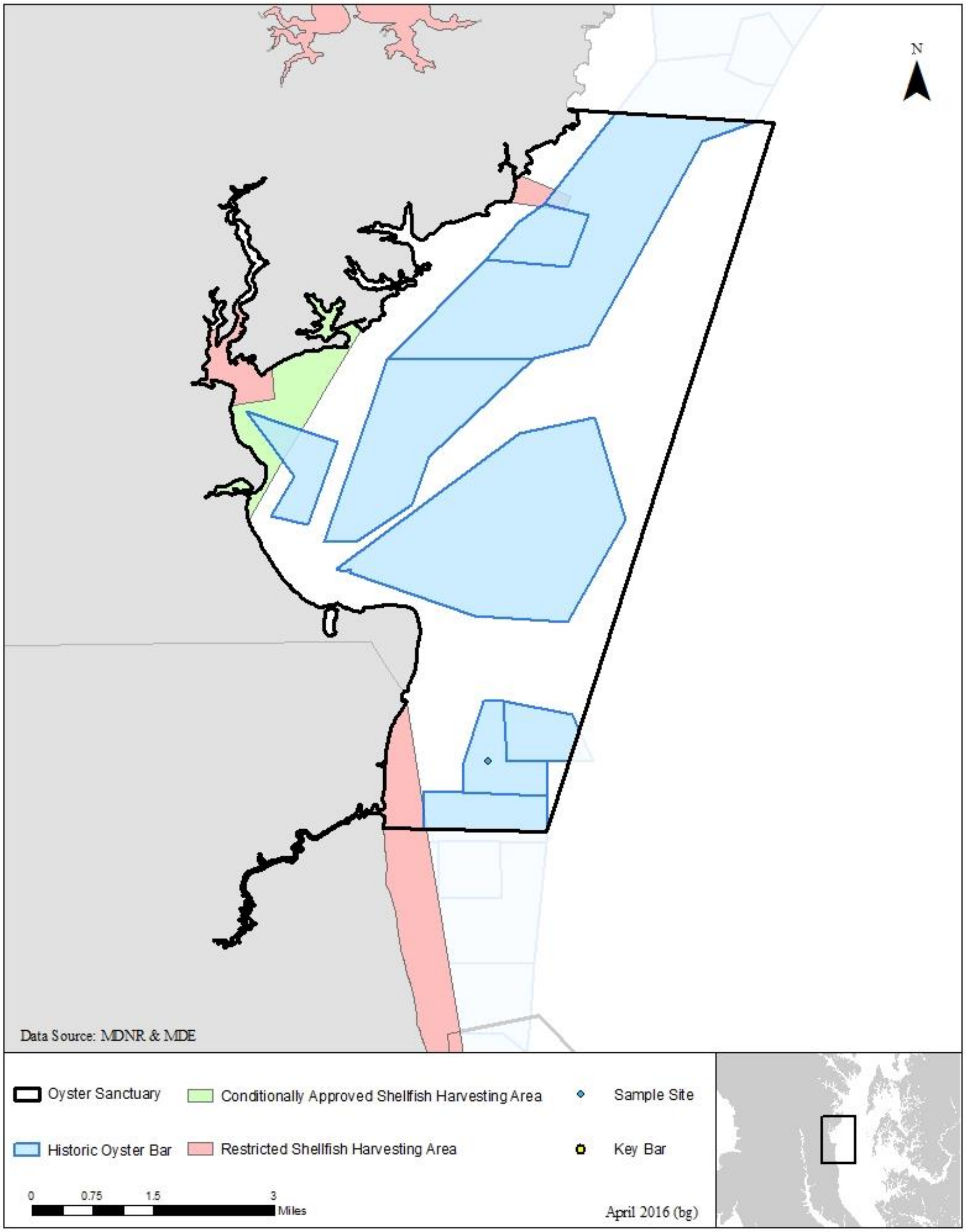

Figure A.12 -1. Herring Bay Sanctuary.

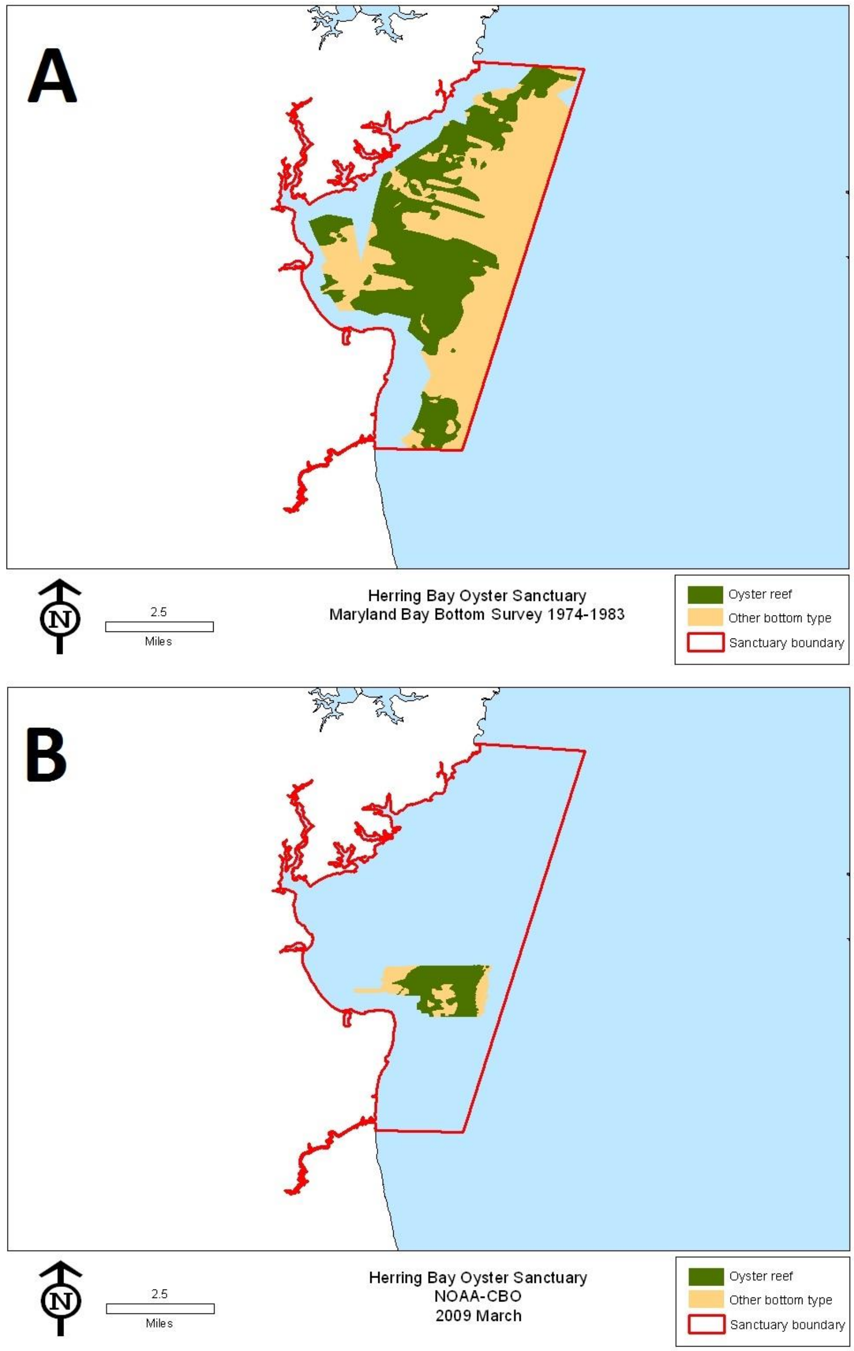

Figure A.12 -2. Herring Bay Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2009. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled 1 oyster bar in this area from 1992 to 2010 and in 2009. From 1990 to 2015, the average number of total live oysters (market, small, and spat) per bushel of material ranged from 6 to 62 (Table A.12-2; Figure A.12-3). The average number of small-sized oysters per bushel ranged from 0 to 16, and the average number of market-sized oysters per bushel ranged from 2 to 60.

Table A.12-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Herring Bay Sanctuary in 2010. ND = No Data. Values are given as means ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	17 / 17	1 / 1
Number of Live Oysters per Bushel	26 ± 3	8
Number of Live Small-Sized Oysters per Bushel	4 ± 1	6
Number of Live Market-Sized Oysters per Bushel	21 ± 3	2
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	18.4 ± 4.1	0

A patent tong population survey was conducted in 2014 (Figures A.12-4). No such population survey was conducted prior to the establishment of the sanctuary. No live oysters were found during the survey.

Oyster Size Structure

The Fall Survey has not measured oyster shell height in this area since 1990.

Biomass

The Fall Survey has not measured oyster biomass in this area since 1990.

Recruitment (Spatfall)

The Fall Survey found spat in this area in only two years, 1999 and 2003. Spat count ranged from 2 to 4 spat per bushel of material (Figure A.12-3).

Mortality

The average mortality from 1990 to 2009 was 18.4% ± 4.1%, with a maximum of 55.6% in 1999 (Table A.12.2; Figure A.12-5). The high mortality in 1999 was likely due to drought leading to high salinity and consequently high disease rates. Mortality was 0% from 2004 to 2008 and 2010.

Disease

The Fall Survey has not measured oyster disease in this area since 1990.

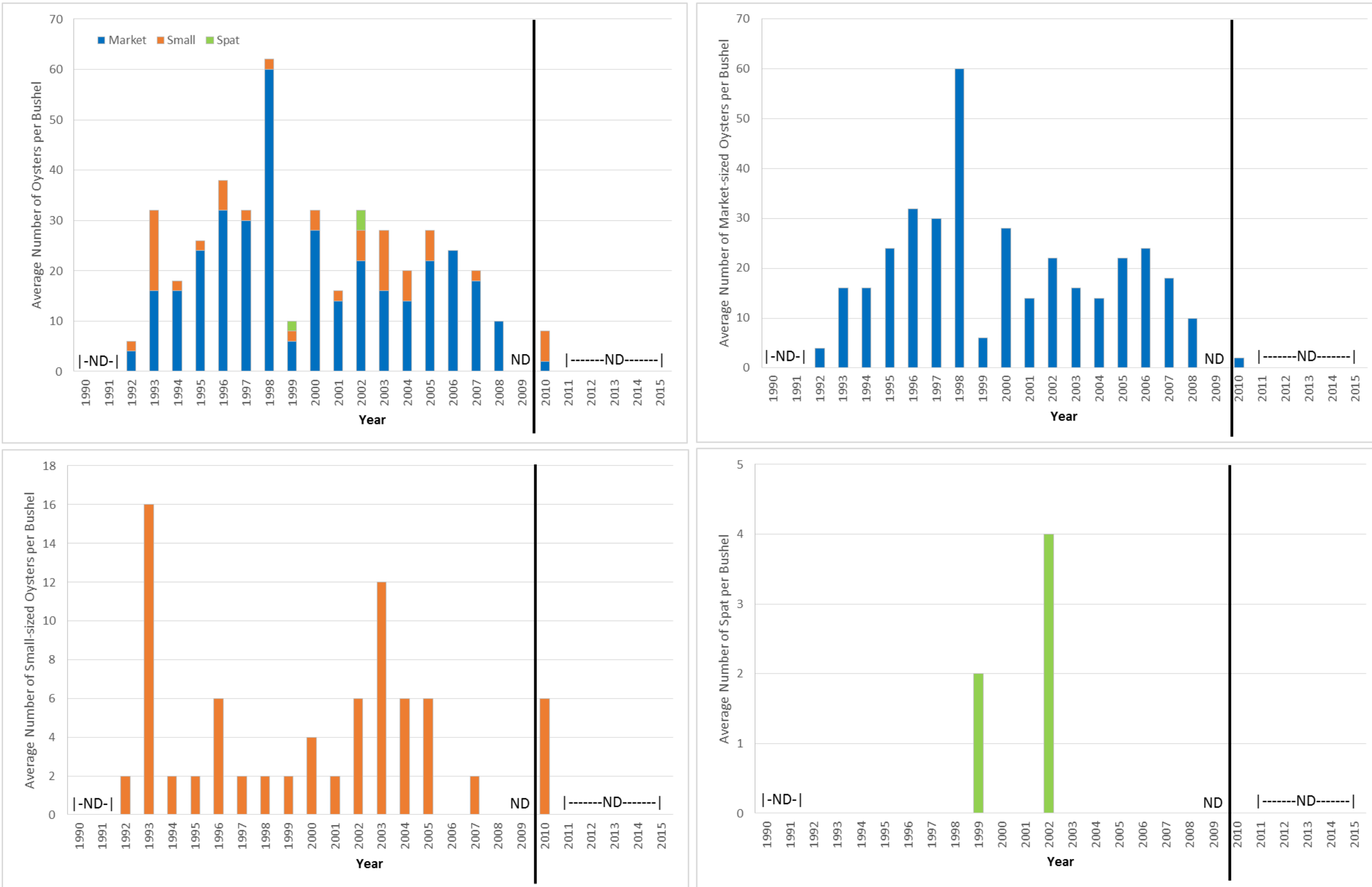

Figure A.12-3. Average number of live oysters per bushel of material by size class in the Herring Bay Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data.

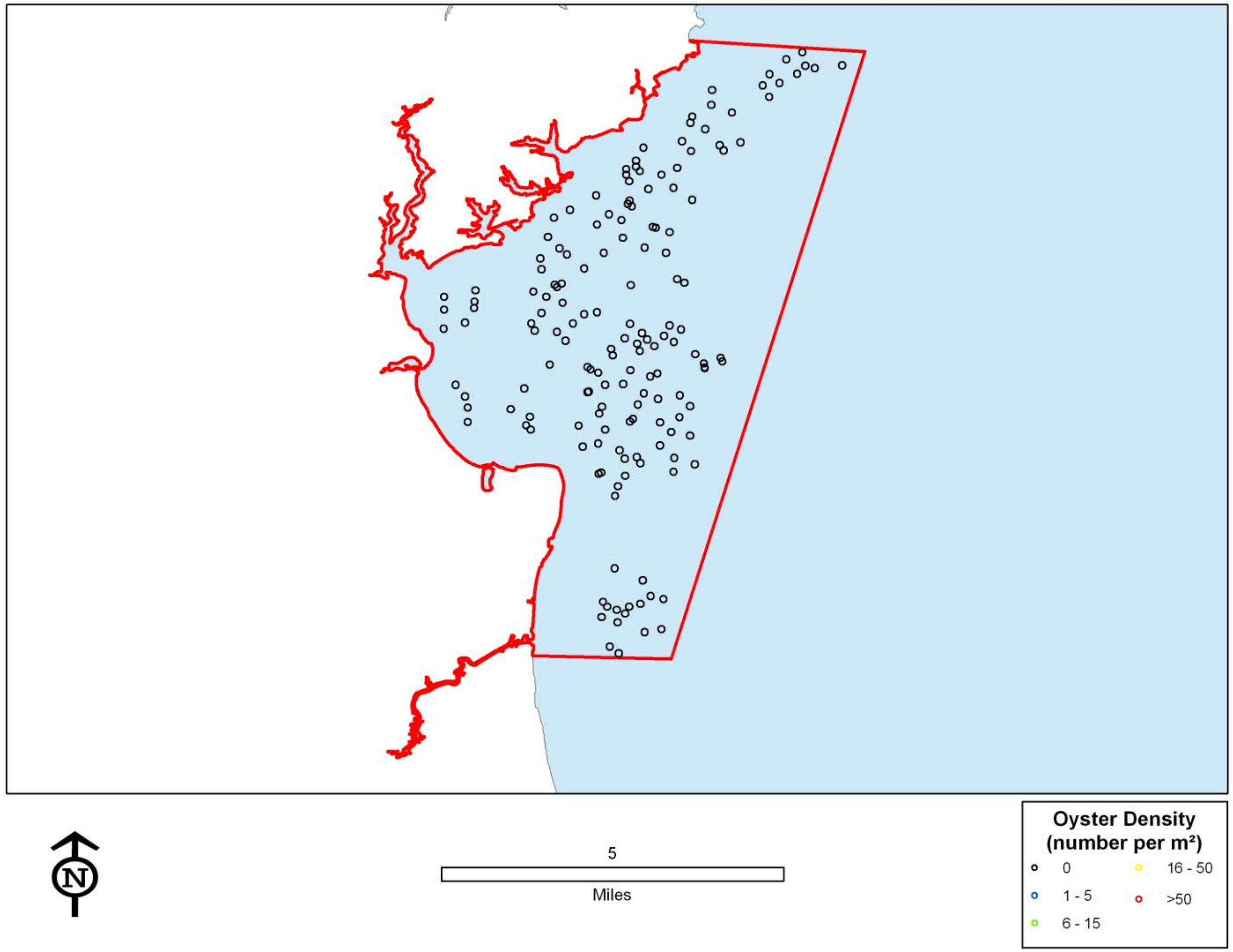

Figure A.12-4. Map of the 2014 oyster density in the Herring Bay Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

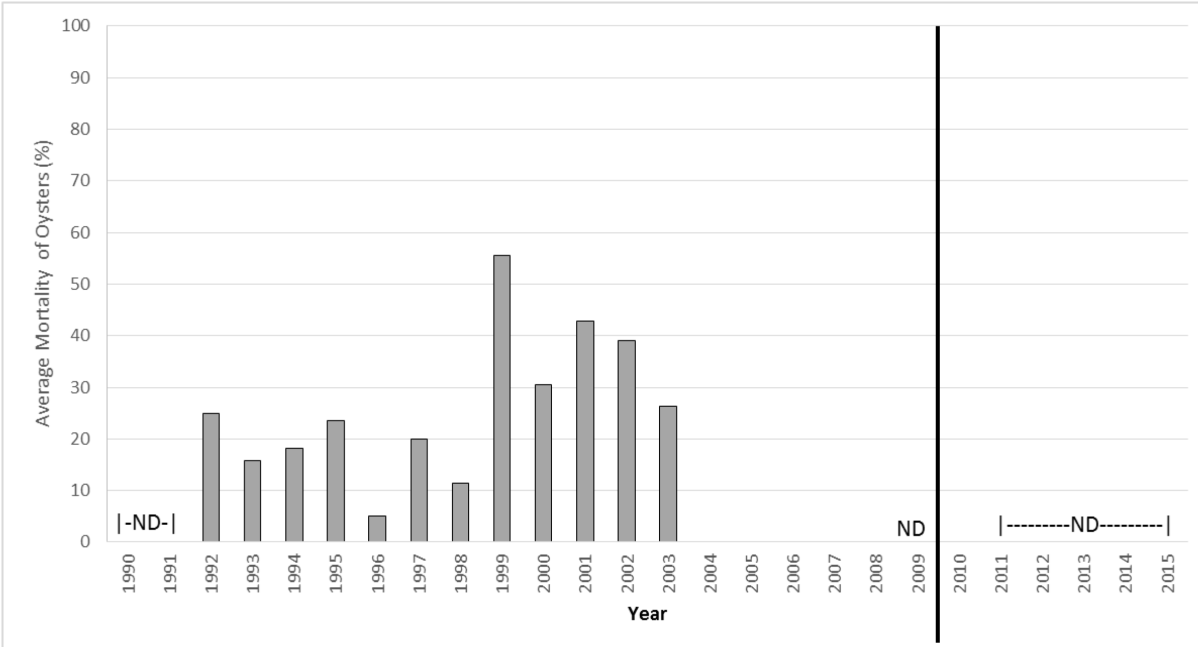

Figure A.12-5. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Herring Bay Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error. ND = No Data.

Harvest

The sanctuary is located within two NOAA Code Areas (027 and 127). Because the sanctuary is located within two NOAA Codes and there is area in the NOAA Codes that area not a sanctuary currently, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. Harvester reports show no oyster catch on bars located in Herring Bay Sanctuary prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.13: Hooper Strait Sanctuary

The Hooper Strait Sanctuary is located in the lower eastern portion of Maryland's Chesapeake Bay, a high salinity (greater than 14 ppt) region (Figure A.13-1). The sanctuary was created in 2009 and encompasses 7,307 acres of which 5,317 (73%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 15 historic oyster bars within the sanctuary[34].

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.13-2). Of the 5,476 acres surveyed within the sanctuary, 1,278 (23%) were classified as oyster reef habitat. In 2010 Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 4,487 acres surveyed in 2010, 516 acres (11%) were classified as oyster reef habitat. Comparing the area investigated by both surveys, there appears to be a loss of oyster habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

Both replenishment and restoration planting activities have occurred in this area since 1990 (Table A.13-1). Dredged shell was planted in 2002 to enhance the public fishery. In 2009, after the area was a sanctuary, hatchery spat-on-shell was planted for restoration purposes.

Table A.13-1. Replenishment and restoration planting activities occurring since 1990 in the area of Hooper Strait Sanctuary established in 2009. S = Planting activity occurring after the area was established as a sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
2002	Dredged Shell	10.57	106.61	-
2009 (S)	Hatchery Spat-on-Shell	15.45	-	34.47

[34] See chart 36 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

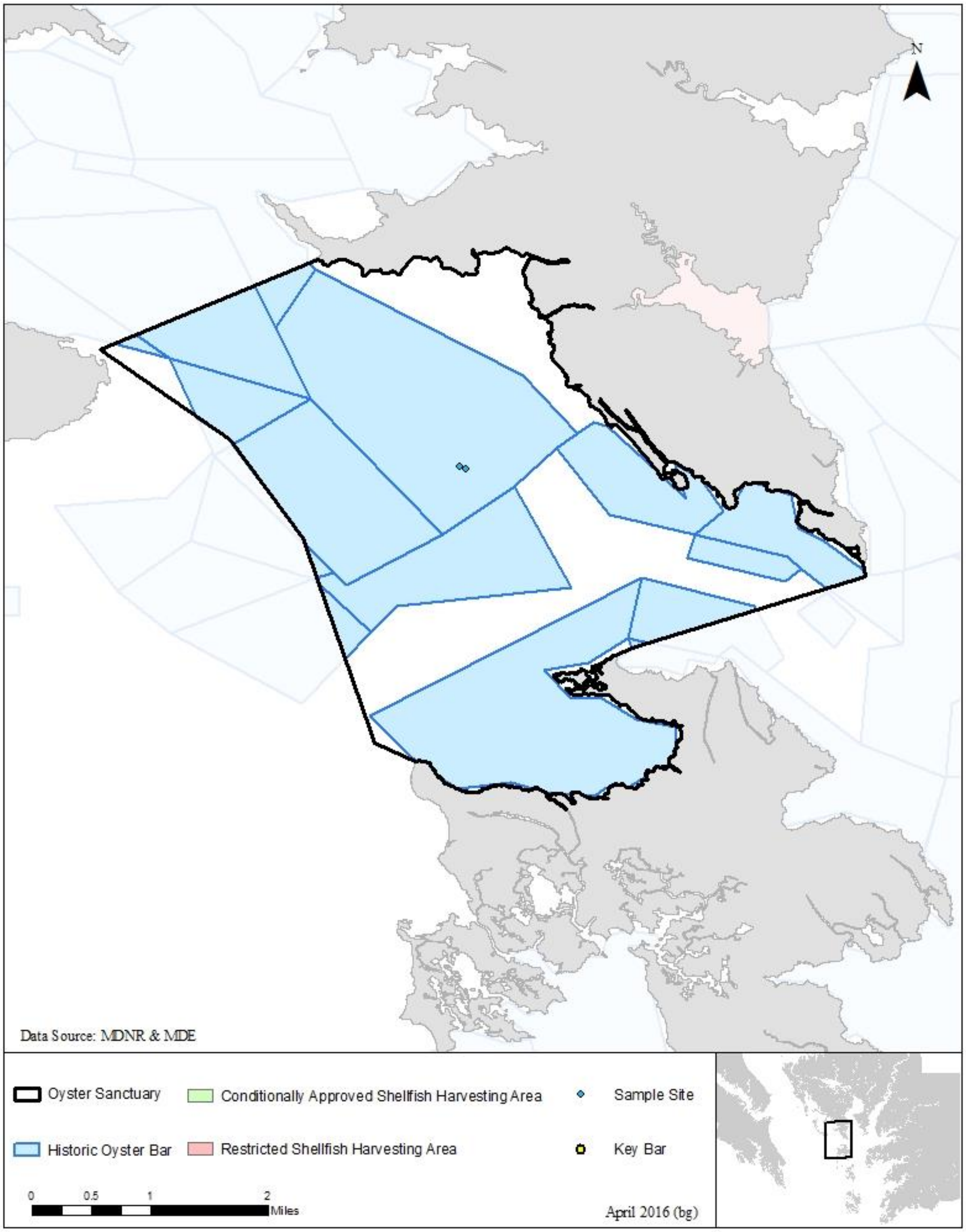

Figure A.13 -1. Hooper Strait Sanctuary.

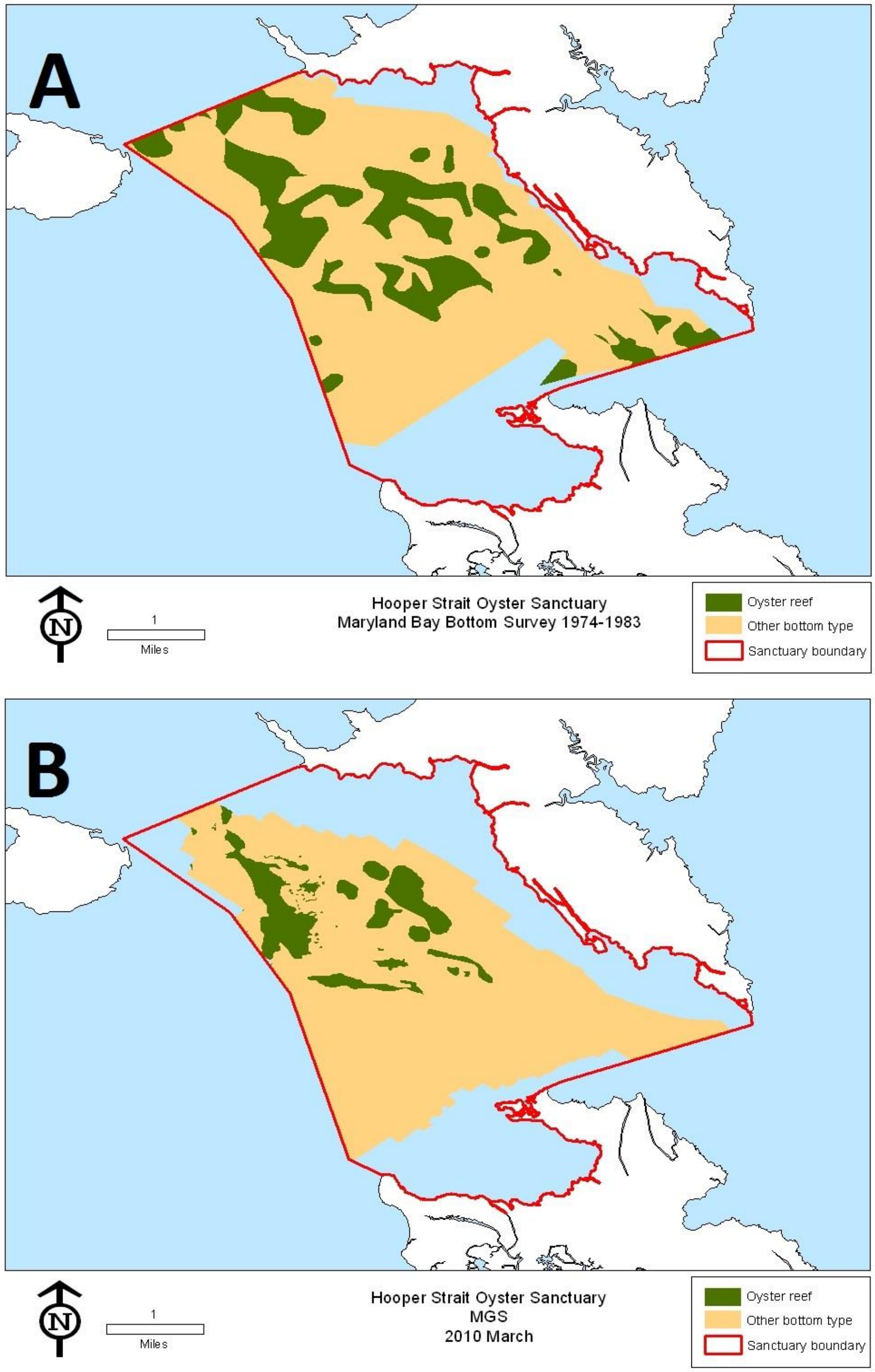

Figure A.13-2. (A) Hooper Strait Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2010. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled 1 to 3 oyster bars in this area since 1990 with an average of 2 oyster bars sampled annually. The average number of total live oysters (market, small, and spat) per bushel of material increased after the establishment of the sanctuary (Table A.13-2; Figure A.13-3). The average number of small-sized oysters per bushel was similar before and after the creation of the sanctuary, whereas the average number of market-sized oysters per bushel increased after sanctuary creation. There were more small-sized than market-sized oysters both before and after sanctuary creation.

Table A.13-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Herring Bay Sanctuary in 2009. ND = No Data. Values are given as means ± standard error.

	1990-2008	**2009-2015**
Number of Years Sampled / Number of Samples	19 / 36	7 / 14
Number of Live Oysters per Bushel	210 ± 33	271 ± 33
Number of Live Small-Sized Oysters per Bushel	86 ± 14	94 ± 11
Number of Live Market-Sized Oysters per Bushel	15 ± 3	32 ± 5
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	27.9 ± 4.4	20.9 ± 5.6

A patent tong population surveys were conducted in 2013 (Figures A.13-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 1.03 ± 0.41 oysters m^{-2} (mean ± standard error, n= 150). The density of small-sized oysters was greater than the density of market-sized oysters (0.88 ± 0.35 and 0.13 ± 0.06 oysters m^{-2}, respectively). Eighty-five percent of samples had no live oysters or boxes. Density of live oysters generally increased with the volume of shell available, although there were two samples with shell but few oysters suggesting factors other than cultch influence density (Figures 4.13-5).

Oyster Size Structure

The Fall Survey has not measured oyster shell heights in this area since 1990. Shell heights were measured during the patent tong population survey, however (Figure A.13-6). Shell height ranged from 11-109 mm, indicating the presence of multiple age classes.

Biomass

The Fall Survey has not measured oyster biomass in this area since 1990.

Recruitment (Spatfall)

Based on Fall Survey samples from 1990 to 2015, the average number of spat per bushel of material ranged from 0 to 479. The highest spatfalls occurred in 1991 and 2007 (Figure A.13-3). Periods of low spatfall included 1996 to 1998 and 2003 to 2005. Since 2010, the spatfall has been relatively high.

Based on the patent tong population survey in 2013, spat density was 0.01 ± 0.01 oysters m^{-2}.

Mortality

Based on the samples collected by the Fall Survey, mortality has ranged from 2% to 71% (Table A.13-2; Figure A.13-7). Average mortality has been slightly lower since creation of the sanctuary.

Disease

The Fall Survey has not measured oyster disease in this area since 1990.

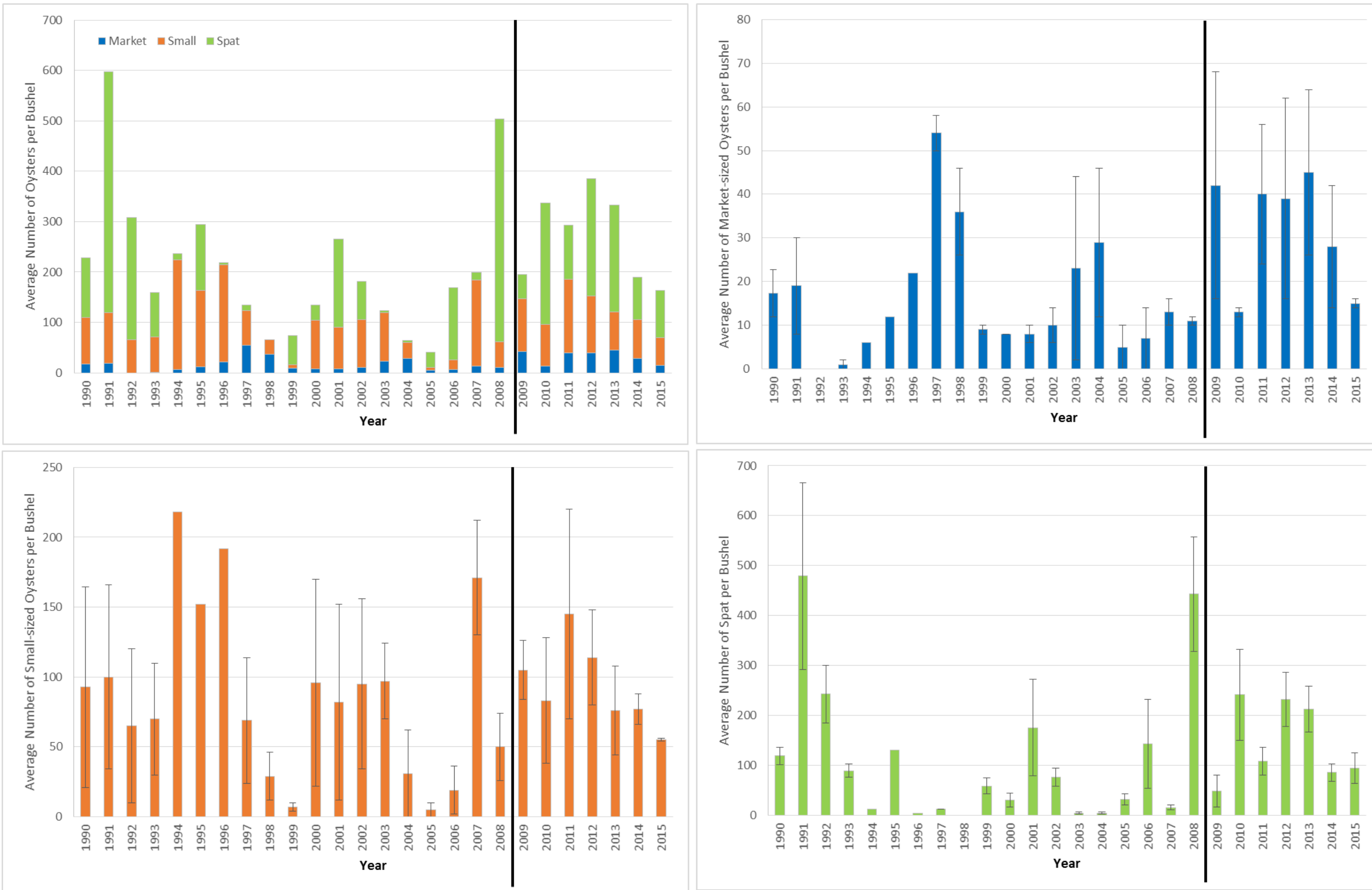

Figure A.13-3. Average number of live oysters per bushel of material by size class in the Hooper Strait Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

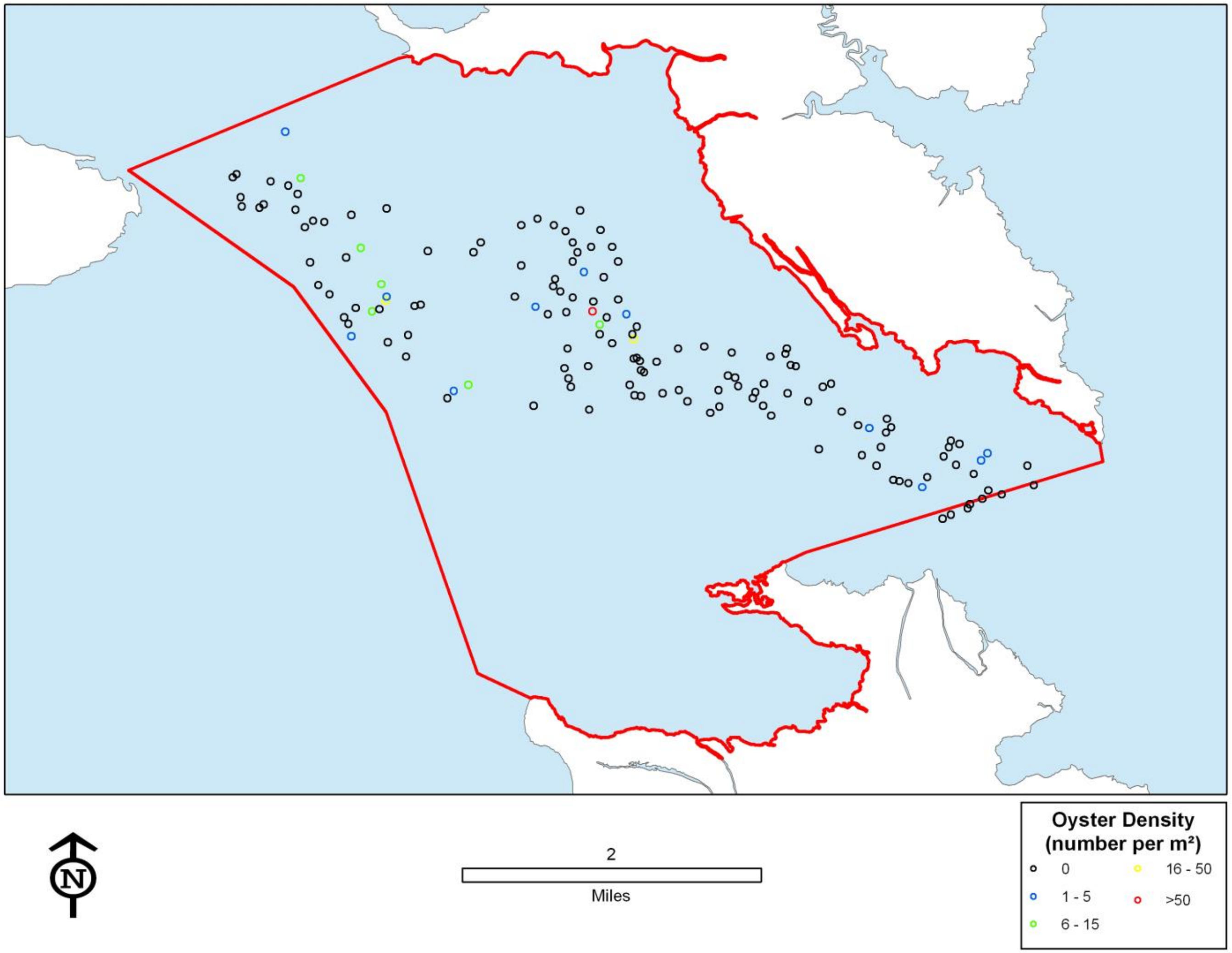

Figure A.13-4. Map of 2014 oyster density in the Hooper Strait Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

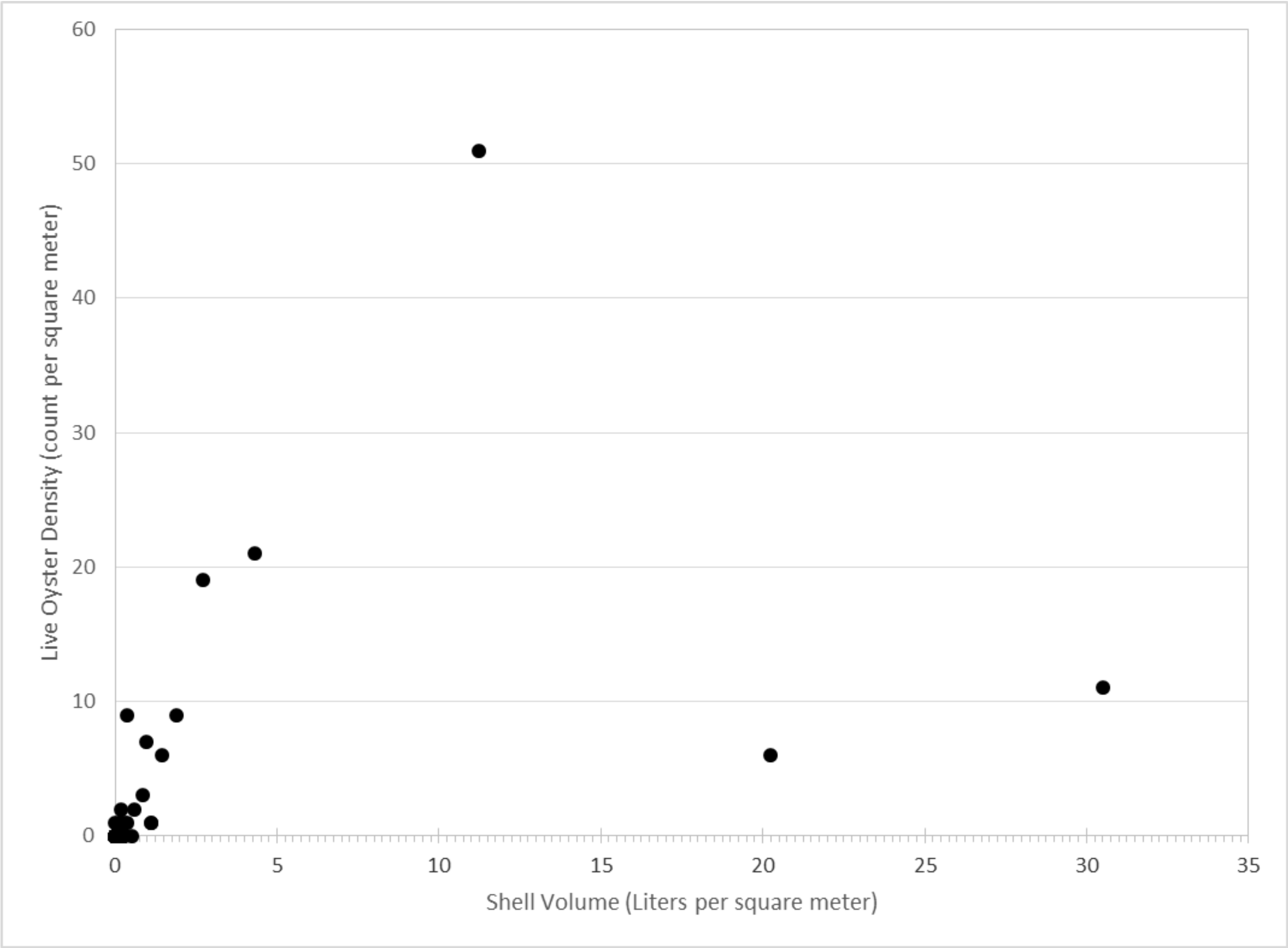

Figure A.13-5. 2014 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Hooper Strait Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

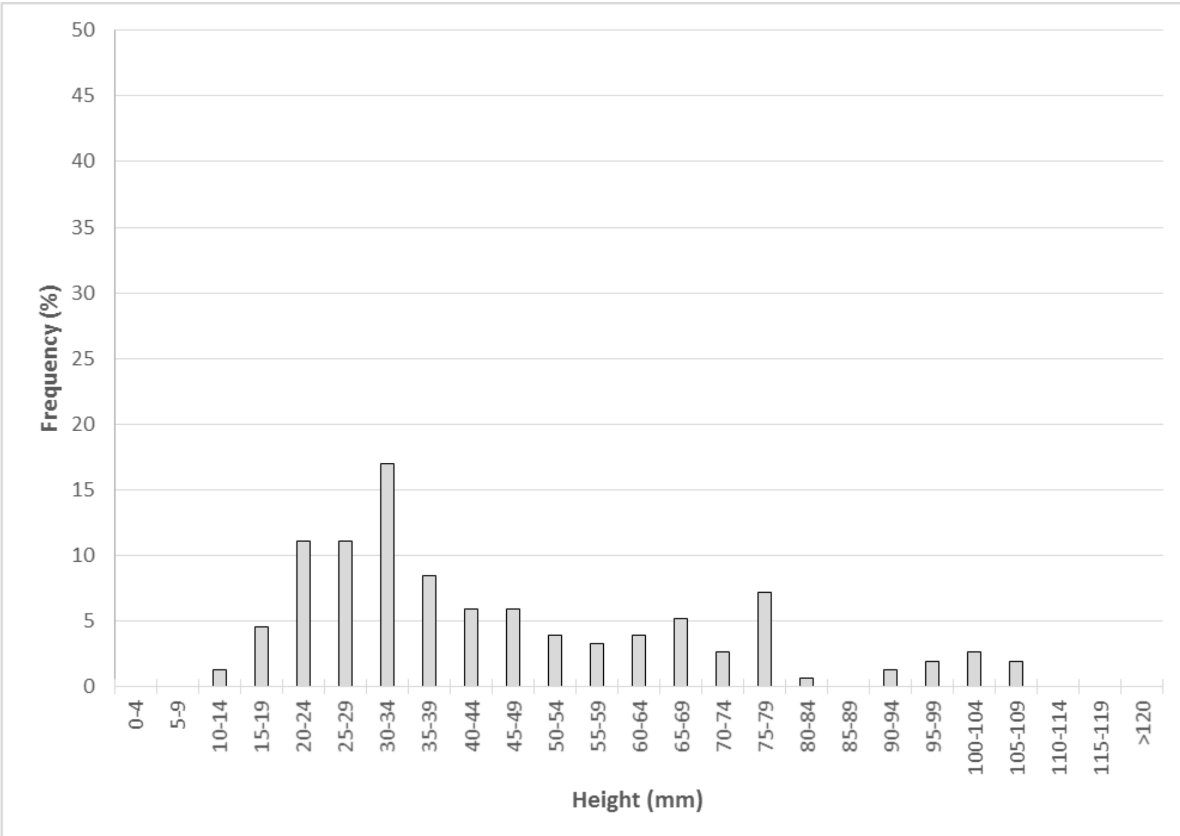

Figure A.13-6. Shell height frequencies of live oysters in the Hooper Strait Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

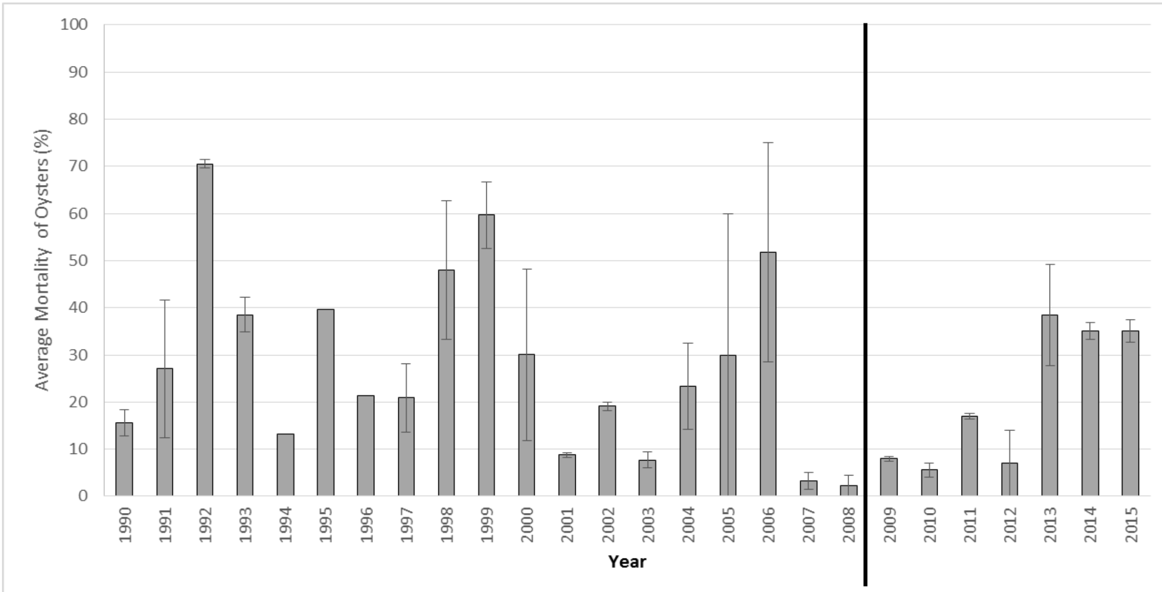

Figure A.13-7. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Hooper Strait Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

Harvest

The sanctuary is located within two NOAA Code Areas (292 and 0142). Because the sanctuary is located within two NOAA Codes and there is area in the NOAA Codes that area not a sanctuary currently, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. Harvester reports show no oyster catch on bars located in Hooper Strait Sanctuary prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.14: Howell Point Sanctuary

The Howell Point Sanctuary is located in middle Choptank River, a low salinity (less than 12 ppt) region (Figure A.14-1). The sanctuary was created in 2001 and encompasses 6 acres of historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments), all located within the Beacons oyster bar. The Howell Point Sanctuary was established for the US Army Corps of Engineers to study the effectiveness of three-dimensional oyster habitat for use in oyster restoration. Location on a three-dimensional reef (top, bottom, or side) did not affect growth rates or disease acquisition. In high energy areas, waves may knock oysters from the top of the mound to the base.[35]

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.14-2). Of the 4.9 acres surveyed within the sanctuary, 1.6 acres (32%) were classified as oyster reef habitat. There have been no additional bottom surveys using side scan sonar of this area.

Restoration and Replenishment Activities

No replenishment efforts took place in this area before it was established in 2001. In 2000-2001, the Army Corps of Engineers planted two shell mounds approximately 6 feet high and in two flat areas using dredged shell. Construction was begun just prior to sanctuary establishment. This area was then partially seeded with hatchery spat-on-shell (Table A.14-1). In 2011, the area was planted with hatchery spat-on-shell.

Table A.14-1. Replenishment and restoration planting activities occurring since 1990 in the area established as Howell Point Sanctuary in 2001. S = planting occurring after the area was established as a sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
2000-2001	Dredged Shell	6.4	184	-
2001(S)	Hatchery Spat-on-Shell	0.4		0.8
2011(S)	Hatchery Spat-on-Shell	7.6		45.9

[35] Paynter, K.T. 2007. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program: 1996-2006. 87 pp.

Oyster Population Characteristics

The Fall Survey has sampled the Howell Point Sanctuary one time since 1990 in 2015 when one sample was taken. The only live oysters collected were market-sized (74 per bushel). Mortality was 13.95%.

The Department has not conducted any patent tong population surveys on the Howell Point Sanctuary since 1990.

Harvest

The sanctuary is located within the 11,934 acres in NOAA Code Area 237. Because the sanctuary makes up a tiny portion of NOAA Code 237, harvest for NOAA Code 237 is likely to have come from places other than the area that became the sanctuary. Therefore, harvest reported by seafood dealers from NOAA Code 237 prior to sanctuary establishment cannot be used to assess harvest in this area. No harvest was recorded on harvester reports from bars located in area prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) in this area. Rodney and Paynter (2006)[36] found higher densities of amphipods, fish, and crabs on restored oyster reefs than unrestored reefs.

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

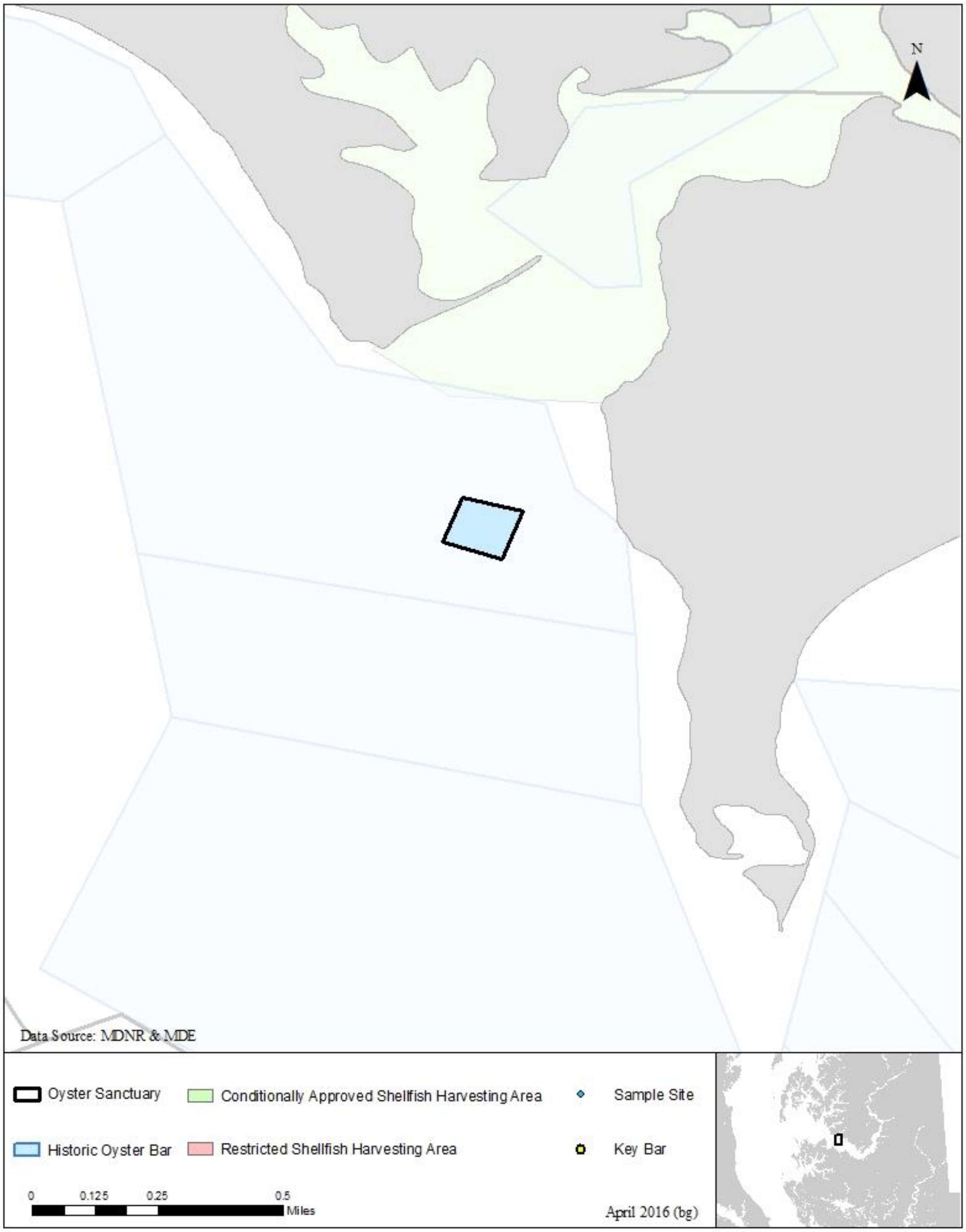

Figure A.14 -1. Howell Point Sanctuary.

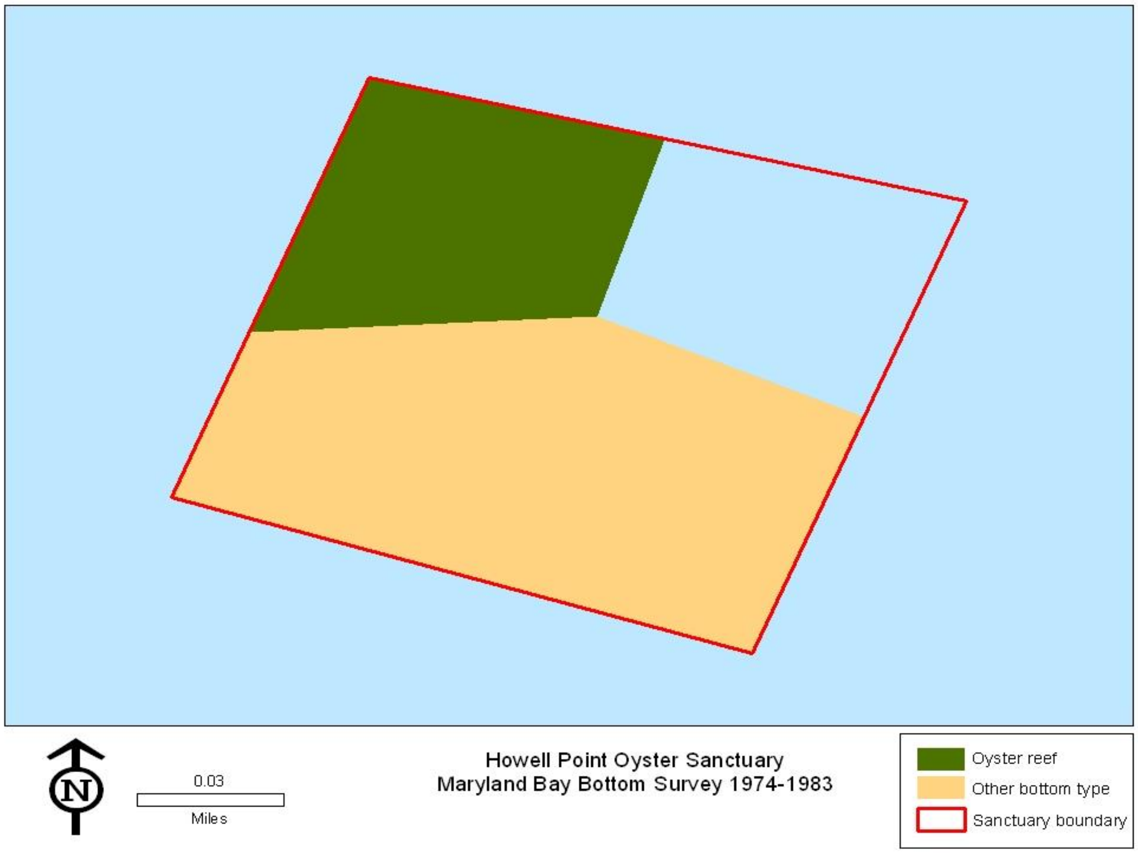

Figure A.14 -2. Howell Point Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict the areas examined during the survey.

Section A.15: Kitts Creek Sanctuary

The Kitts Creek Sanctuary is located in the southeastern portion of Maryland's Chesapeake Bay, a medium salinity (12 to 14 ppt) region (Figure A.15-1). Kitts Creek empties into Pocomoke Sound. The sanctuary was created in 2001 and encompasses 1,181 acres of which 95 acres (8%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 2 historic oyster bars within the sanctuary[37]. Kitts Creek Sanctuary was established due to local legislators' interest in oyster restoration with the intention of population enhancement through natural spat set.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.15-2). Of the 523 acres surveyed within the sanctuary, 499 acres (95%) were classified as oyster reef habitat. There have been no bottom surveys using side scan sonar conducted in Kitts Creek since the Bay Bottom Survey.

Restoration and Replenishment Activities

No restoration efforts have taken place in the sanctuary since it was established in 2001; however, the area received replenishment efforts prior to 2001 (Table A.15-1). Approximately 5,900 bushels of wild seed have been planted since 1990 to support the public fishery.

Table A.15-1. Replenishment planting activities occurring since 1990 in the area established are Kitts Creek Sanctuary in 2001.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1998	Wild Seed	9.90	1.75	-
1999	Wild Seed	9.59	1.80	-
2000	Wild Seed	5.02	2.35	-

[37] See chart 49 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

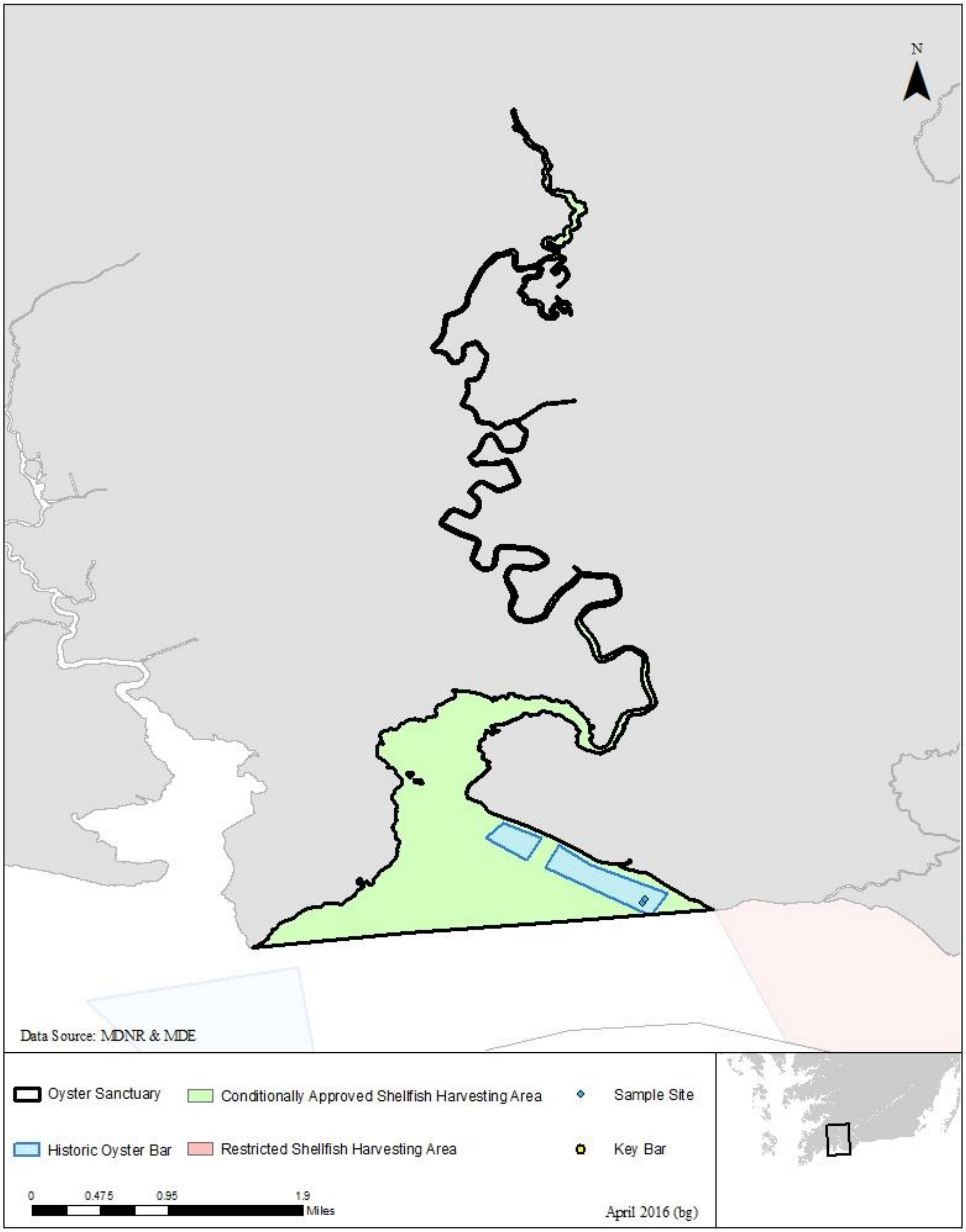

Figure A.15 -1. Kitts Creek Sanctuary.

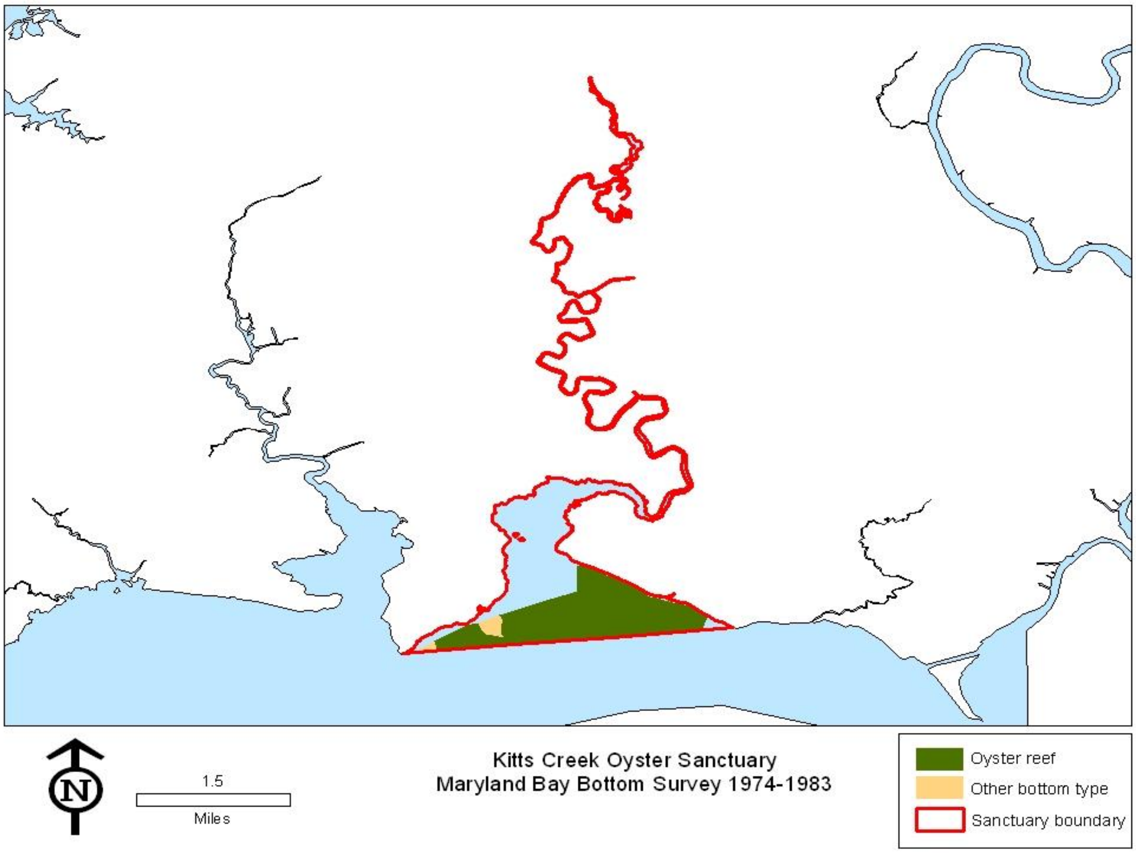

Figure A.15 -2. Kitts Creek Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict the areas examined during the survey.

Oyster Population Characteristics

The Fall Survey has sampled 1 oyster bar annually in this area from 1990 to 1992 and 1998 to 2007. No samples have been collected since 2007. The average number of total live oysters per bushel (market, small, and spat) decreased after the sanctuary was established (Table A.15.2; Figure A.15-3), mostly due to the decrease in small oysters. The number of market-sized oysters was similar before and after the creation of the sanctuary.

Table A.15-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Kitts Creek Sanctuary in 2001. ND = No Data. Values are given as means ± standard error.

	1990-2000	**2001-2015**
Number of Years Sampled / Number of Samples	5 / 5	7 / 7
Number of Live Oysters per Bushel	173 ± 32	117 ± 21
Number of Live Small-Sized Oysters per Bushel	111 ± 41	58 ± 15
Number of Live Market-Sized Oysters per Bushel	53 ± 12	44 ± 12
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality	25.9 ± 6.1	22.9 ± 7.1

A patent tong population survey has not been conducted on Kitts Creek since 1990 by the Department.

Oyster Size Structure

The Fall Survey has not measured oyster shell heights in this area since 1990.

Biomass

The Fall Survey has not measured oyster biomass in this area since 1990.

Recruitment (Spatfall)

Based on the Fall Survey samples, spatfall has ranged from 0 to 88 spat per bushel with the highest spatfall occurring in 2006 (Figure A.15-3).

Mortality

Based on Fall Survey box counts, the average mortality, which ranged from 5.2% to 60.3%, was similar before and after sanctuary establishment (Table A.15-2; Figure A.15-4).

Disease

The Fall Survey has not measured oyster disease in this area since 1990.

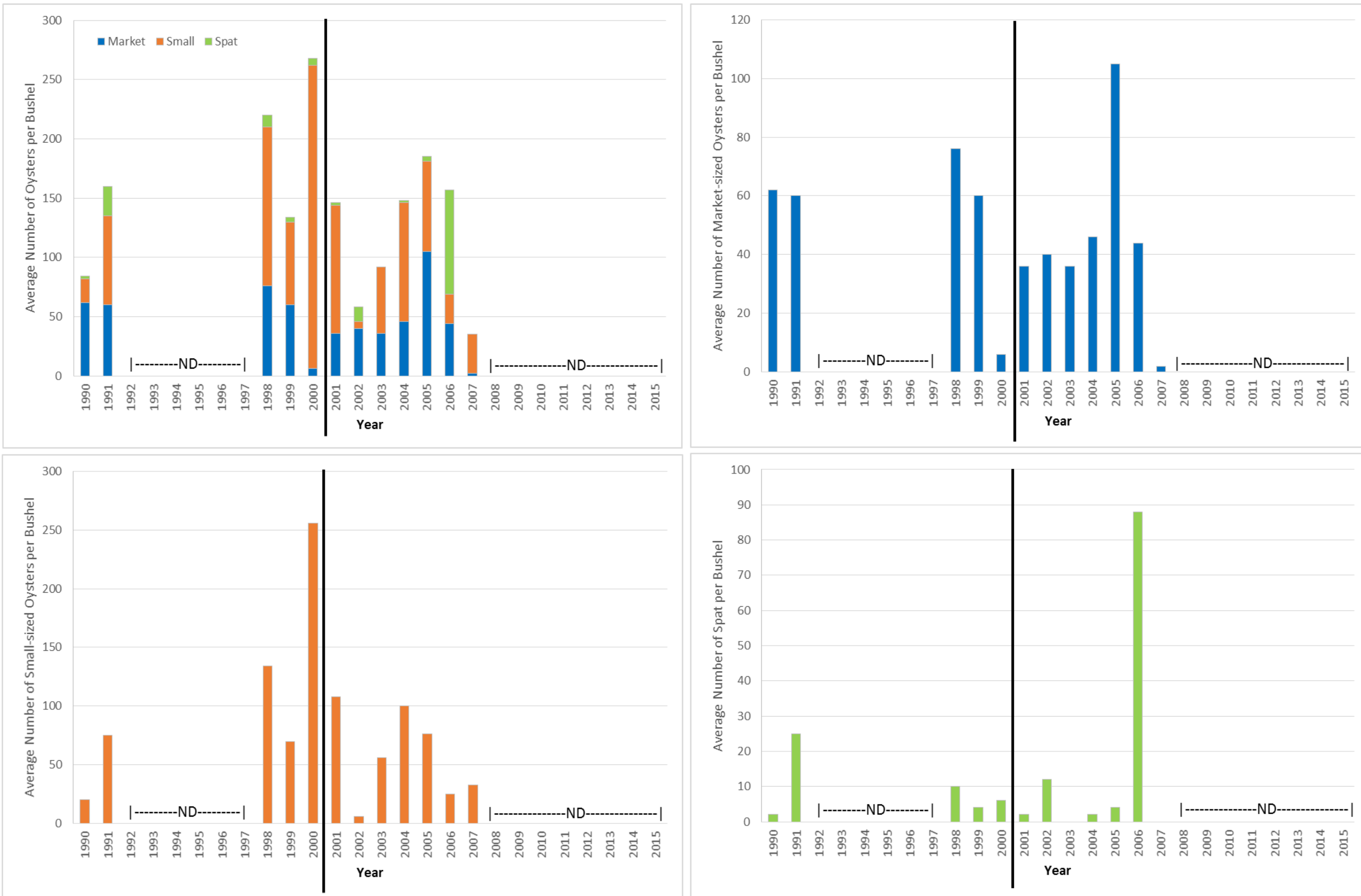

Figure A.15-3. Average number of live oysters per bushel of material by size class in the Kitts Creek Sanctuary. The black line denotes the year the sanctuary was established. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data.

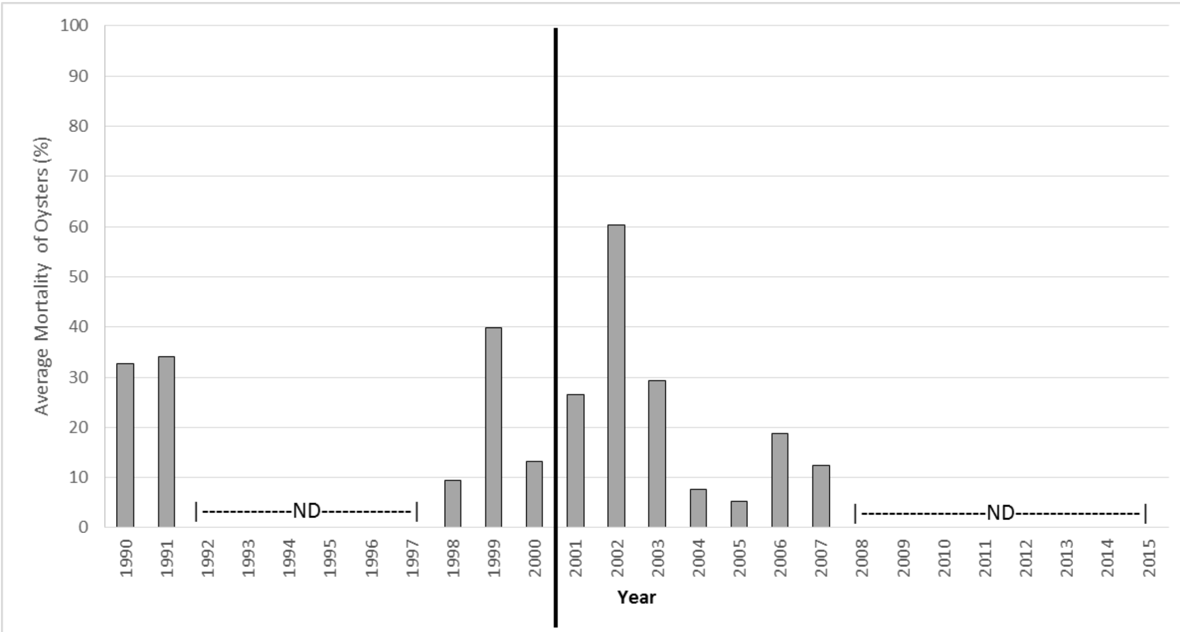

Figure A.15-4. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Kitts Creek Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. ND = No Data.

Harvest

The sanctuary encompasses 6.8% of the 17,434 acres in NOAA Code 092. Because harvest for NOAA code 092 may have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. There was no harvester-reported catch on bars located in Kitts Creek Sanctuary prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Data Hub recorded monthly water quality at station XAJ8271 (37.97073, -75.65047) in this area (Figure A.15-6). Only surface measurements were taken for chlorophyll a, salinity, Secchi depth, total suspended solids, and water temperature from 2012 to 2014. Water quality was favorable for oysters during this period.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

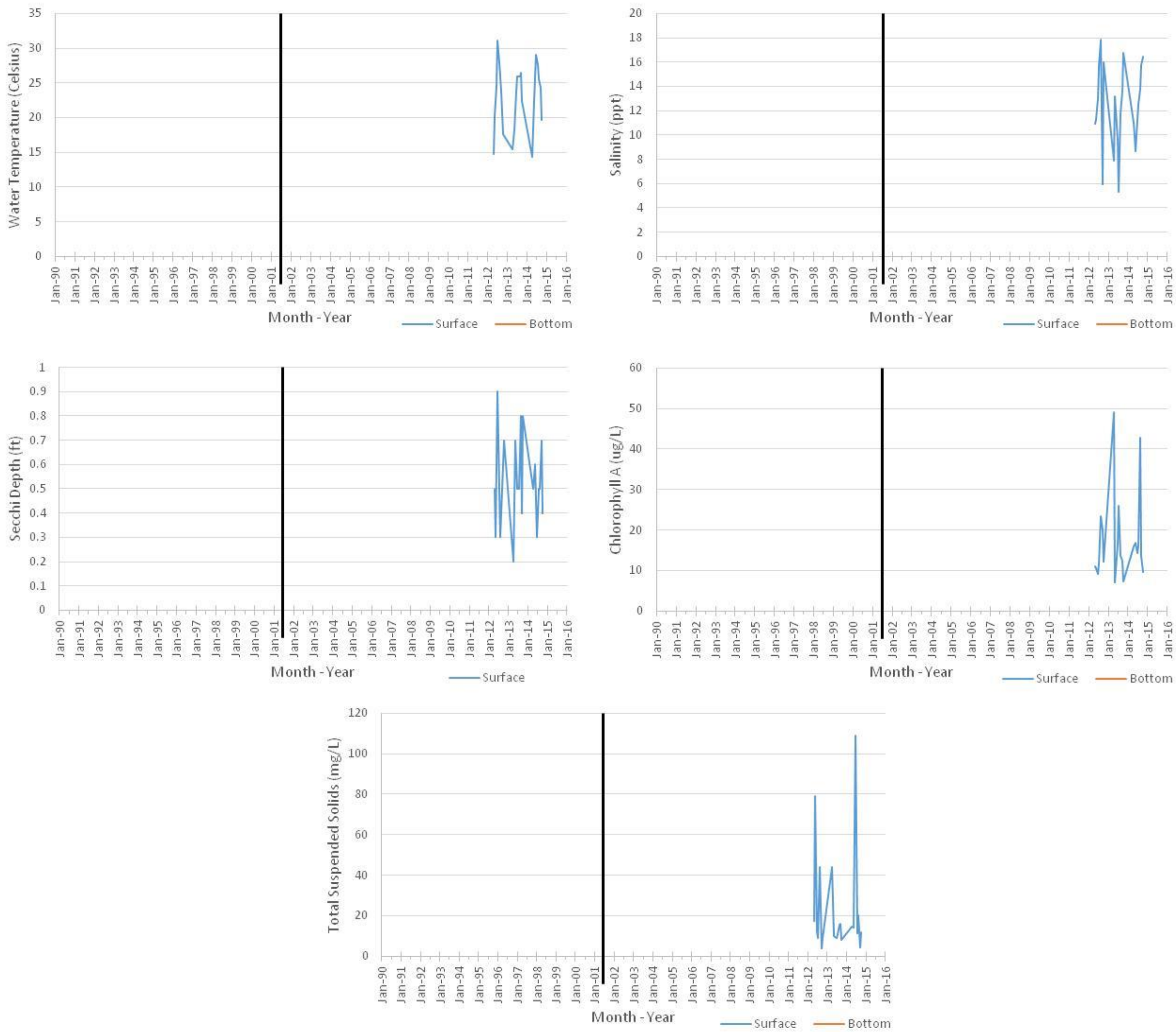

Figure A.15-6. Surface water quality data collected at Station XAJ8271 in the Kitts Creek Sanctuary from 2012-2014. Black line denotes the date the sanctuary was established.

Section A.16: La Trappe Sanctuary

The La Trappe Sanctuary is located in La Trappe Creek, a tributary of the Choptank River. The sanctuary is in a low salinity (less than 12 ppt) region (Figure A.16-1). The sanctuary was created in 2010 and encompasses 377 acres of which 13 acres (3.5%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There is one historic oyster bar located partially within the sanctuary (La Trappe bar). Due to high fecal coliform counts and the potential for bacterial contamination of shellfish, Maryland Department of the Environment has classified a portion of the sanctuary as restricted, meaning no shellfish harvest is permitted. The rest of the sanctuary is classified as conditionally closed, meaning that shellfish cannot be harvested for three days following a rainfall event of one inch or greater over 24 hours.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.16-2). Of the 50 acres surveyed within the sanctuary, 6.6 acres (13%) were classified as oyster reef habitat. In 2010, DNR staff conducted a bottom survey in La Trappe Creek using a sounding pole to determine bottom type. A sounding pole can be used to qualitatively assess the bottom type (mud, sand, shell, and stones) by evaluating the vibrations transmitting up the pole. No shell was located during the 2010 survey. No recent side scan sonar surveys have been conducted in the La Trappe Sanctuary.

Restoration and Replenishment Activities

There have been no restoration or replenishment efforts in this area since 1990.

Oyster Population Characteristics

The Fall Survey did not sample any oyster bars within this area between 1990 and 2014. In 2015, one sample was collected during the Fall Survey and no oysters were found. No patent tong population surveys have been conducted by the Department in the sanctuary to date.

Harvest

The sanctuary encompasses 3% of the 11,394 acres in NOAA Code 237. Because harvest for NOAA code 237 is likely to have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. There was no harvester-reported catch on bars located in sanctuary prior to the area becoming a sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or ecological services in this area.

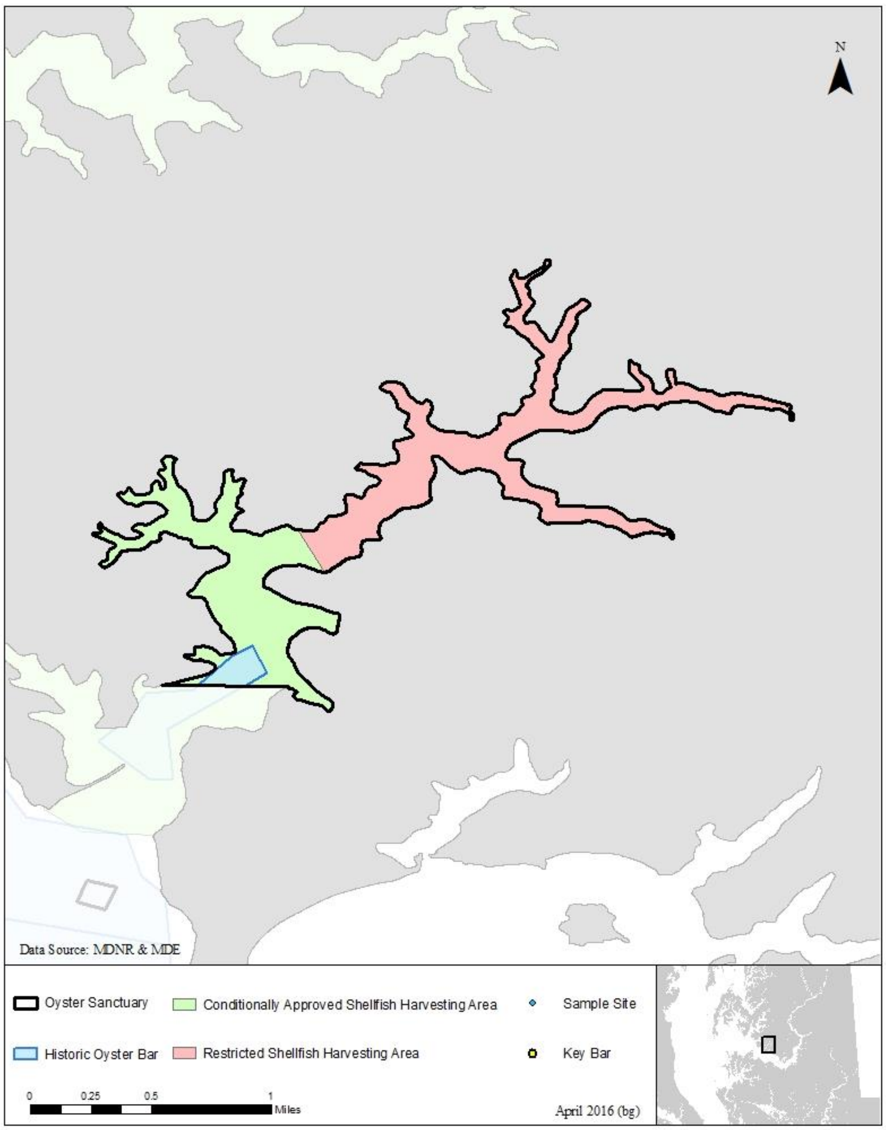

Figure A.16 -1. La Trappe Sanctuary.

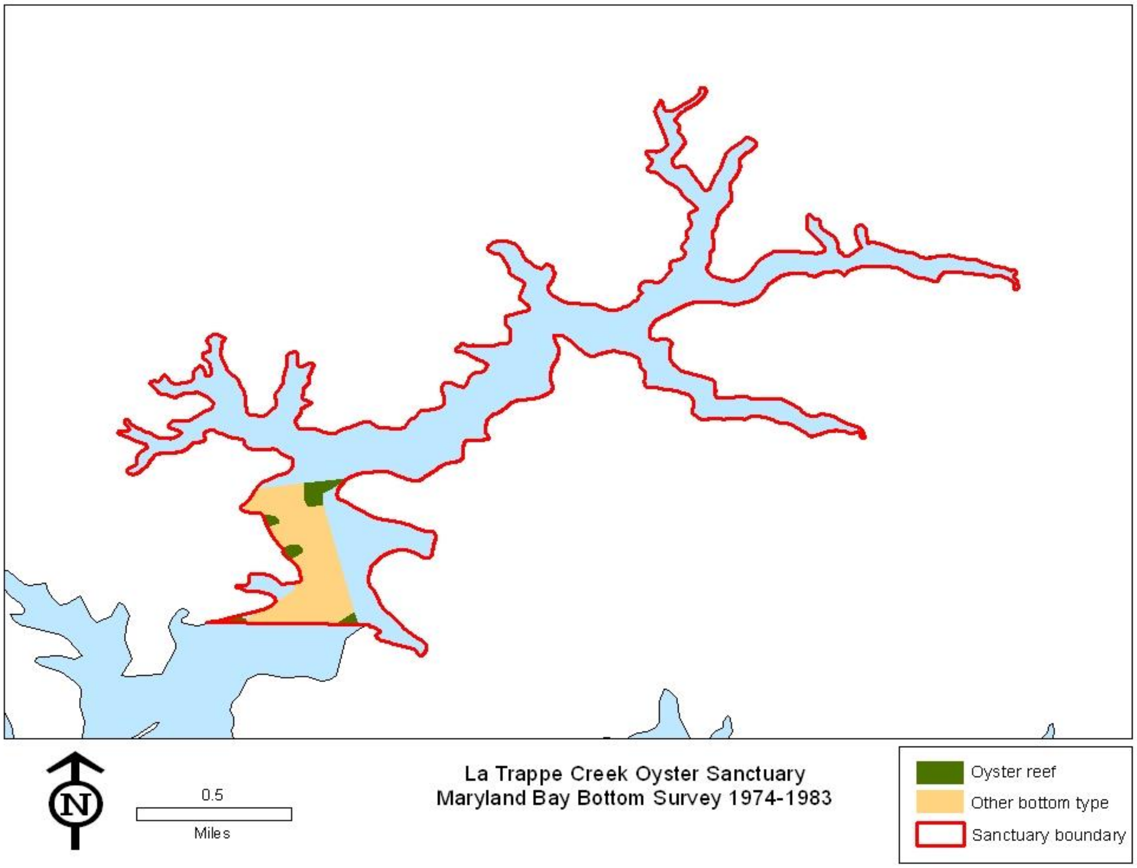

Figure A.16-2. La Trappe Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict the areas examined during the survey.

Section A.17: Little Choptank River Sanctuary

The Little Choptank River Sanctuary is located in the central portion of Maryland's eastern shore of Chesapeake Bay, a low salinity (less than 12 ppt) region (Figure A.17-1). The sanctuary was created in 2010 and encompasses 9,415 acres of which 1,713 (18%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 18 historic oyster bars within the sanctuary[38]. The Little Choptank River Sanctuary has been selected for large-scale oyster restoration under the 2014 Chesapeake Bay Watershed Agreement.

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.17-2). Of the 2,953 acres surveyed within the sanctuary, 1,891 (64%) were classified as oyster reef habitat. In 2009 Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 3,175 acres surveyed in 2009, 740 acres (23%) were classified as oyster reef habitat. Comparing the area investigated by both surveys, there appears to be a substantial loss of oyster habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

Substantial replenishment and restoration activities have taken place in this area since 1990 (Table A.17-1). From 1990-2002 fresh shell, dredged shell, and wild seed were placed in this area to enhance the public fishery. From 2002-2004 hatchery spat-on-shell were planted on Susquehanna bar for research purposes. In 2011, the large scale restoration on the sanctuary commenced. The restoration plan calls for 1.9 billion spat-on-shell to be planted on over 400 acres of restored oyster bottom. As of 2015, 45.8 acres of oyster bottom have received restoration efforts and 102.6 acres have received partial restoration efforts. 222.1 million spat-on-shell have been planted.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 250 cages and planted approximately 75,000 oysters.

[38] See chart 25 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

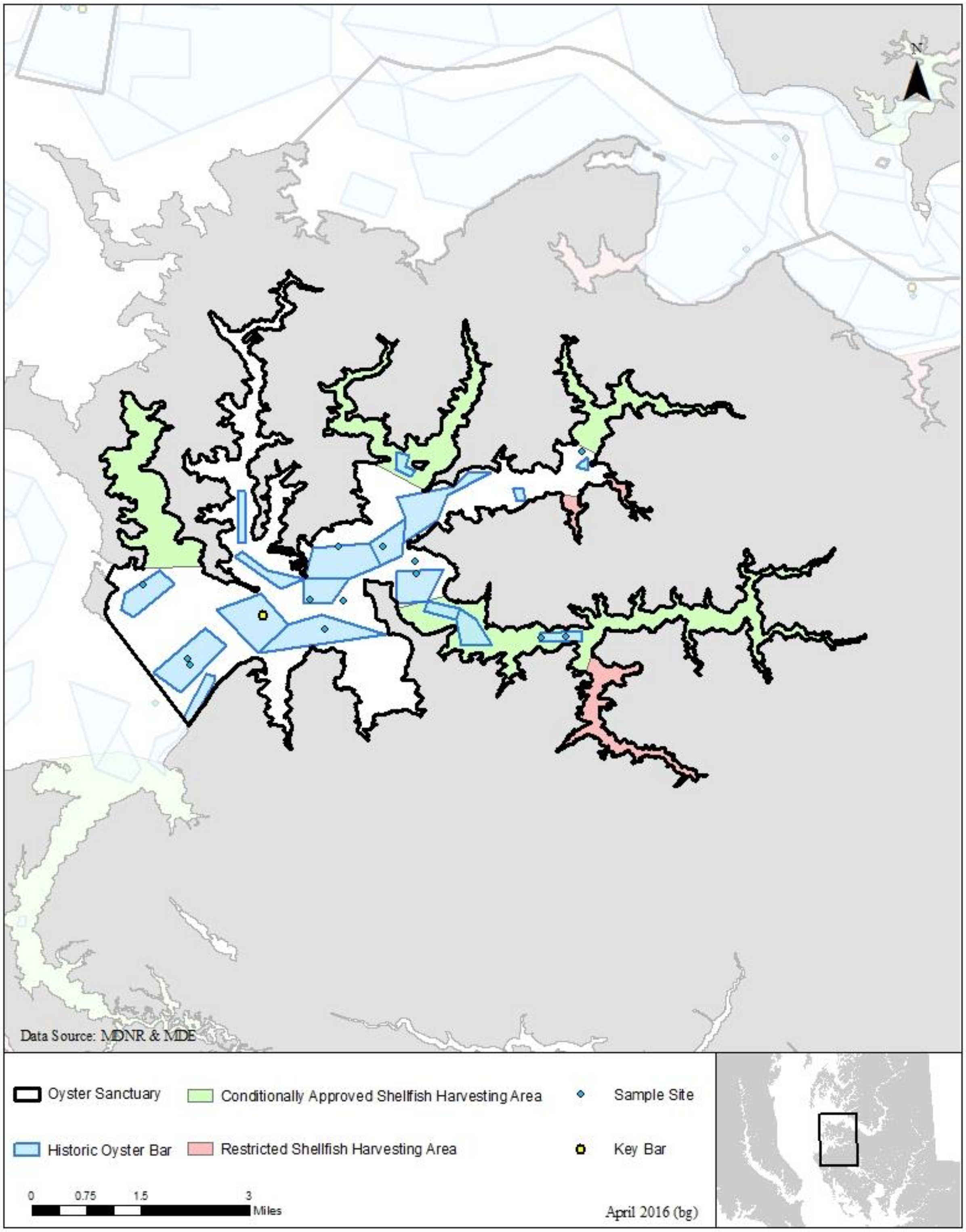

Figure A.17 -1. Little Choptank River Sanctuary.

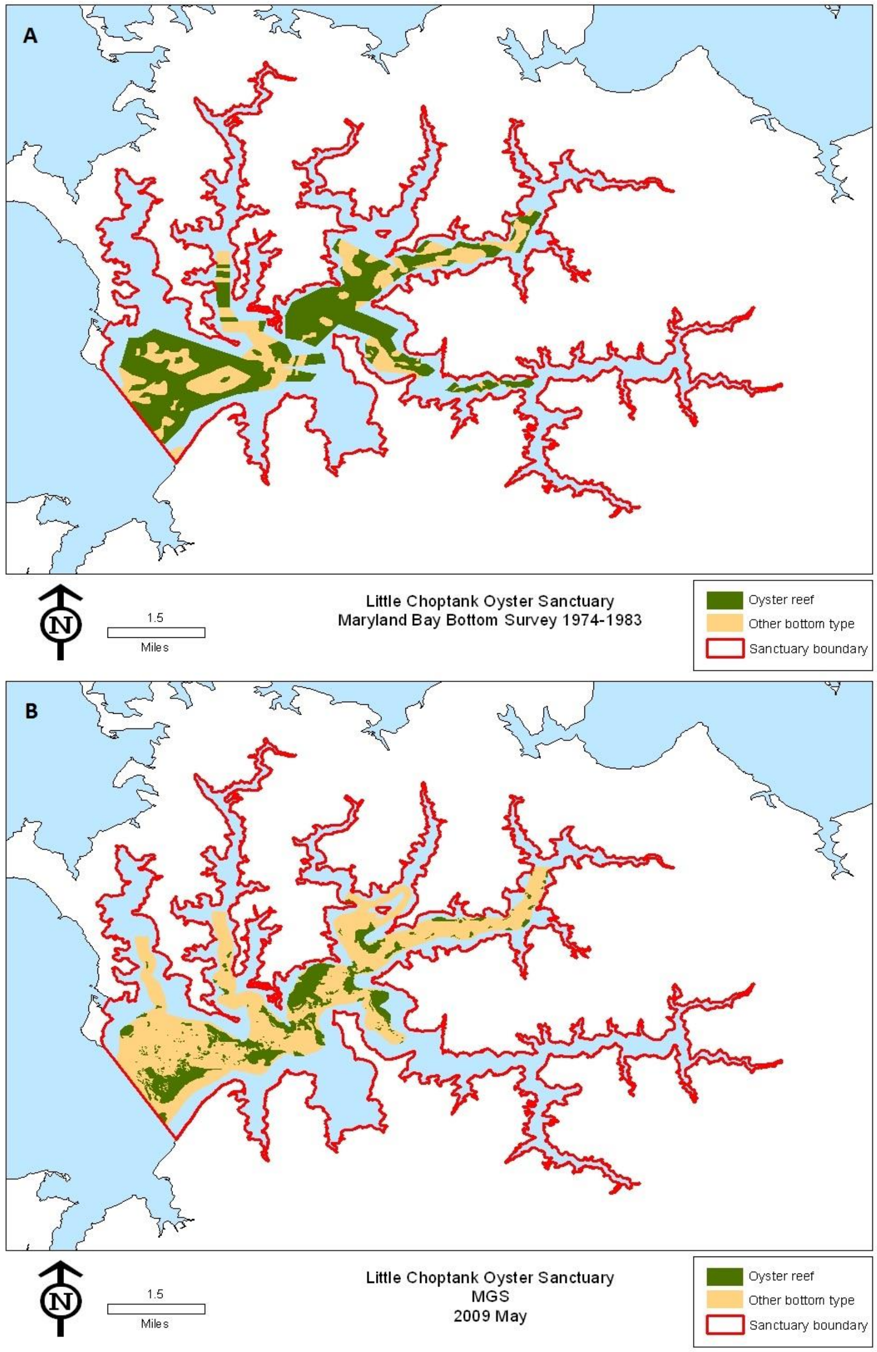

Figure A.17 -2. Little Choptank River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2009. Tan and green colored areas depict areas examined during the surveys.

Table A.17-1. Replenishment and restoration planting activities occurring since 1990 in area of the Little Choptank River Sanctuary. S = Planting activity occurring after the area was established as a sanctuary in 2010. ND = No Data				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Fresh Shell	1.20	4.44	-
1997	Dredged Shell	10.10	45.07	-
1997	Fresh Shell	3.43	17.25	-
1998	Dredged Shell	20.97	77.03	-
2000	Dredged Shell	23.21	100.88	-
2001	Wild Seed	3.60	8.90	-
2002	Dredged Shell	34.04	84.76	-
2002	Wild Seed	4.35	14.00	-
2002	Hatchery Spat-on-Shell	ND	-	3.25
2003	Hatchery Spat-on-Shell	ND	-	2.3
2004	Hatchery Spat-on-Shell	ND	-	0.94
2011 (S)	Hatchery Spat-on-Shell	22.57	-	45.66
2014 (S)	Hatchery Spat-on-Shell	17	-	81.34
2014 (S)	Fossil Shell and Stone	95.2	2296.5	-
2015 (S)	Hatchery Spat-on-Shell	34.1	-	150.76
2015 (S)	Fossil Shell and Stone	32.2	765.5	-

Oyster Population Characteristics

The Fall Survey has sampled five to twelve oyster bars in this area since 1990 with an average of nine oyster bars sampled annually. The 2014 sample on Cason bar, a key bar where disease and biomass are examined, was taken half on the hatchery spat-on-shell restoration planting and half on an area not planted. It is unknown is the 2015 sample taken on Cason bar was on the hatchery spat-on-shell restoration planting because the track line of the dredge was not recorded. In 2015, there is one known sample taken on Susquehanna bar that was on a hatchery spat-on-shell restoration planting area.

The average number of total live oysters (market, small, and spat) per bushel was the same before and after the establishment of the sanctuary (Table A.17-2; Figure A.17-3). The average number of small-sized oysters was similar before and after the sanctuary was established; however, there has been in increase in the number of small oysters since 2002. The number of market-sized oysters has increased since the establishment of the sanctuary, likely due to low mortality, lack of harvest, and seed planting. The similarity of the total counts before and after sanctuary creation may be due to an increase in the number of markets balancing the decrease in number of spat.

Table A.17-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Little Choptank River Sanctuary in 2010. Values are given as means ± standard error.		
	1990-2009	**2010-2015**
Years Sampled / Number of Samples	20 / 189	6 / 54
Number of Live Oysters per Bushel	224 ± 53	224 ± 20
Number of Live Small-Sized Oysters per Bushel	97 ± 13	101 ± 14
Number of Live Market-Sized Oysters per Bushel	34 ± 5	92 ± 18
Live Oyster Biomass (g Dry Weight per Bushel)	123 ± 20	237 ± 35
Mortality (%)	24.9 ± 4.9	11.8 ± 2.0

Three patent tong surveys were conducted in the sanctuary prior to the initiation of large-scale restoration, one in November and December 2011 (Paynter et al. 2012)[39], one in January and Febuary 2012 (Versar 2012)[40], and one in April 2014 (conducted by the Department). Paynter et al. (2012) found the highest average oyster density (45.5 ± 15.2 m^{-2}, mean ± standard error) on seed plantings. Average oyster density on natural shell bottom was lower (5.8 ± 0.7 m^{-2}). The highest oyster density found by Versar (2012) was on Tobacco Stick bar (25.33 ± 8.79m^{-2}). Portions of this oyster bar had been planted with hatchery-reared spat in 2011.

The Department found an average oyster density of 17.17 ± 1.85 m^{-2} across natural and planted bottom during the 2014 survey (Figure A.17-4). Densities of small- and market-sized oysters were similar (8.13 ± 1.01 and 6.97 ± 0.68 oysters m^{-2}, respectively). Forty percent of the samples taken had no live oysters or boxes. Live oyster density increased with volume of shell (Figure A.17-5).

Paynter et al. found a density of 54 oysters m^{-2} on Cason bar, an area that had both wild oysters and hatchery plantings.[41]

The areas receiving restoration activities within the sanctuary will be monitored three years after the activities have occurred. The first monitoring will occur in 2017. Control sites within the sanctuary were established to gauge the effectiveness of restoration treatments and will be monitored at the same time as the restoration sites. The control sites were areas that were suitable for restoration with seed or substrate and seed, but left unrestored. These areas were not true

[39] Paynter, K.T., A. Michaelis, and H. Lane. 2012. Oyster population and habitat assessment, Harris Creek and the Little Choptank River. Report to NOAA Chesapeake Bay Office. 81 pp. http://oysterrecovery.org/oyster-reef-monitoring/
[40] Versar. 2012. An assessment of oyster resources in Harris Creek and Little Choptank River, Chesapeake Bay. Report to NOAA Chesapeake Bay Office. 33 pp. http://oysterrecovery.org/oyster-reef-monitoring/
[41] Paynter, K.T., H. Lane, and A. Michaelis. 2013. Paynter Lab Annual Monitoring and Research Summary 2012. Report to the Oyster Recovery Partnership. 110 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2012%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

controls in that they were not exact replicates of the treated sites (exact replicates are not possible given variation in flow, salinity, and bottom type). Furthermore, it is not possible to isolate the control sites from the treated sites, and restoration on treated sites may affect control sites. For example, as oysters grow on treated sites, they may provide larvae to adjacent control sites. Given these caveats, control sites still provide valuable information on effectiveness of restoration efforts, and control sites will be monitored along with actively restored areas.

Oyster Size Structure

The Fall Survey has measured oyster shell heights in this area at Cason bar since 1990 (Figure A.17-6). Shell heights were also measured during the patent tong population survey (Figure A.17-7). The number of large oysters increased between 2012 and 2015, likely due to good spat sets in 2010 and 2012, high survivorship, and lack of harvest. Oyster height ranges during this time period have been wide (e.g. 11 to 151 mm in the 2014 patent tong survey), indicating the presence of multiple age classes.

Monitoring a hatchery planting after one year, Paynter et al. (2013) found an average shell height of 42.2 mm. Nearby wild oysters had an average shell height of 93.0 mm.[5]

Biomass

Biomass of oysters from Cason bar collected by the Fall Survey has increased since the creation of the sanctuary, with the highest biomass of 354 grams dry weight per bushel occurring in 2013 (Table A.17-2; Figure A.17-8). This increase is due to the increasing number and size of oysters.

Paynter et al found a biomass of approximately 28 g m^{-2} on Cason Bar in 2012.[5]

Recruitment (Spatfall)

Based on Fall Survey data, average spatfall from 1990 to 2015 ranged from an average of 0 to 959 spat per bushel with the highest spatfall occurring in 1991 (Figure A.17-3). Average spat count was higher before sanctuary creation than after (93 ± 16 and 30 ± 15, respectively), but this is driven by the anomalous high 1991 spatfall. If the 1991 spatfall is excluded, average spatfalls before and after sanctuary creation (47 ± 6 and 30 ± 5, respectively) are more similar. Average spat density from the 2014 patent tong survey was 2.07 ± 0.26 m^{-2}.

Mortality

Based on Fall Survey box counts, the average mortality after sanctuary establishment was lower than the average mortality before sanctuary establishment (Table A.17-2; Figure A.17-9). The high mortality prior to the area becoming a sanctuary is most likely due to the high disease levels from 1999 to 2002.

Disease

Dermo disease pressure has fluctuated widely from 1990 to 2015, ranging from 3% to 100% (Figure A.17-11). Dermo prevalence was high during most of this period, greater than 80% during 19 of the 26 years disease information was collected. Although dermo prevalence was frequently high, mean intensities never reached lethal levels (greater than5).

Monitoring a one-year-old hatchery planting in 2012, Paynter et al. found a dermo prevalence of 70%. Nearby wild oysters had a dermo prevalence of 97%.[5]

MSX prevalence also fluctuated widely over the same period, from 0% to 59% with a period of high intensity from 1999-2002 (Figure A.17-10).

The combined effects of dermo and MSX diseases resulted in high mortalities from 2001 to 2003 (Figure A.17-10). The population has rebounded due to several years of high recruitment, the cessation of harvest, and an extended period of low disease pressure following the disease outbreak (Tarnowski 2015)[42].

[42] Tarnowski, M. 2015. Natural recovery of an eastern oyster population from a catastrophic event and its implications for restoration planning. Journal of Shellfish Research 34: 684-685.

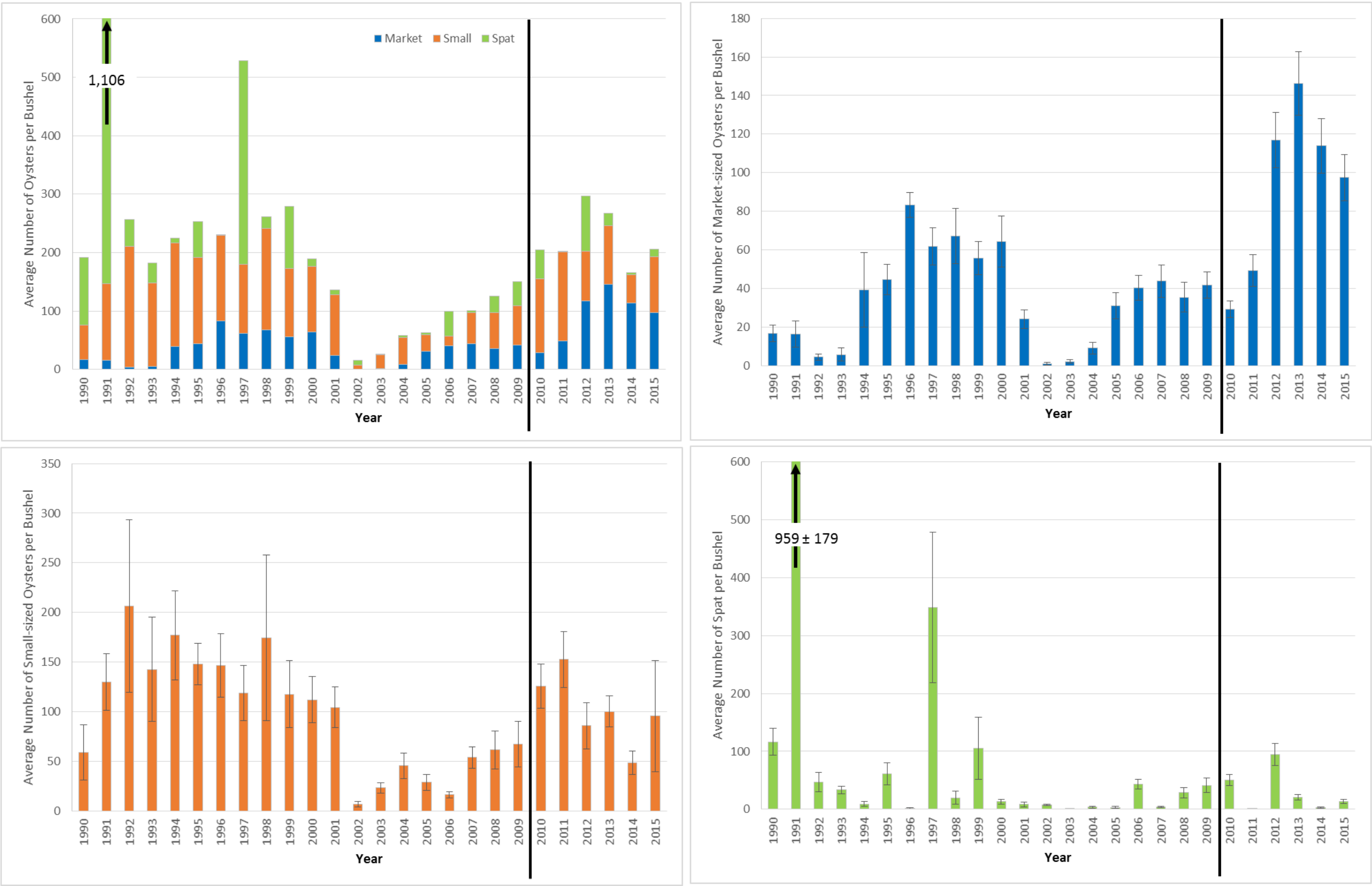

Figure A.17-3. Average number of live oysters (Number of Markets per Small) per bushel of material by size class in the Little Choptank River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

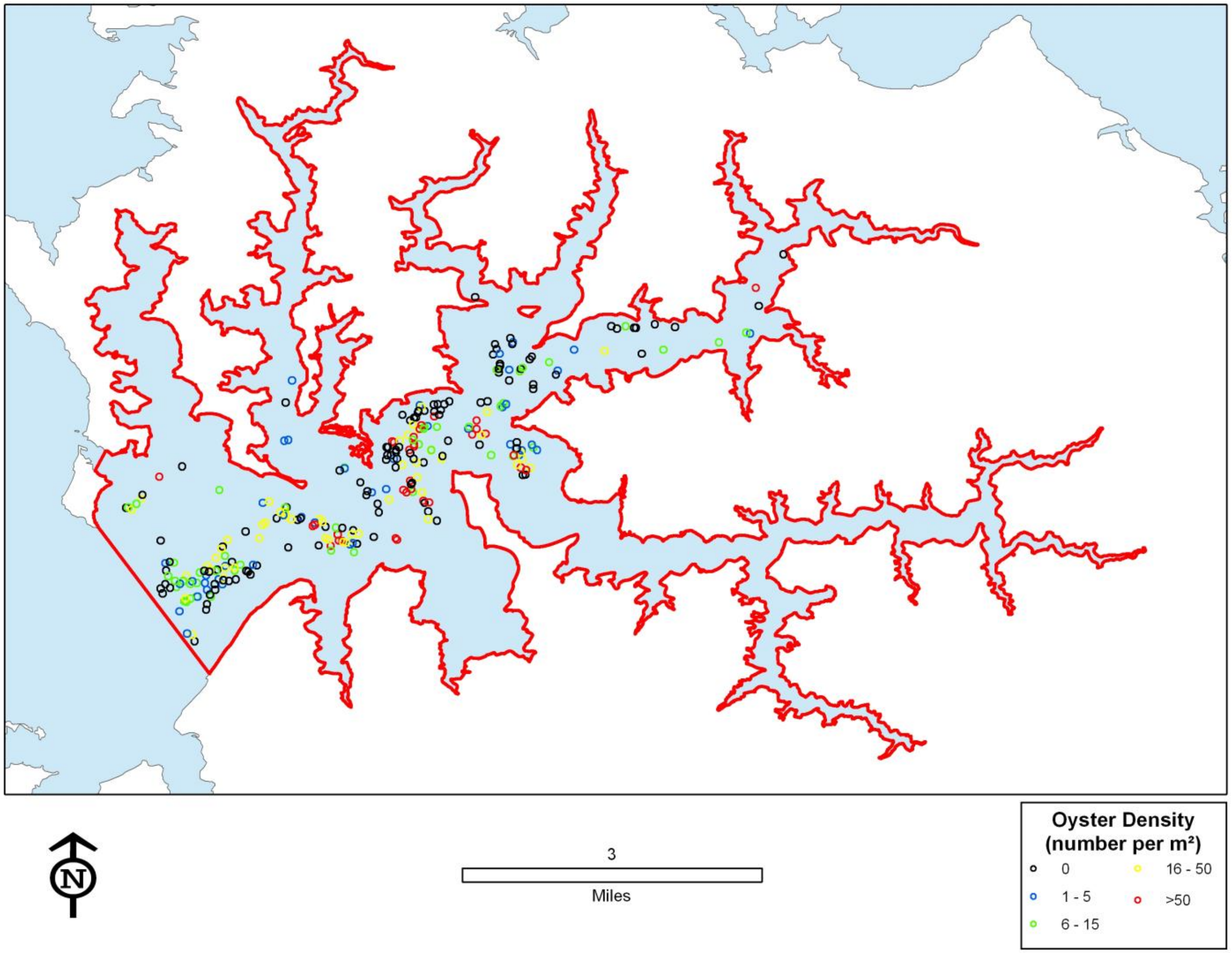

Figure A.17-4. Map of 2014 oyster density in the Little Choptank River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

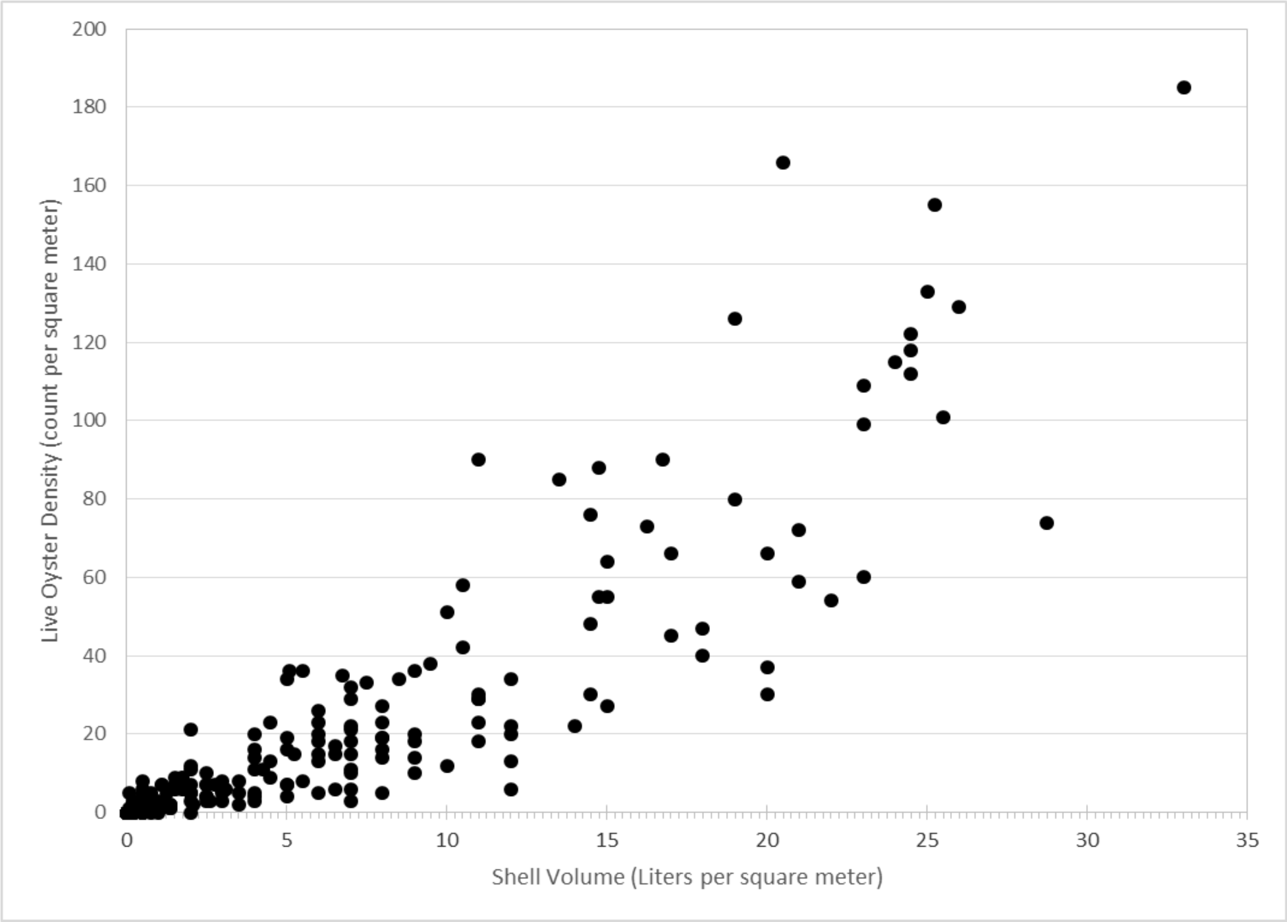

Figure A.17-5. 2014 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Little Choptank River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

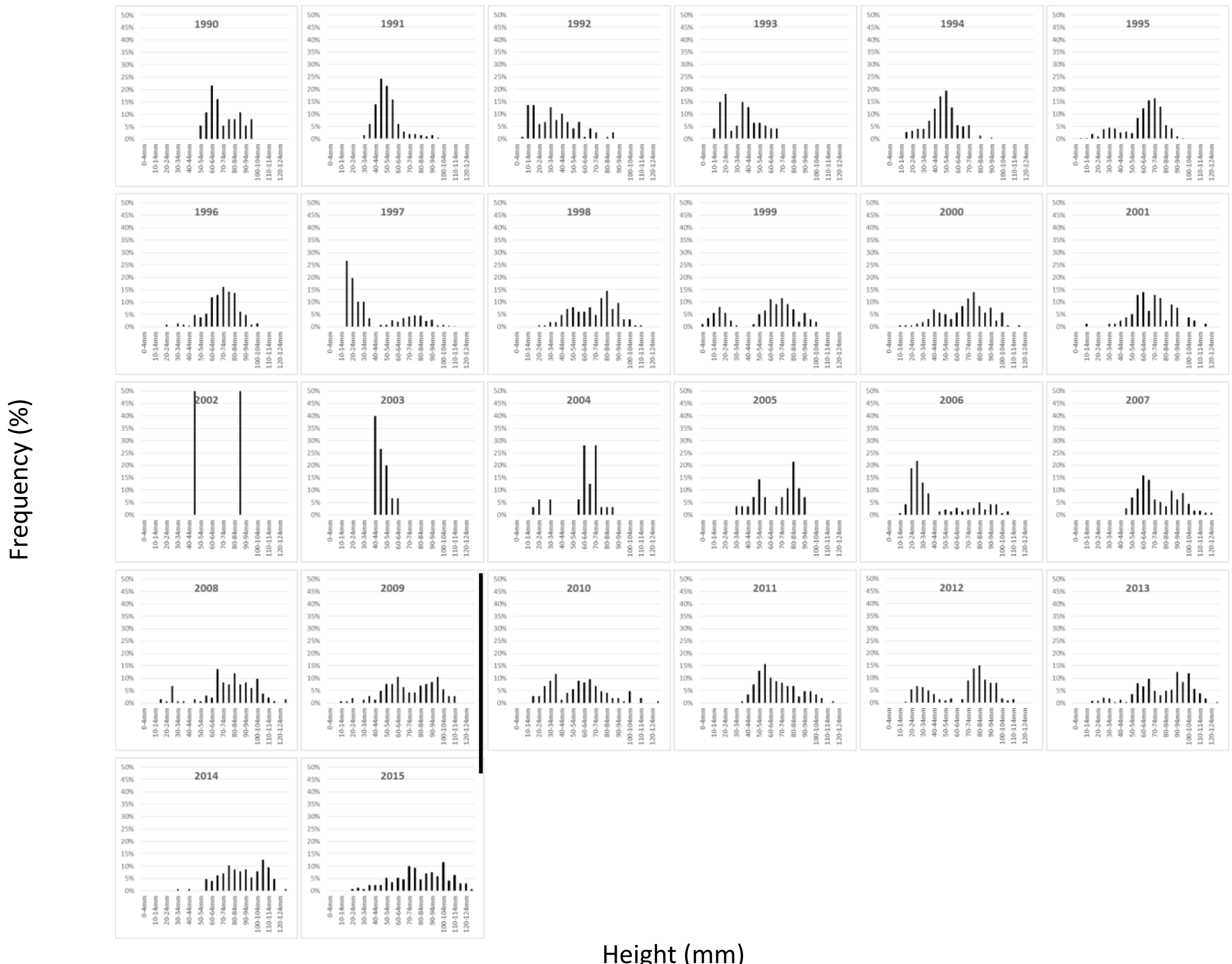

Figure A.17-6. Shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the Little Choptank River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Cason bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

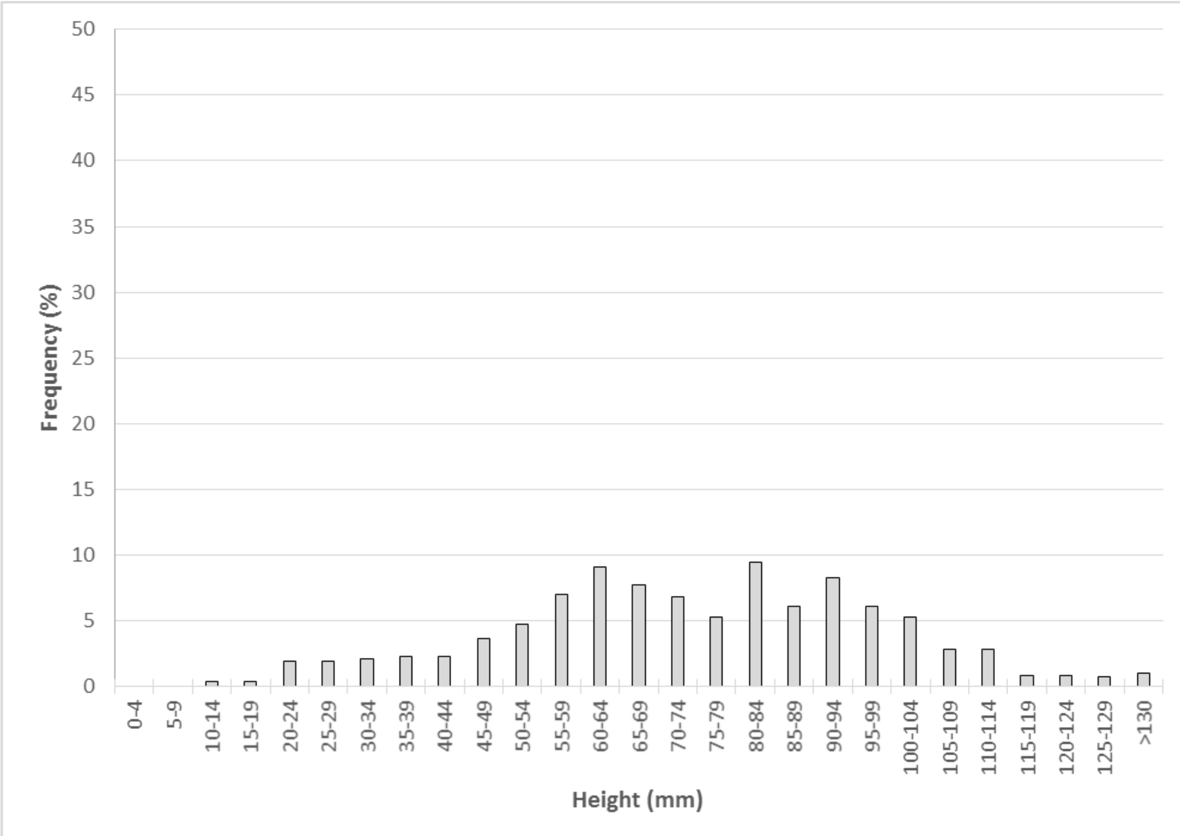

Figure A.17-7. Shell height frequencies of live oysters in the Little Choptank River Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

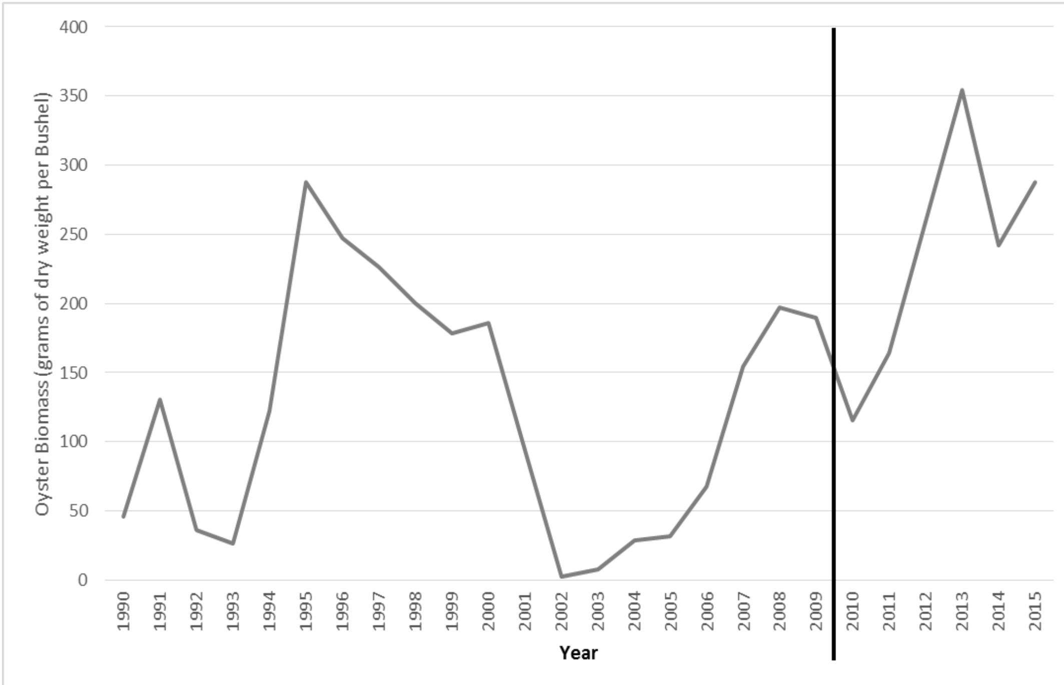

Figure A.17-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 on Cason bar in the Little Choptank River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line indicates the date the sanctuary was established.

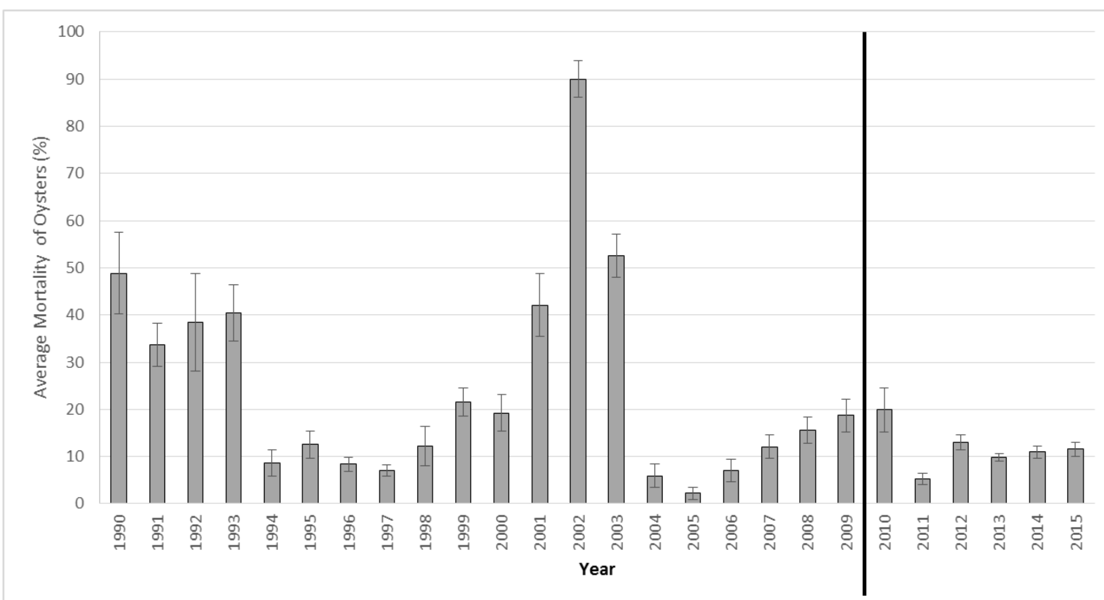

Figure A.17-9. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Little Choptank River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

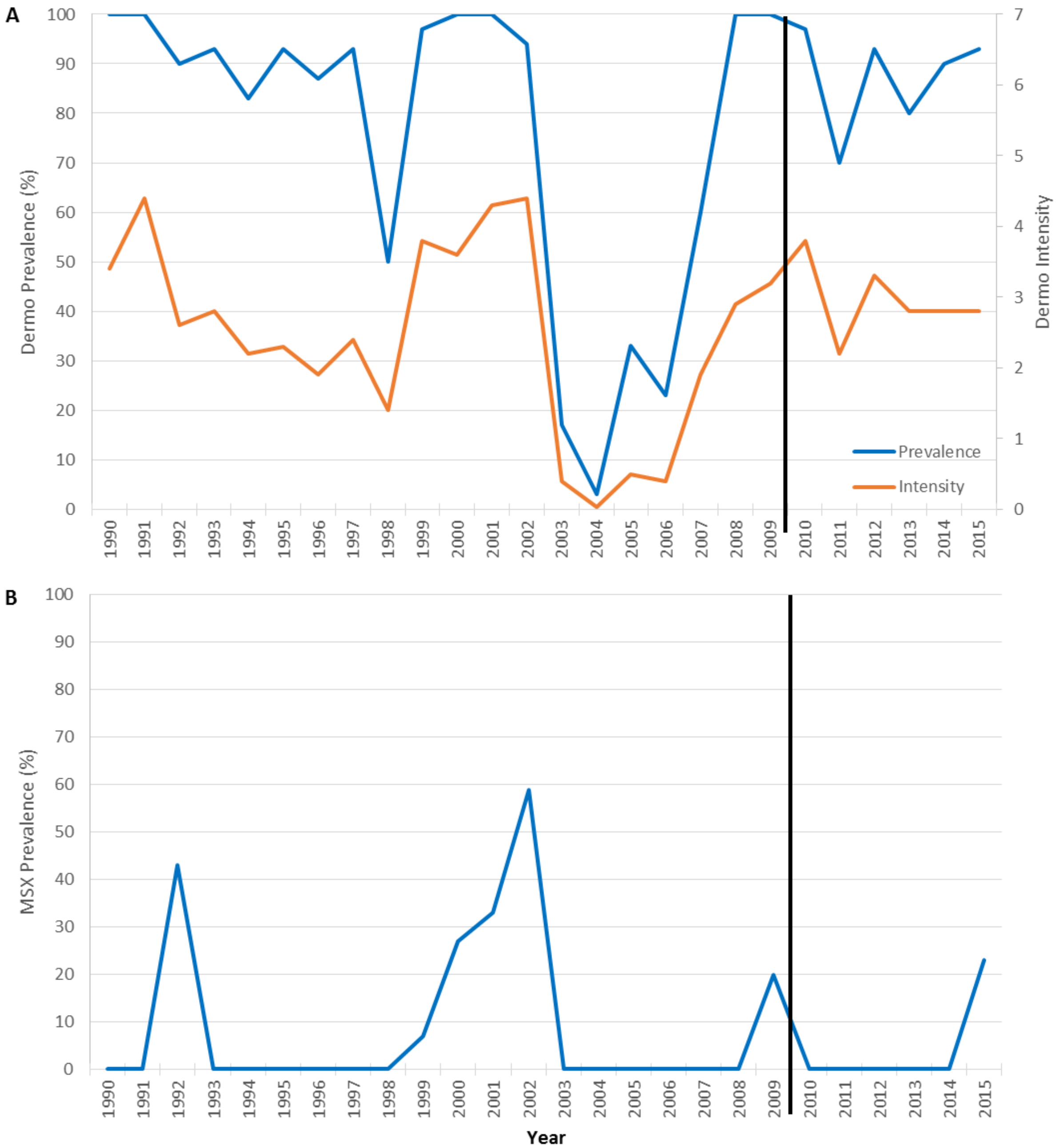

Figure A.17-10. Oyster disease prevalence and intensity from 1990 to 2015 in the Little Choptank River Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Cason bar.

Harvest

The sanctuary encompasses 48% of the 19,423 acres in NOAA Code 053. Harvest reported by seafood dealers prior to the establishment of the sanctuary peaked in the 1998-1999 season at 84,076 bushels (Figure A.17-11). The average harvest per season from 1990 to 2009 was 13,810 bushels. In the 2009-2010 harvest season, the last season before the establishment of the sanctuary, commercial watermen recorded a catch of 780 bushels via harvester reports in the Little Choptank River.

After the establishment of the sanctuary in 2010, 49% of the Little Choptank River remained available for harvest. The highest catch after sanctuary establishment occurred during the 2014-2015 season (Figure A.17-11) and was 3,928 bushels.

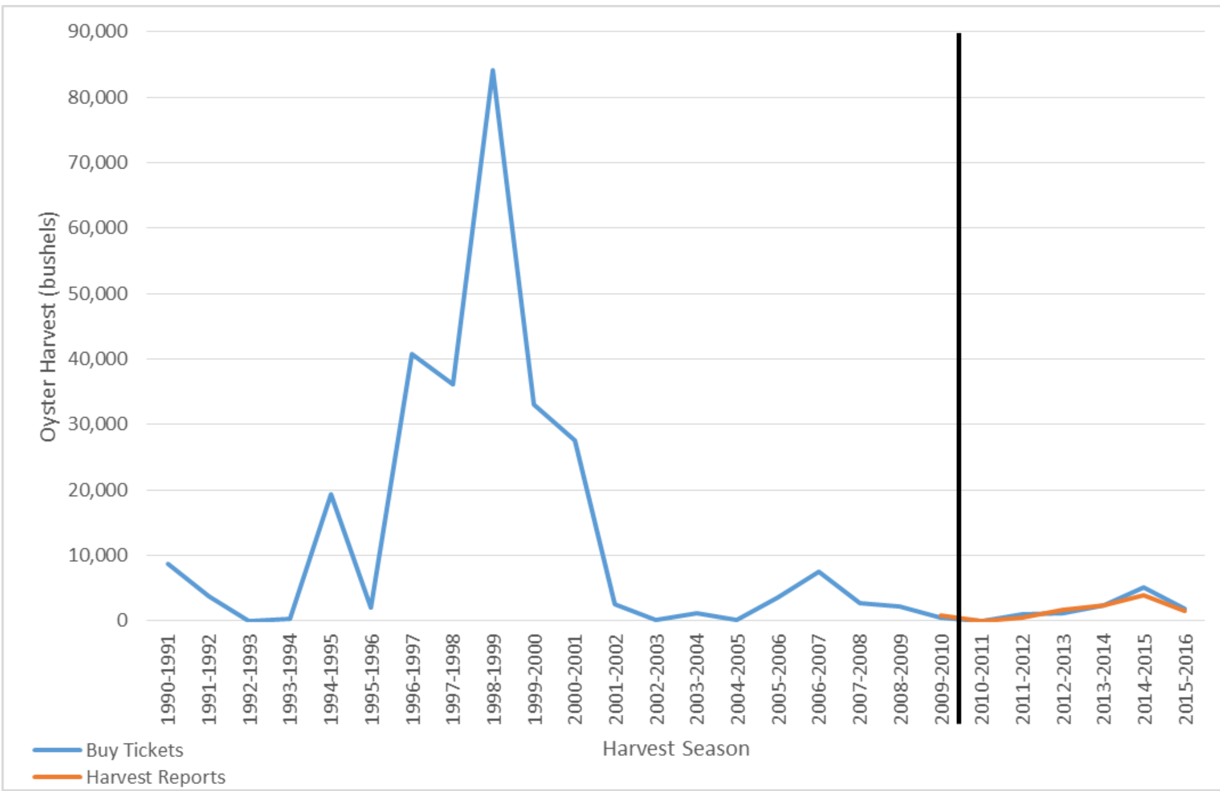

Figure A.17-11. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in the Little Choptank River. In 2010, 66% of the Little Choptank River became an oyster sanctuary (denoted by the black line).

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.18: Lower Chester River Sanctuary

The Lower Chester Sanctuary is located at the mouth of the Chester River, a low salinity (less than 12 ppt) area (Figure A.18-1). The sanctuary was created in 2010 and encompasses 24,147 acres of which 6,930 (29%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 21 historic oyster bars within the sanctuary[43]. The Lower Chester includes two previously created sanctuaries: Strong Bay Sanctuary (created in 2003, 320 acres), and East Neck Sanctuary (created in 2007, 78 acres).

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.18-2). Of the 18,259 acres surveyed within the sanctuary, 6,640 (36%) were classified as oyster reef habitat. In 2010 Maryland Geological Survey conducted side scan sonar surveys of some areas within the Lower Chester Sanctuary. Of the 3,053 acres surveyed in 2010, 624 acres (20%) were classified as oyster reef habitat. The greater coverage of the area by the Bay Bottom Survey as compared to the Maryland Geological Survey's side scan sonar work in the Lower Chester Sanctuary precludes comparison of the two surveys.

Restoration and Replenishment Activities

Multiple replenishment activities to support the public fishery have occurred since 1990, including planting approximately 95,000 bushels of wild seed, 598,000 bushels of shell, and 21.96 million hatchery spat-on-shell. Dredged shell and hatchery spat-on-shell were planted in the East Neck and Strong Bay Sanctuaries prior to these areas becoming a part of the Lower Chester River Sanctuary (Table A.18-1). No active restoration efforts have taken place in the sanctuary since its establishment in 2010.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 94 cages and planted approximately 28,000 oysters.

[43] See chart 7 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

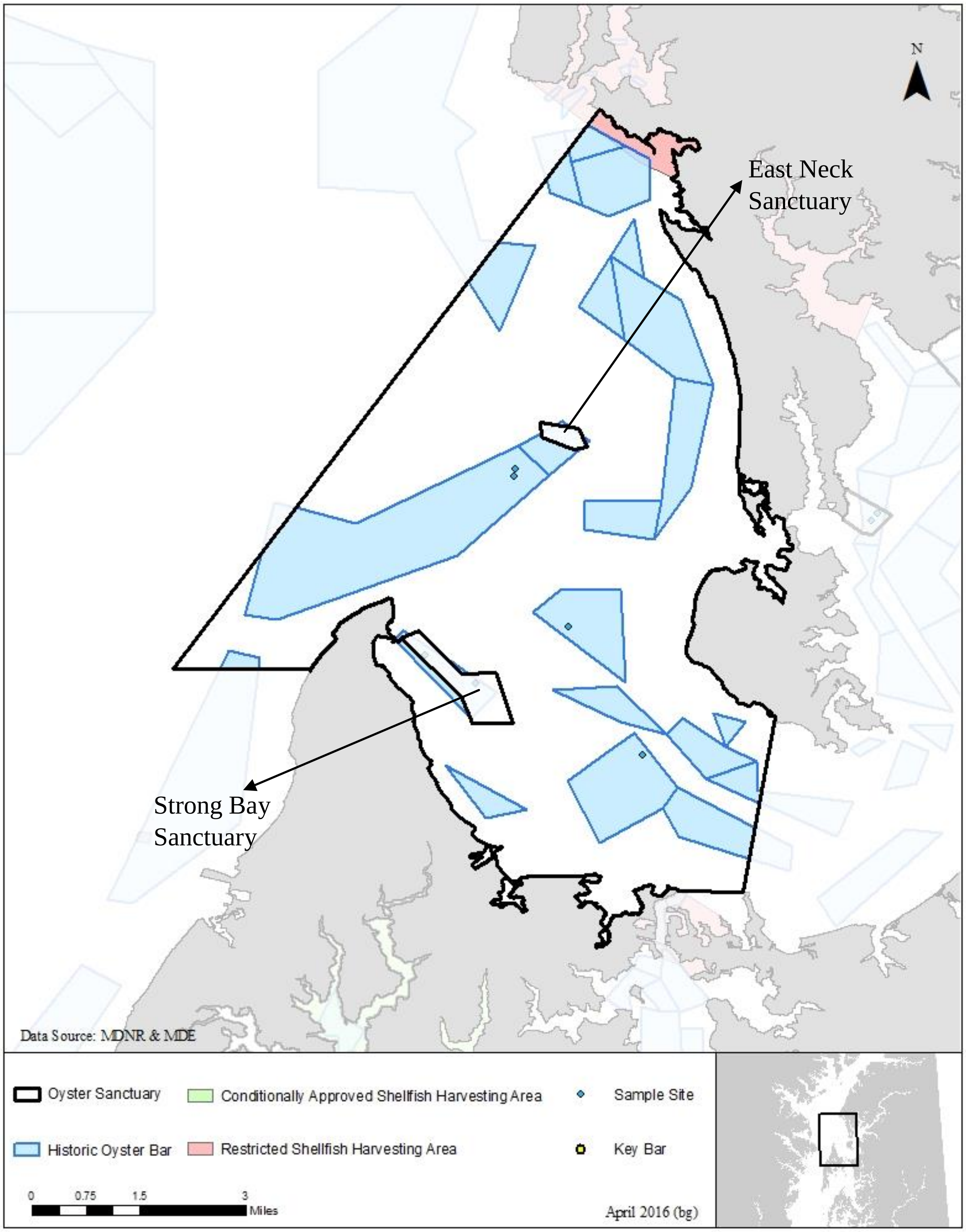

Figure A.18 -1. Lower Chester Sanctuary.

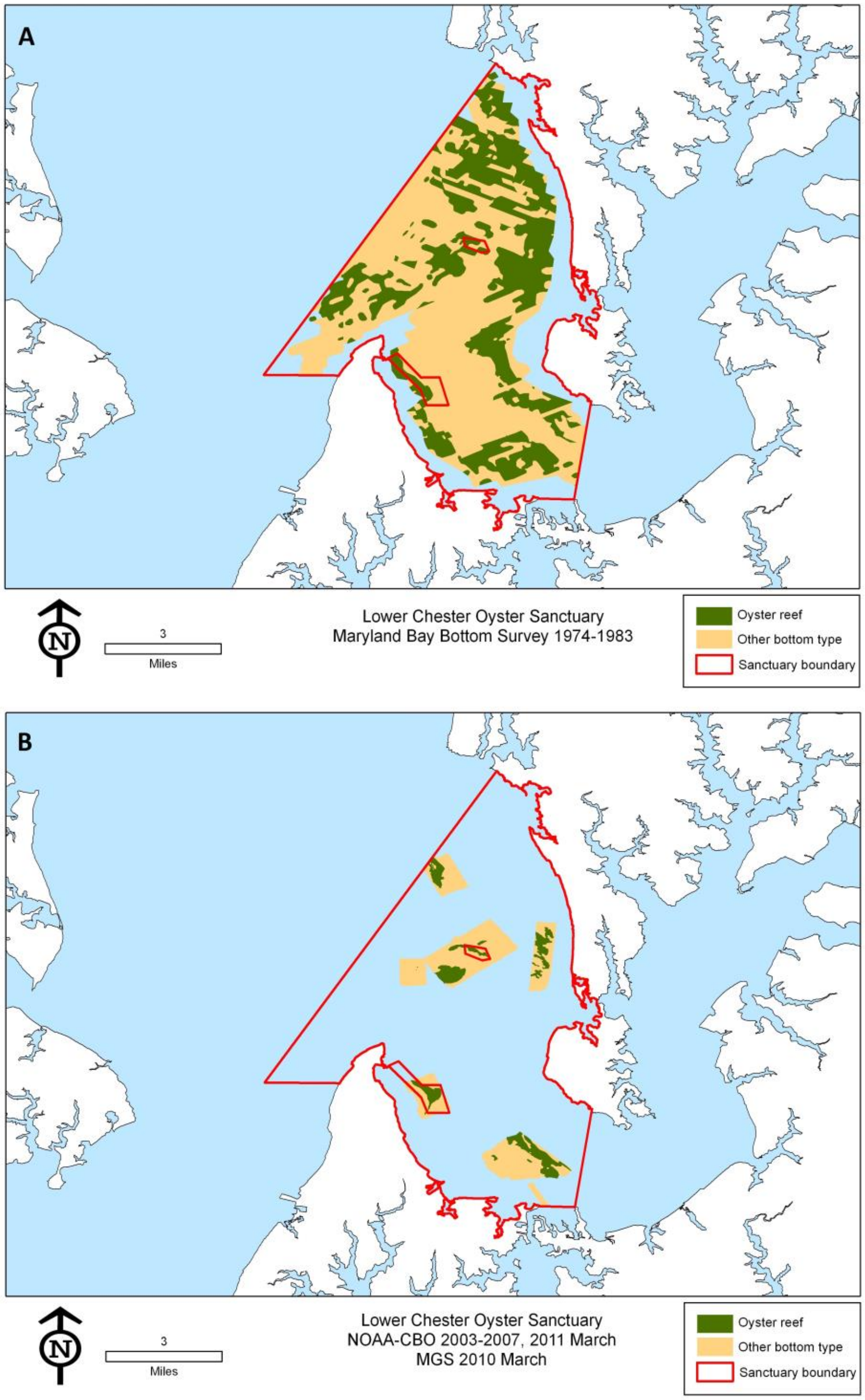

Figure A.18 -2. (A) Lower Chester River Sanctuary bottom types, 1974-1983. Data from Maryland Bay Bottom Survey. (B) Lower Chester River Sanctuary bottom types, 2010. Data from Maryland Geological Survey. Tan and green colored areas depict areas examined during the surveys.

Table A.18-1. Replenishment and restoration planting activities occurring since 1990 in Lower Chester River Sanctuary. S = a planting activity occurring within the East Neck Sanctuary or Strong Bay Sanctuary prior to the establishment of the Lower Chester River Sanctuary in 2010.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Wild Seed	22.88	8.87	-
1991	Wild Seed	19.47	10.03	-
1992	Wild Seed	20.42	5.39	-
1993	Wild Seed	24.81	8.04	-
1994	Dredged Shell	19.90	101.98	-
1994	Wild Seed	12.84	3.40	-
1995	Fresh Shell	3.57	7.65	-
1995	Wild Seed	3.58	3.49	-
1997	Dredged Shell	0.53	3.38	-
1997	Wild Seed	11.46	10.77	-
1998	Wild Seed	53.70	37.90	-
1999	Wild Seed	7.42	4.12	-
2000	Wild Seed	2.44	4.49	-
2002	Dredged Shell	15.24	218.38	-
2003	Dredged Shell	6.74	31.68	-
2003 (S)	Dredged Shell	55.62	253.40	-
2003 (S)	Hatchery Spat-on-Shell	48.88	-	19.80
2005 (S)	Dredged Shell	29.16	221.73	-
2005 (S)	Hatchery Seed	58.46	-	48.88
2006	Dredged Shell	7.01	235.09	-
2006	Hatchery Spat-on-Shell	10.52	-	21.96
2007 (S)	Hatchery Spat-on-Shell	18.24	-	36.66
2008 (S)	Hatchery Spat-on-Shell	24.05	-	41.80
2009 (S)	Hatchery Spat-on-Shell	38.97	-	88.48
2010 (S)	Hatchery Spat-on-Shell	63.65	-	77.99

Oyster Population Characteristics

The Fall Survey has sampled two to five oyster bars in this area since 1990 with an average of four oyster bars sampled annually. The average number of total live oysters per bushel (market, small, and spat) decreased after sanctuary establishment (Table A.18-2; Figure A.18-3). The large amount of spat planted prior to 2010 may have been responsible for the higher oyster abundance during this time period. The average number of small oysters decreased after the establishment of the sanctuary, while the average number of market-sized oysters remained the same.

Table A.18-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Lower Chester River Sanctuary in 2010. ND = No Data. Values are given as means ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 67	6 / 24
Number of Live Oysters per Bushel	112 ± 16	58 ± 4
Number of Live Small-Sized Oysters per Bushel	39 ± 11	10 ± 3
Number of Live Market-Sized Oysters per Bushel	53 ± 7	47 ± 3
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	12.4 ± 2.5	12.1 ± 1.1

The Paynter Laboratory (Lane et al. 2011[44]; Paynter 2011[45]; Paynter et al. 2012[46], 2013[47], 2014[48]) sampled hatchery plantings on Hickory Thicket and Strong Bay bars in the Lower Chester Sanctuary from 2008-2013. Density was as high as 202.8 m^{-2} during the year of a planting, and as low as 0.7 m^{-2} three years after a planting.

A patent tong population survey of the sanctuary was conducted in 2014 (Figures A.18-4). The average density of live oysters was 0.07 ± 0.04 m^{-2} (mean ± standard error, n = 275). Most of the samples (98%) contained no live oysters or boxes. The majority of the oysters were found in the footprint of the old Strong Bay Sanctuary, the site of numerous plantings. Oyster density was low even in samples with a lot of shell (Figure A.18.5), suggesting larval supply or water quality, rather than bottom habitat, may be responsible for the low numbers.

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[44] Lane, H., A. Michaelis, and K.T. Paynter. 2011. Oyster Restoration Monitoring 2010. Report to the Oyster Recovery Partnership. 87 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2010%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

[45] Paynter, K.T. 2011. 2008 Sanctuary Assessment. Report to the U.S. Army Corps of Engineers, Baltimore District. 67 pp. http://www.nab.usace.army.mil/Portals/63/docs/Environmental/Oysters/2008SanctuaryAssessment.pdf

[46] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

[47] Paynter, K., H. Lane, and A. Michaelis. 2013. Paynter Lab Annual Monitoring and Research Summary 2012. Report to the Oyster Recovery Partnership. 110 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2012%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

[48] Paynter, K.T., A. Michaelis, and A. Handschy. 2014. Paynter Lab Annual Monitoring and Research Summary 2013. Report to the Oyster Recovery Partnership. 135 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2013%20Paynter%20Lab%20Annual%20Monitoring%20Report%20to%20ORP.pdf

Oyster Size Structure

Oysters collected from this area during the Fall Survey were not measured. However, oyster shell heights were measured during the 2014 patent tong population survey (Figure A.18-6). All of the oysters found were greater than 65 mm shell height, indicating no recent recruitment.

Paynter and colleagues measured hatchery planted oysters. Average shell heights ranged from 50.2 mm at one year post-planting to 125 mm at six years post-planting.

Biomass

The Fall Survey has not collected any information on oyster biomass since 1990 in this area.

Paynter and colleagues calculated biomass of hatchery plantings. Biomass of three year old plantings ranged from 0.2 to 17.3 g m^{-2}.

Recruitment (Spatfall)

Recruitment in this area is sporadic, with spat found in 10 of the 26 years since 1990 (Figure A.18-3). Maximum spat counts were recorded in 2005 at a site planted with hatchery seed, with 730 spat per bushel. Excluding planted wild and hatchery seed, average spat fall is the same before and after sanctuary establishment (1 ± 1 spat per bushel) with a maximum average spatfall of 7 spat per bushel (Figure A.18-7).

No spat were collected during the patent tong population survey performed in 2014 by the Department.

Mortality

Based on Fall Survey box counts, average mortality was similar before and after sanctuary establishment (Table A.18-2; Figure A.18-8). Mortality ranged from 0% to 44%.

Disease

The Fall Survey has not collected any information on oyster disease since 1990 in this area.

Paynter and colleagues analyzed hatchery plantings for dermo.[49] From 2005-2013 dermo prevalence ranged from 0 to 100%. Dermo prevalence was less than 90% from 2012-2013.

[49] Paynter, K.T. 2007. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program: 1997-2006. 87 pp.

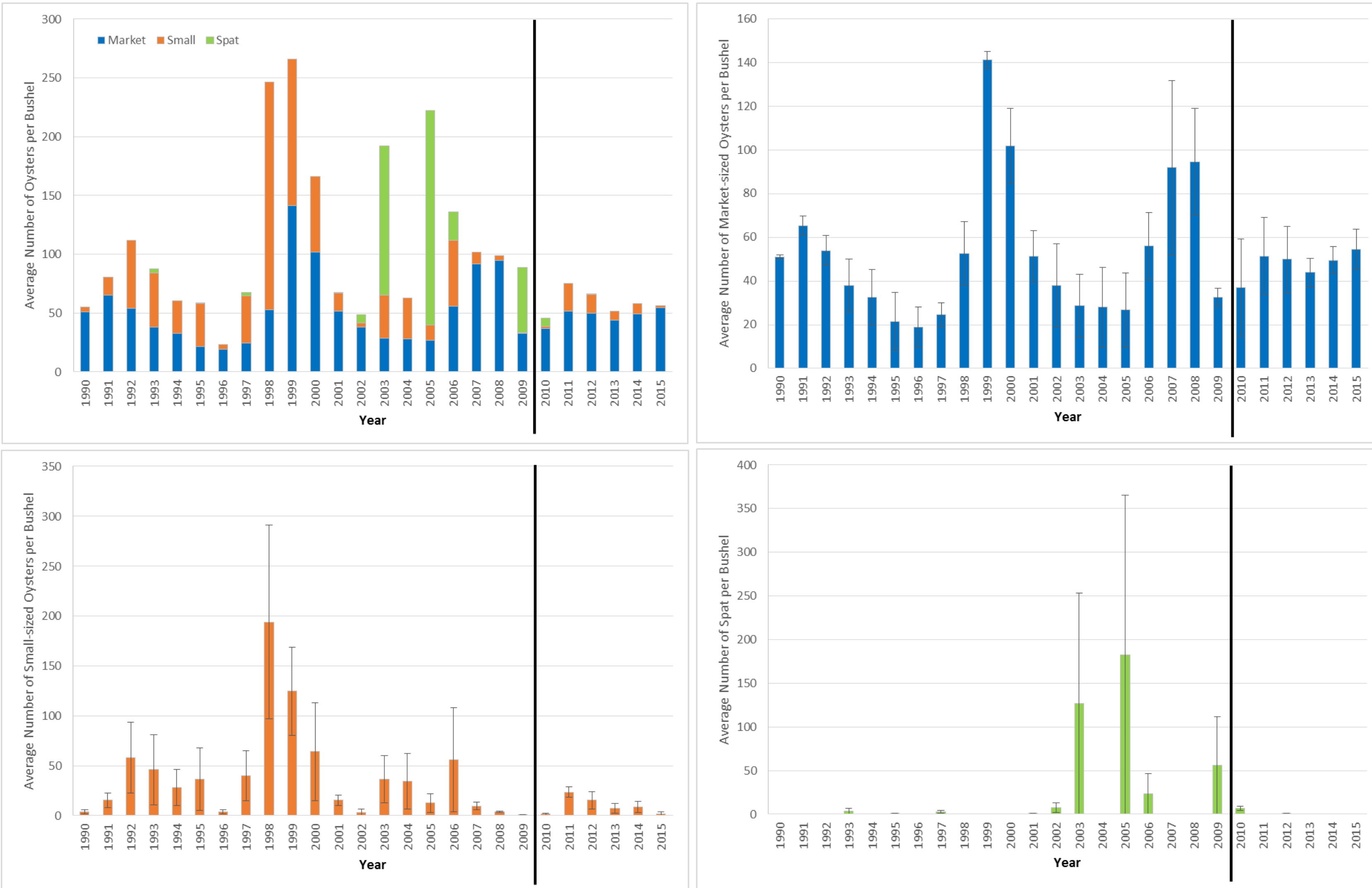


Figure A.18-3. Average number of live oysters per bushel of material by size class in the Lower Chester River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

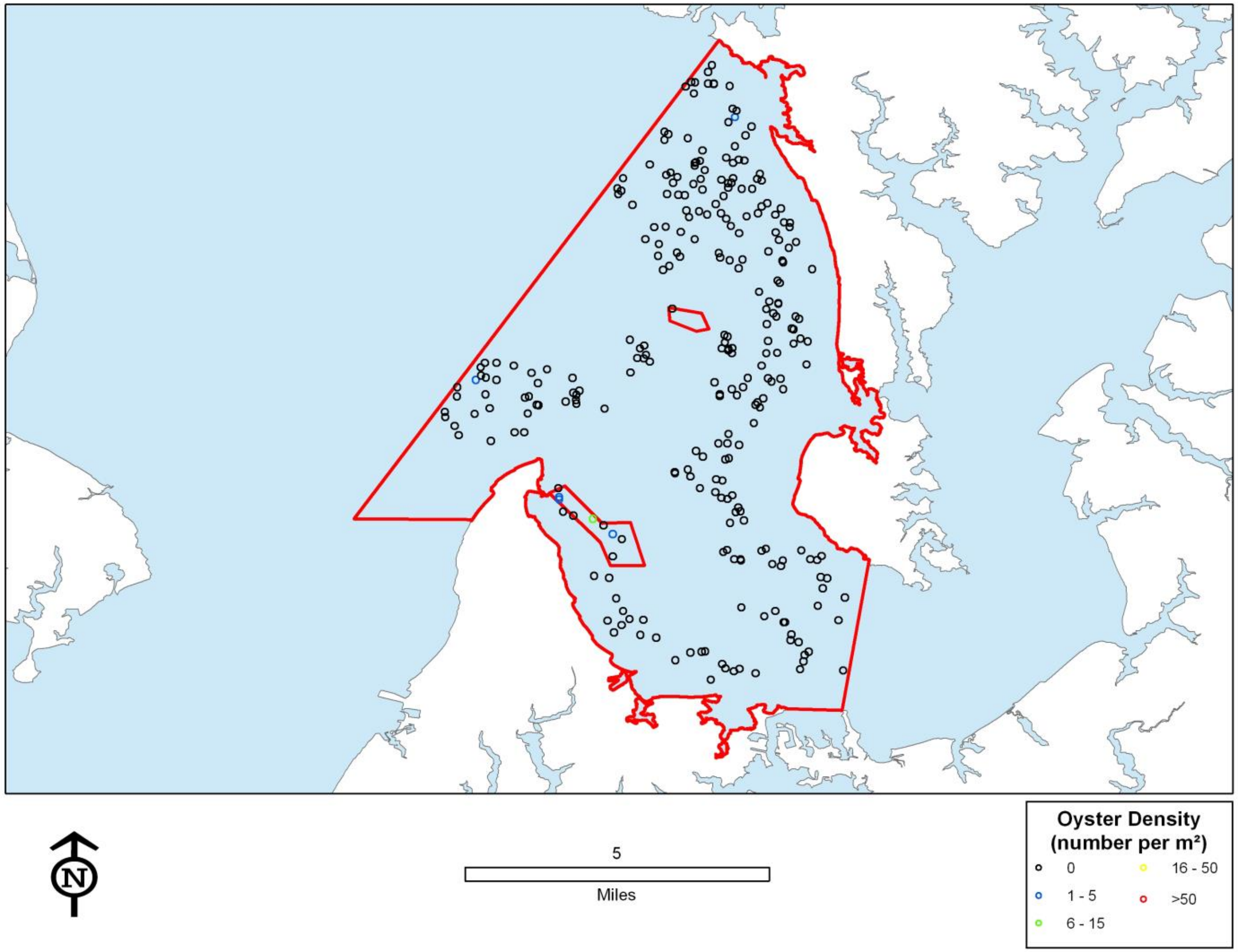


Figure A.18-4. Map of 2014 oyster density in the Lower Chester River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

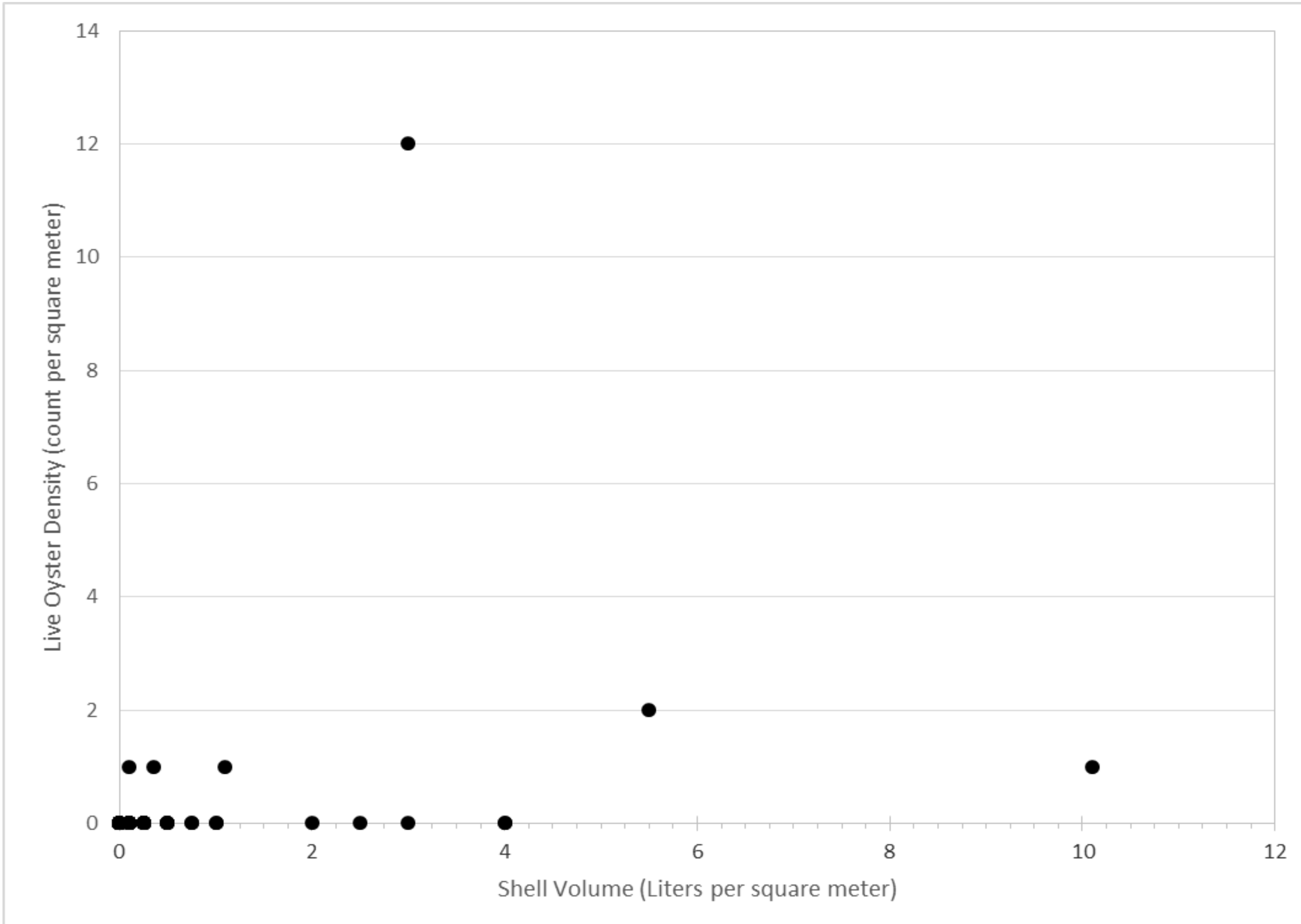


Figure A.18-5. 2014 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Lower Chester River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

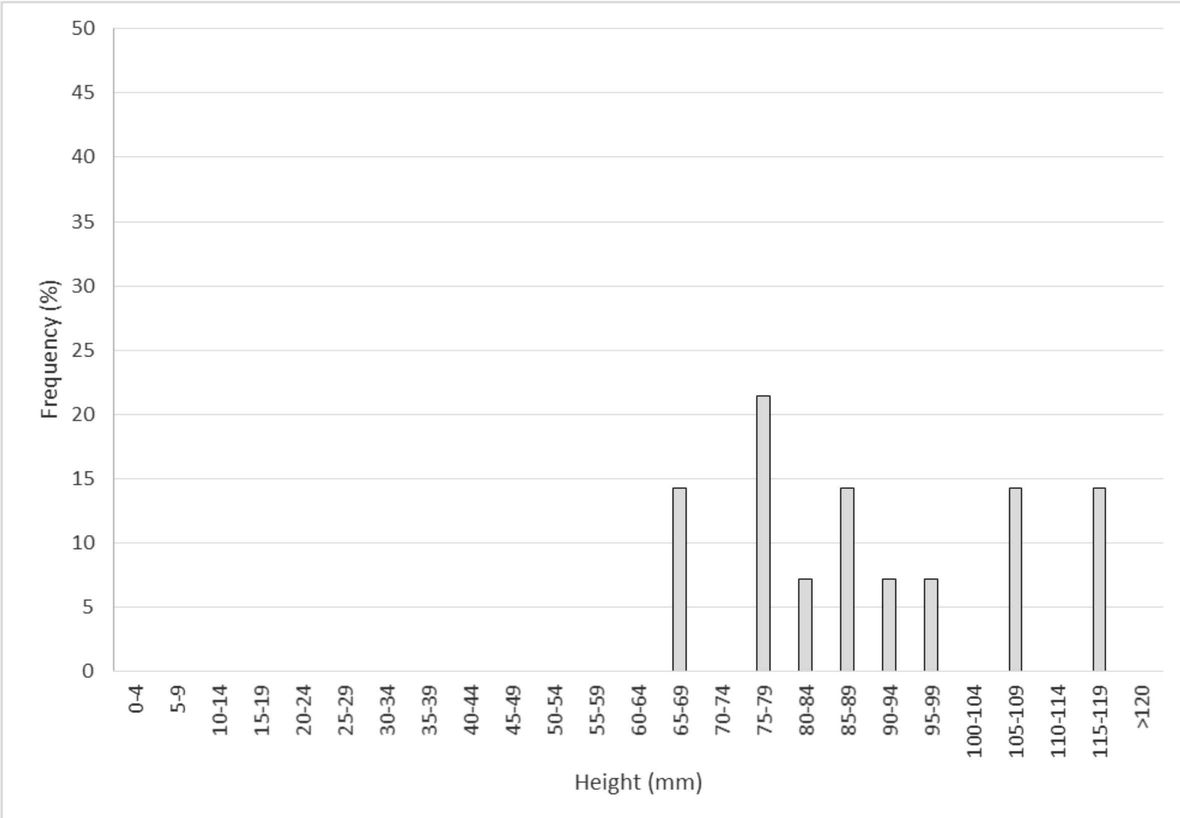


Figure A.18-6. Shell height frequencies of live oysters in the Lower Chester River Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

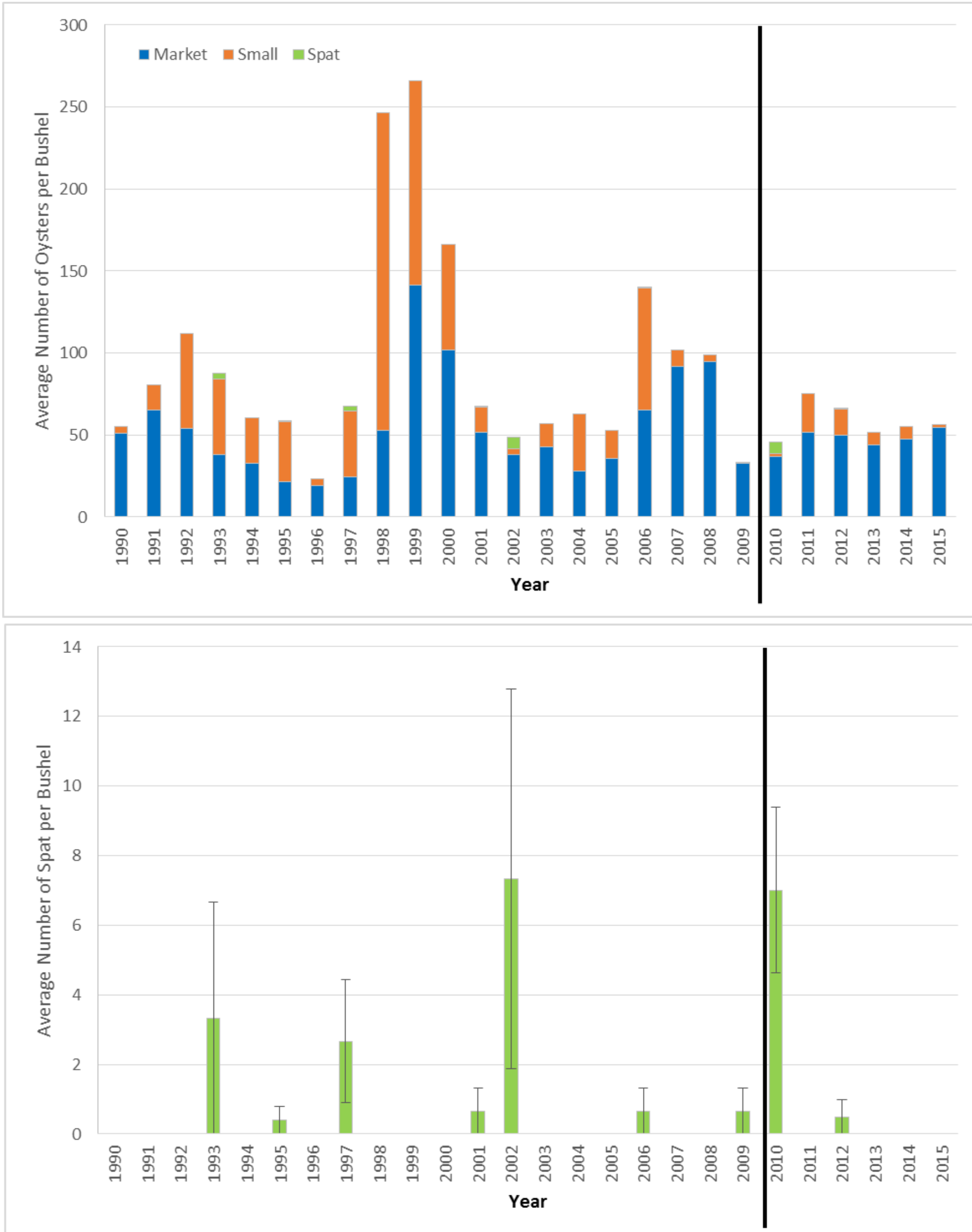


Figure A.18-7. Average number of total live oysters and spat per bushel of material in the Lower Chester River Sanctuary after excluding Fall Survey samples taken on planted hatchery spat-on-shell and wild seed. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey.

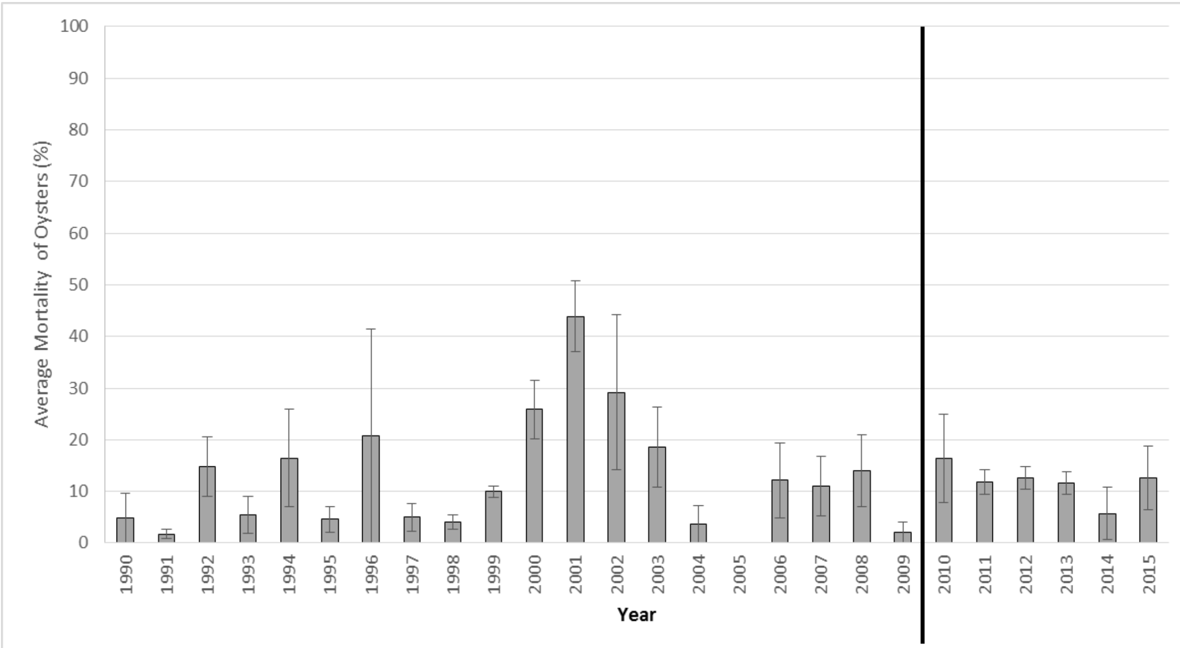


Figure A.18-8. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Lower Chester River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

Harvest

The sanctuary falls between two NOAA Code Areas (025 and 131), but does not constitute the entirety of either code area. Because the sanctuary is located within two NOAA Codes and there is area in the NOAA Codes that area not a sanctuary currently, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. In the 2009-2010 harvest season, commercial watermen reported a catch of 51 bushels in the area that is now the sanctuary.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Data Hub recorded monthly water quality values at station XHG0859 (39.0139, -76.2349) in this area from 2003 to 2006 (Figure A.18-9). Water quality was favorable for oysters during this time except for periods of low salinity in June 2003, August 2003, and May 2004.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

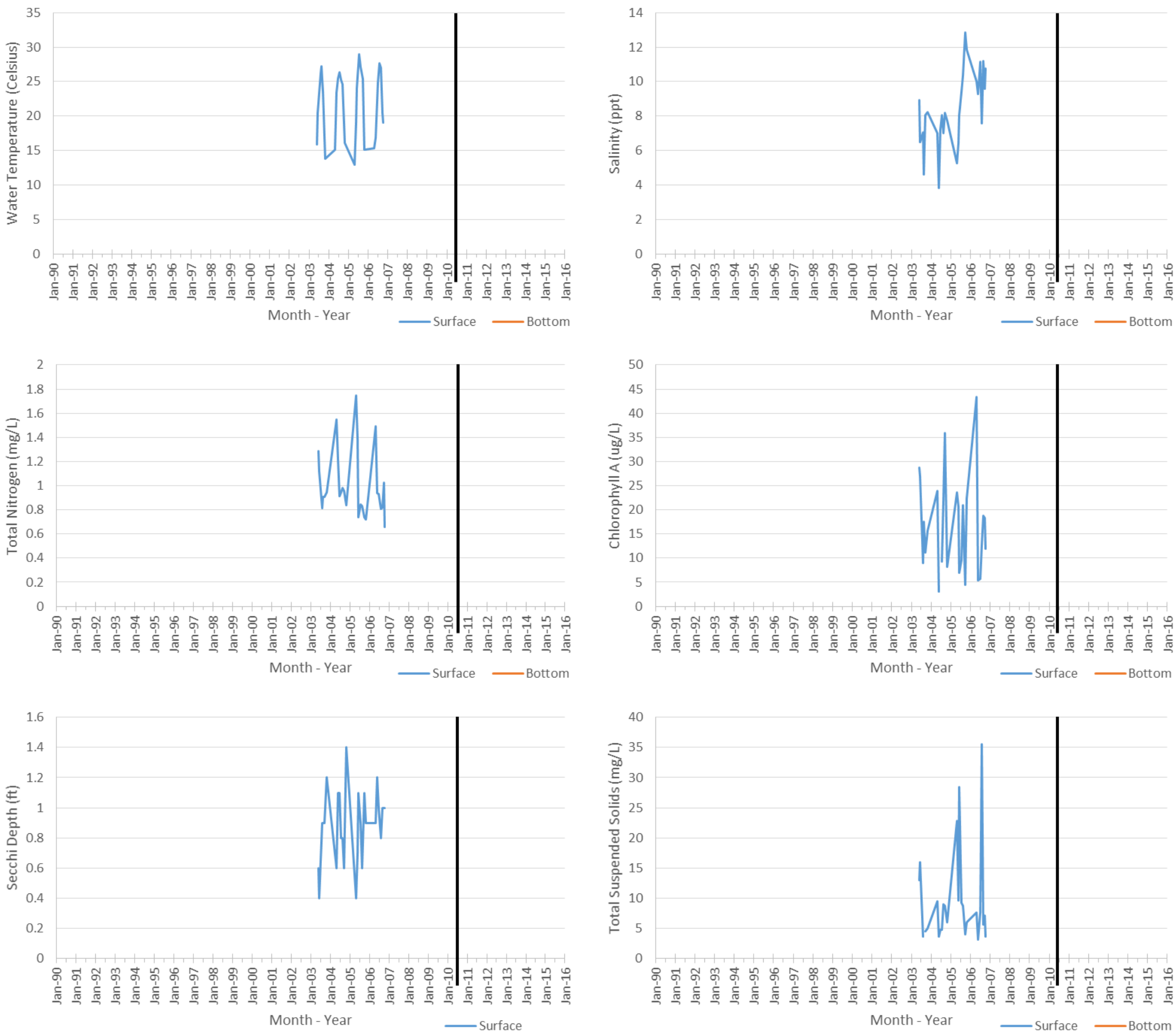


Figure A.18-9. Water quality data collected at Station XHG0859 within the area now established as Lower Chester River Sanctuary from 2004 to 2006. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.

Section A.19: Lower Choptank River Sanctuary

The Lower Choptank River Sanctuary is located on the south shore of the Choptank River at its mouth, a low salinity (less than 12 ppt) area (Figure A.19-1). The sanctuary was created in 2010 and encompasses 7,172 acres of which 4,217 (59%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 14 historic oyster bars within the sanctuary[50].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.19-2). Of the 4,785 acres surveyed within the sanctuary, 1,990 (42%) were classified as oyster reef habitat. In 2013 Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 5,088 acres surveyed in 2013, 531 acres (10%) were classified as oyster reef habitat, indicating a substantial loss of habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

Both replenishment and restoration activities have taken place in this area (Table A.19-1). Wild seed and dredged shell were planted to enhance the public fishery prior to the area becoming a sanctuary. Hatchery spat-on-shell was planted in 2011 for restoration purposes.

Table A.19-1. Replenishment and restoration planting activities occurring since 1990 in Lower Chester River Sanctuary. S = planting activity occurring in the sanctuary area after it was established in 2010.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1995	Wild Seed	9.65	6.41	-
1997	Wild Seed	13.84	8.83	-
2000	Dredged Shell	24.88	152.18	-
2001	Dredged Shell	25.43	158.38	-
2011 (S)	Hatchery Spat-on-Shell	18.36	-	35.17

[50] See charts 19 and 20 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

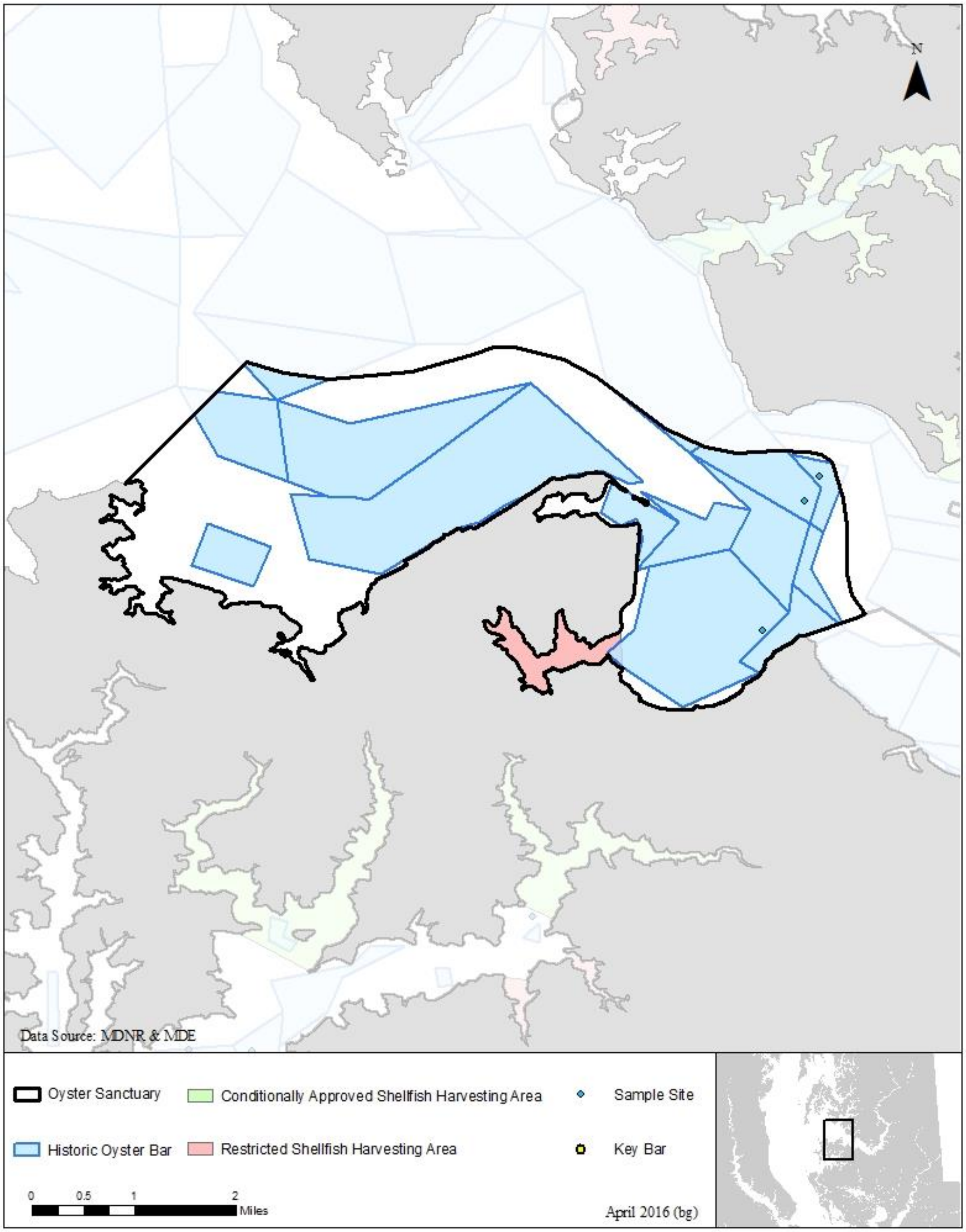


Figure A.19 -1 Lower Choptank River Sanctuary.

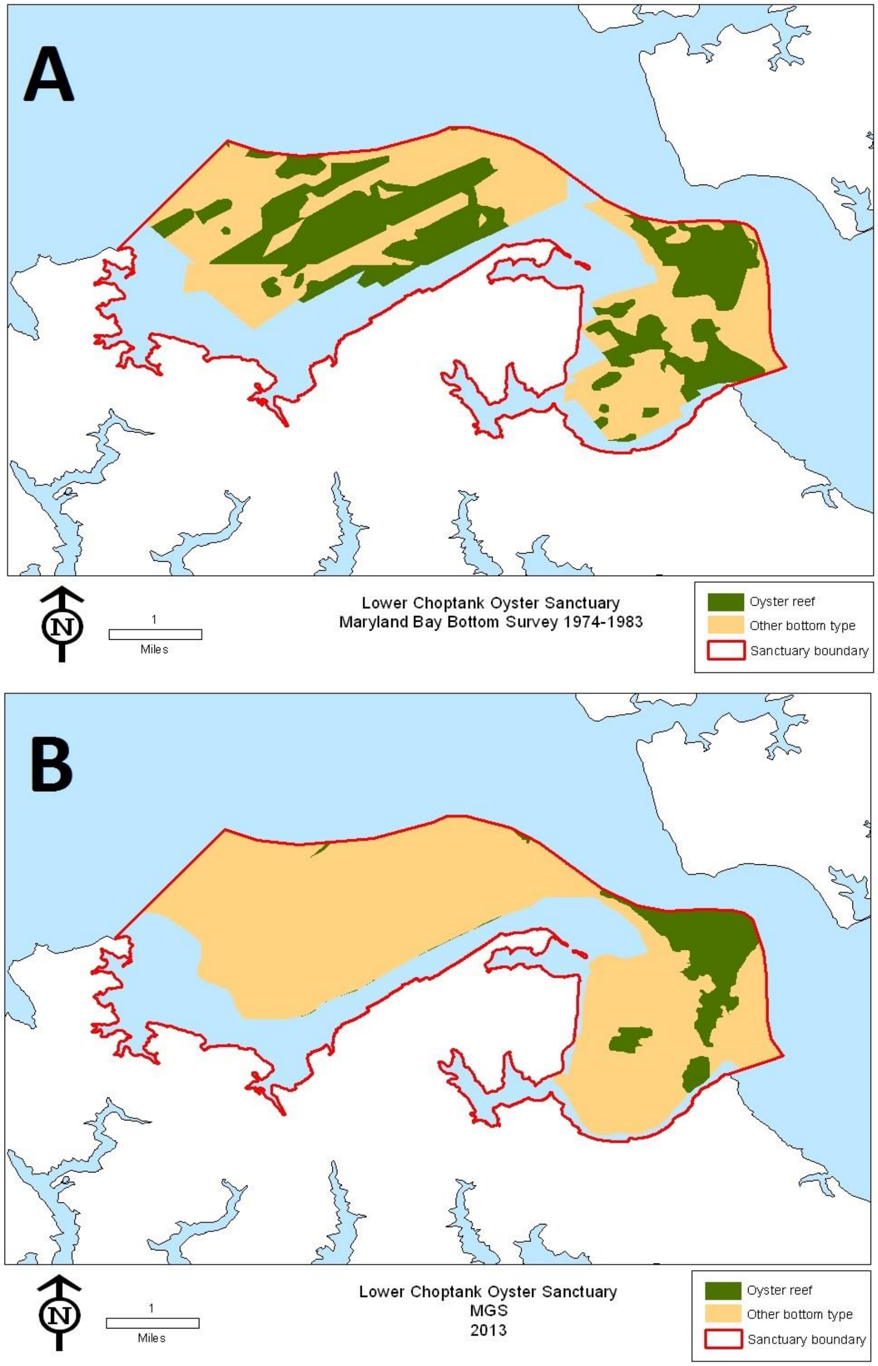


Figure A.19 -2. Lower Choptank River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2013. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled 1 to 3 oyster bars in this area since 1990 with an average of 2 oyster bars sampled annually. The average number of live oysters per bushel (market, small, and spat) increased after sanctuary establishment (Table A.19-2; Figure A.19-3), due to the increase in number of market-sized oysters. The number of small-sized oysters remained the same (Table A.19.2; Figure A.19-4). The increase in number of large may be due to low natural mortality coupled with cessation of harvest.

Table A.19-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Lower Choptank River Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 38	6 / 6
Number of Live Oysters per Bushel	72 ± 15	114 ± 9
Number of Live Small-Sized Oysters per Bushel	34 ± 8	33 ± 7
Number of Live Market-Sized Oysters per Bushel	19 ± 3	70 ± 14
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	21.0 ± 4.9	6.8 ± 0.6

A patent tong population survey was conducted in the Lower Choptank Sanctuary in 2013 (Figure A.19-5). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 1.58 ± 0.48 oysters m^{-2} (mean ± standard error, n= 151). Eighty-one percent of samples had no live oysters or boxes. Oyster density increased with the volume of shell (Figure A.19.6).

Oyster Size Structure

Oysters collected by the Fall Survey in this area were not measured. Oyster shell heights were measured during the patent tong population survey (Figure A.19-7). Market-sized oysters dominated the population, but spat and small oysters were present, indicating recent recruitment.

Biomass

Oyster biomass has not been calculated from Fall Survey samples collected from this area since 1990.

Recruitment (Spatfall)

Based on Fall Survey data, spatfall ranged from an average of 0 spat per bushel to 221, with the highest spatfall occurring in 1991 (Figure A.19-3). There were high spat counts in 2010 and 2012 (30 spat per bushel). During the patent tong population survey of 2013, 17 spat were collected yielding a density of 0.11 ± 0.05 m^{-2}.

Mortality

Based on Fall Survey box counts, average mortality was less than 10% from 2005-2015. (Figure A.19-8). Average mortality was lower after sanctuary establishment than before.

Disease

Oysters collected by the Fall Survey in this area have not been analyzed for disease since 1990.

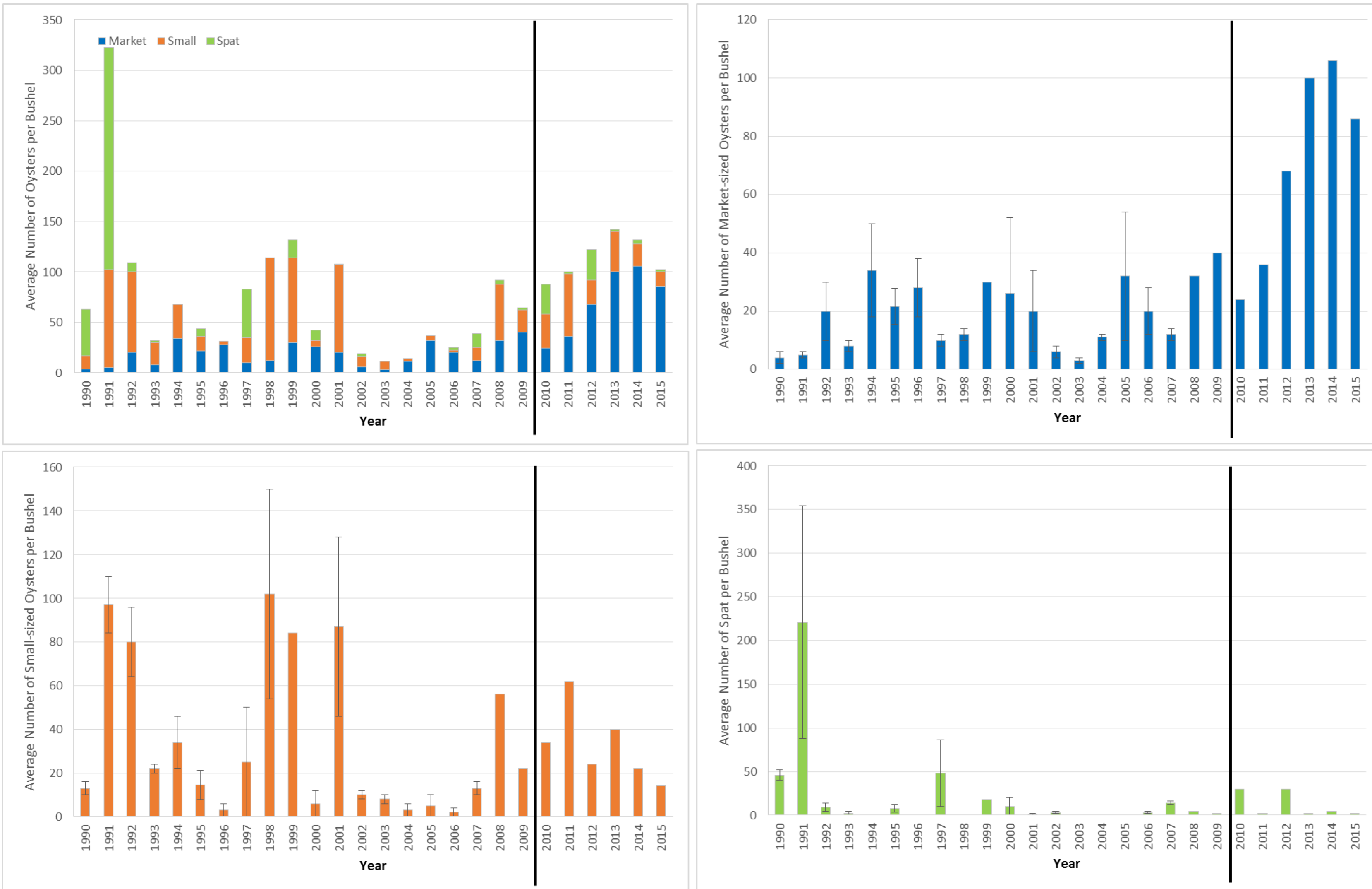


Figure A.19-3. Average number of live oysters per bushel of material by size class in the Lower Choptank Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

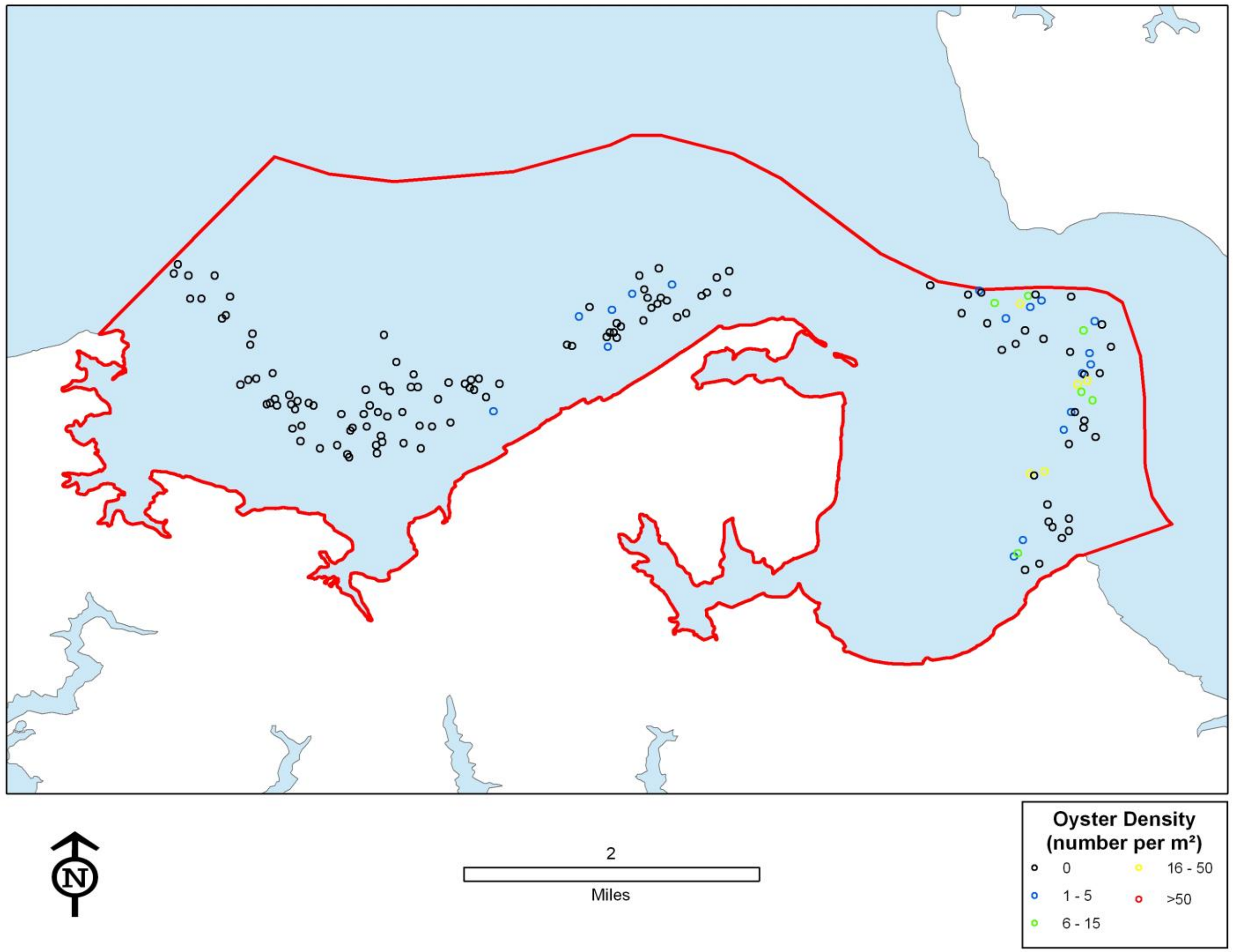


Figure A.19-4. Map of 2013 oyster density in the Lower Choptank Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

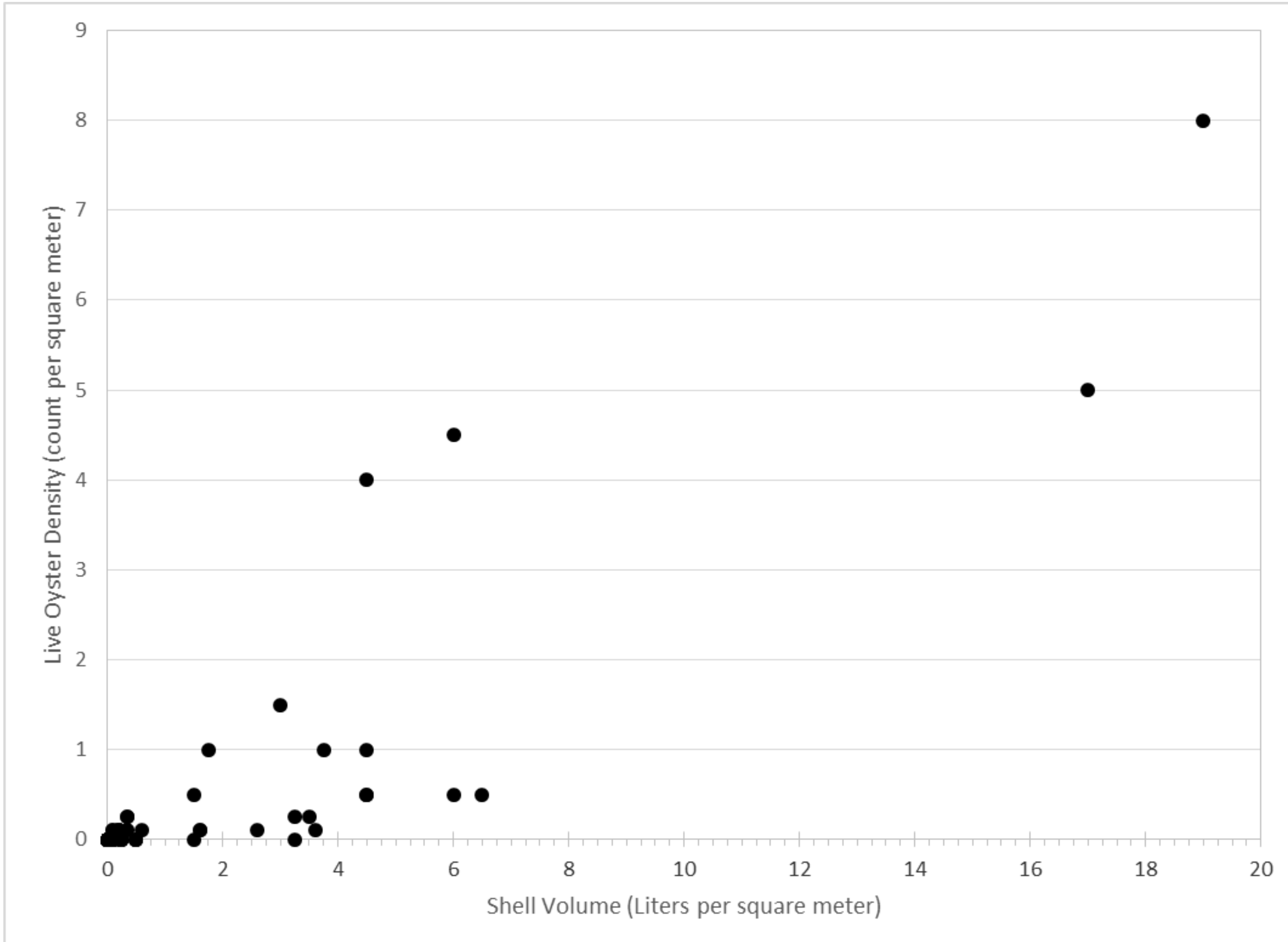


Figure A.19-5. 2013 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Lower Choptank River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

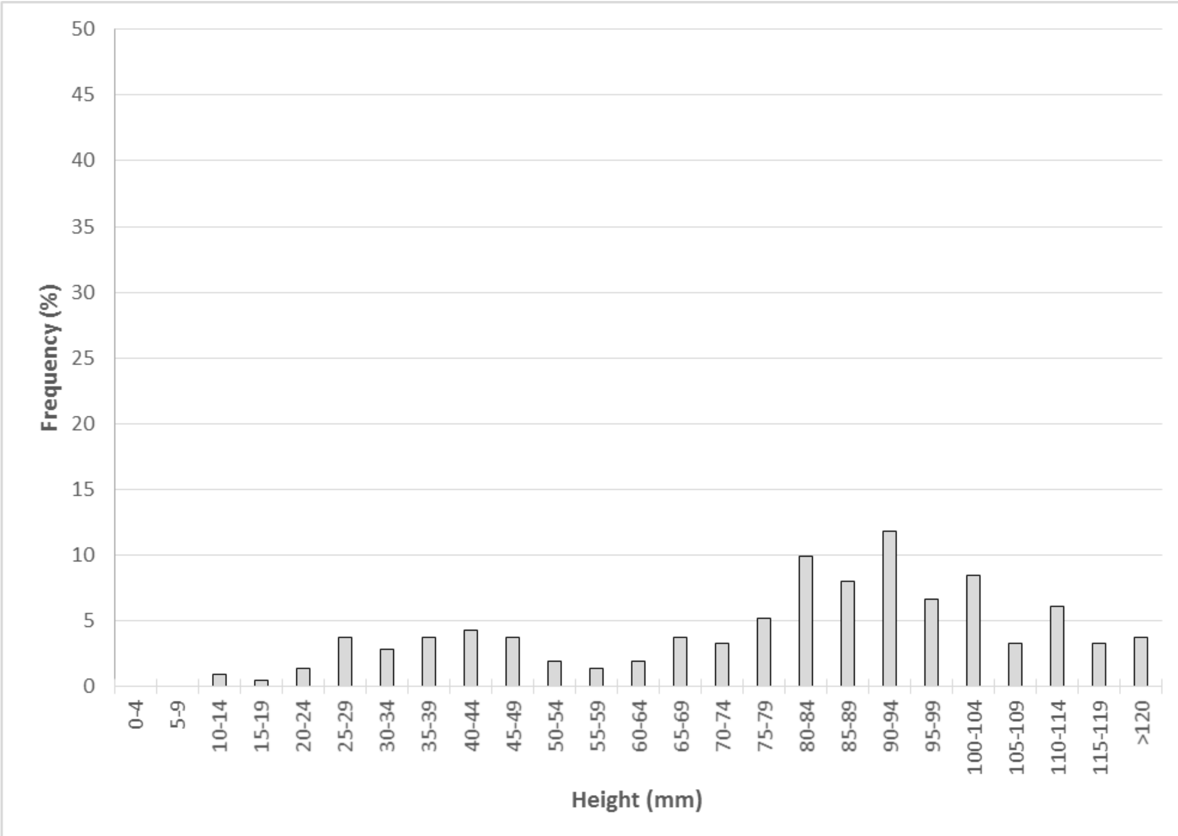


Figure A.19-6. Shell height frequencies of live oysters in the Lower Choptank Sanctuary in 2013. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

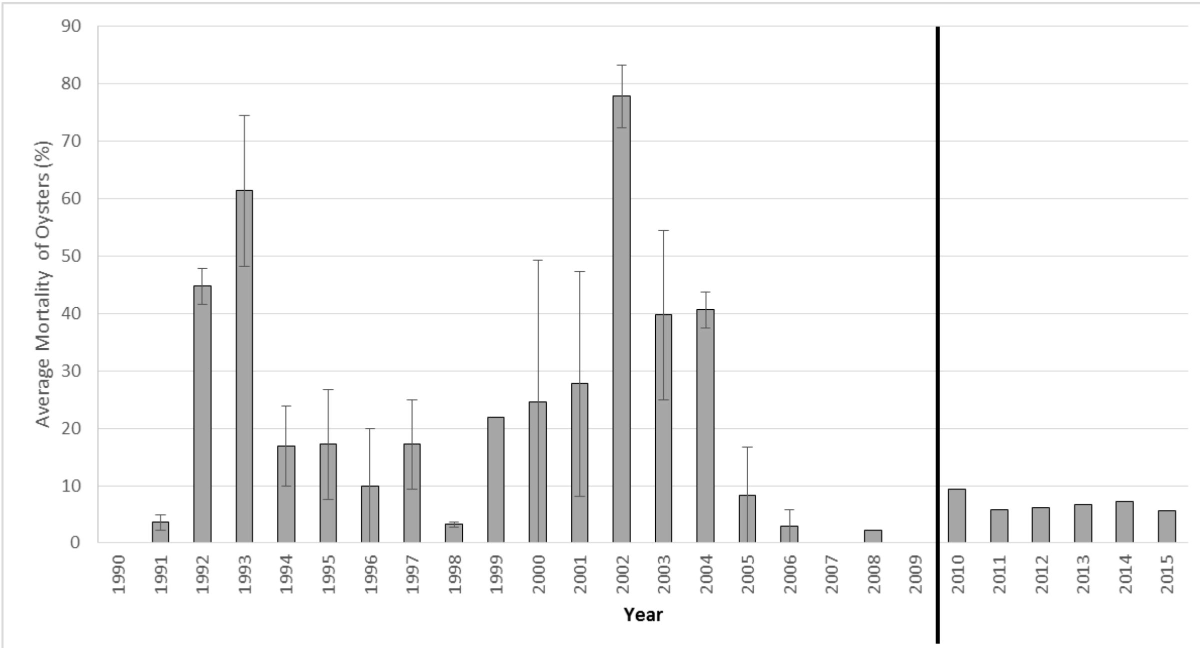


Figure A.19-7. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Lower Choptank Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

Harvest

The sanctuary falls between two NOAA Code Areas (137 and 237), but does not constitute the entirety of either code area. Therefore, seafood dealer reports cannot be used to say anything about harvest in the sanctuary as the catch in a particular NOAA code may have come from areas outside the sanctuary. In the 2009-2010 harvest season, commercial watermen reported a catch of 78 bushels in the area that is now the Lower Choptank Sanctuary.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Data Hub recorded water quality data at 3 stations in this area (Figure A.19-8). Stations within the sanctuary included: XEG6966 (38.6159;-76.2234), XEG8593 (38.6428;-76.178), XEH7912 (38.6313;-76.1469). Surface chlorophyll a, salinity, secchi depth, total nitrogen, total suspended solids, and water temperature were measured. Water quality was favorable for oysters during the time period examined. No water quality data have been collected since the establishment of the sanctuary.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

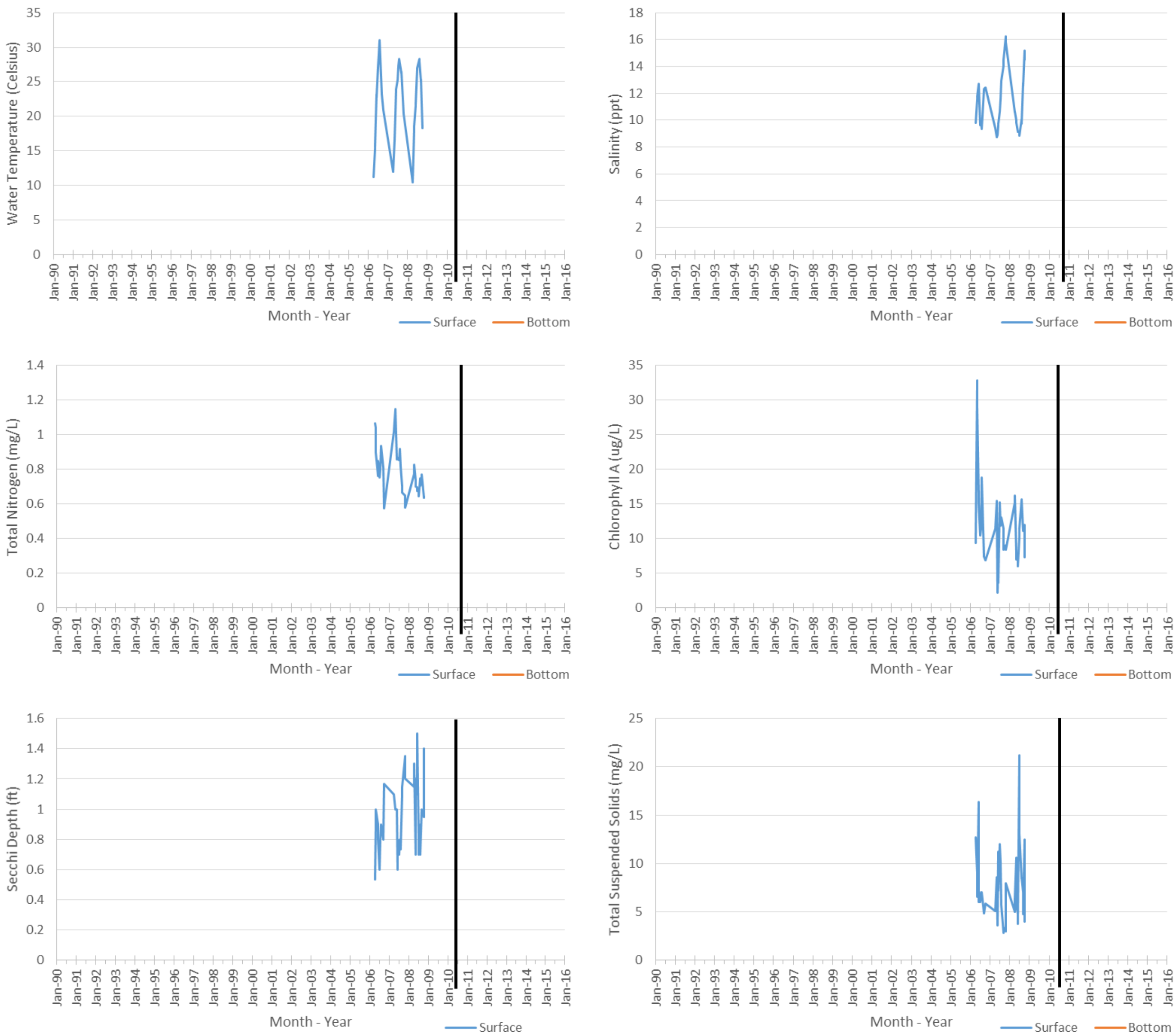


Figure A.19-8. Water quality data collected at multiple stations within the area now established as Lower Choptank River Sanctuary from 2006 to 2008. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.

Section A.20: Lower Mainstem Sanctuary

The Lower Mainstem Sanctuary is located in the lower eastern portion of Maryland's Chesapeake Bay, a medium salinity (12 to 14 ppt) region (Figure A.20-1). The sanctuary was created in 2010 and encompasses 38,290 acres of which 8,234 (22%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 6 historic oyster bars within the sanctuary[51].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.20-2). Of the 32,868 acres surveyed within the sanctuary, 3,603 (11%) were classified as oyster reef habitat. No additional bottom surveys using side scan sonar have been conducted since the Bay Bottom Survey.

Restoration and Replenishment Activities

Prior to the establishment of the sanctuary since 1990, over 2 million bushels of dredged shell were planted to enhance the public fishery (Table A.20-1). No restoration efforts have taken place since sanctuary creation.

Table A.20-1. Replenishment planting activities occurring since 1990 in Lower Mainstem Sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1991	Dredged Shell	69.62	441.04	-
1992	Dredged Shell	52.01	329.52	-
1993	Dredged Shell	54.26	343.73	-
1994	Dredged Shell	36.12	228.85	-
1995	Dredged Shell	51.30	643.02	-
2002	Dredged Shell	21.58	133.04	-
2006	Dredged Shell	14.41	88.69	-

[51] See chart 41 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

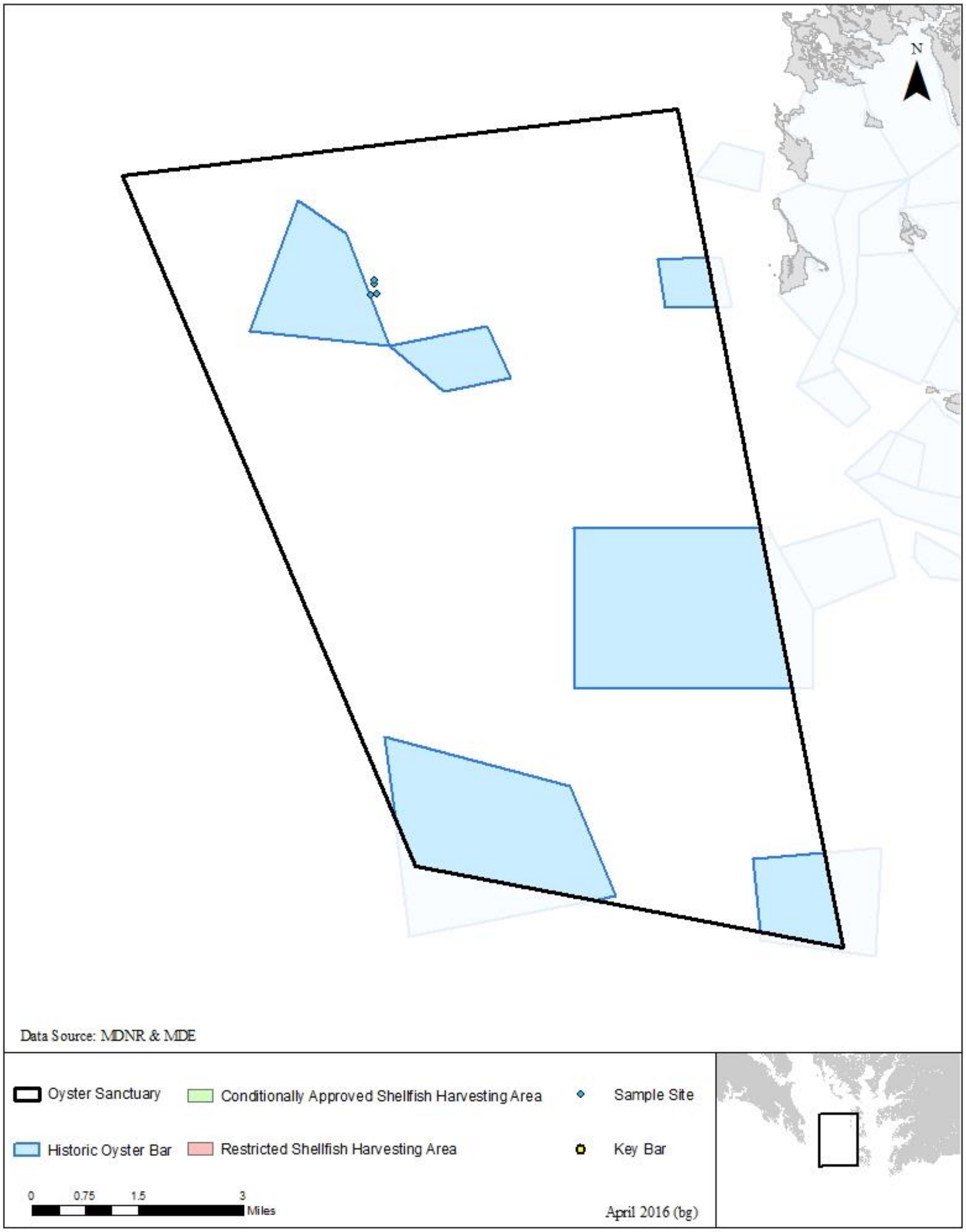


Figure A.20 -1. Lower Mainstem Sanctuary.

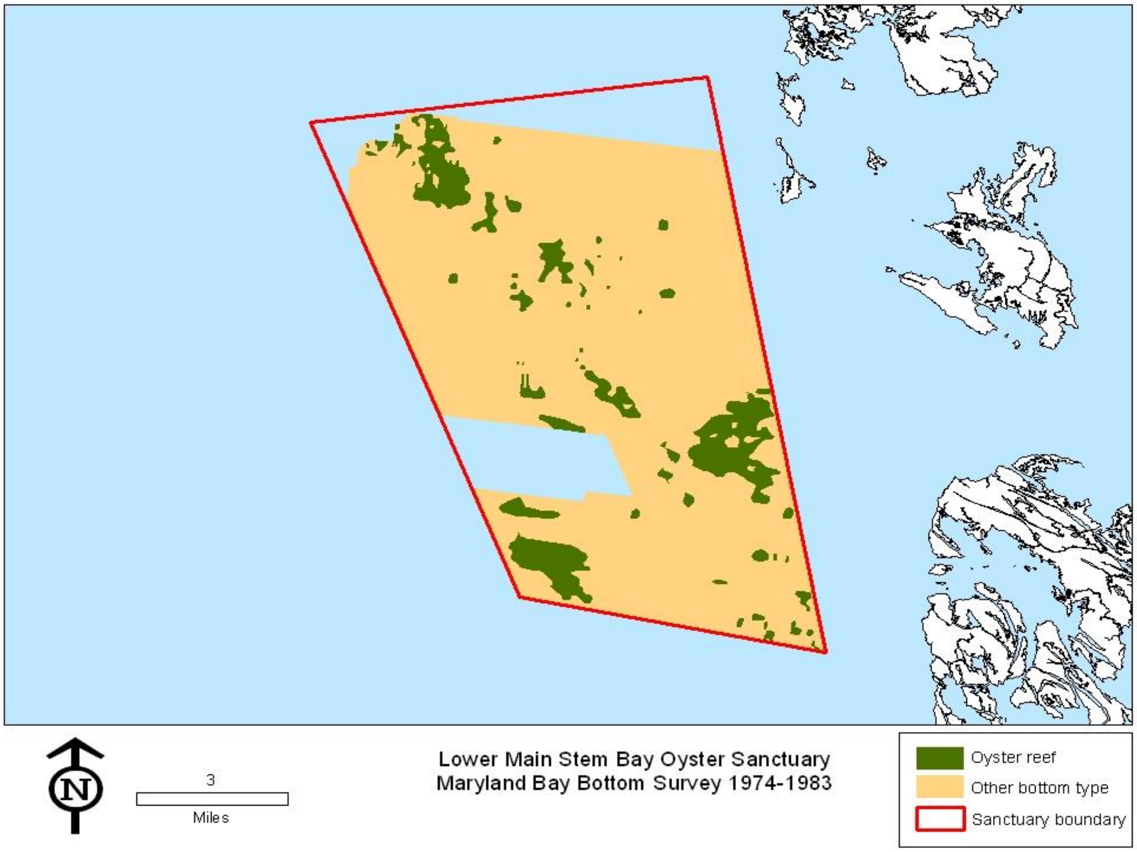


Figure A.20 -2. Lower Mainstem Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict areas examined during the survey.

Oyster Population Characteristics

The Fall Survey has sampled one oyster bar annually in this area between 2000 and 2006; after 2006 two samples were collected on the same bar. No samples were collected in this area between 1990 and 1999. The average number of total live oysters per bushel (market, small, and spat) decreased after establishment of the sanctuary (Table A.20-2; Figure A.20-3), mostly due to the decrease in the number of small oysters.

Table A.20-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Lower Mainstem Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	10 / 14	6 / 12
Number of Live Oysters per Bushel	417 ± 76	223 ± 49
Number of Live Small-Sized Oysters per Bushel	176 ± 63	104 ± 20
Number of Live Market-Sized Oysters per Bushel	46 ± 17	43 ± 13
Live Oyster Biomass (g Dry Weight per Bushel)	ND	91 ± 23.2
Mortality (%)	23.5 ± 6.6	33.9 ± 9.5

A patent tong population survey was conducted in 2015 (Figures A.20-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 0.22 ± 0.05 oysters m^{-2} (mean ± standard error, n= 285). Most of the samples (88%) had no live oysters or boxes. The volume of live oysters increased with the volume of shell (Figure A.20.5).

Oyster Size Structure

Shell heights of oysters collected from Fall Survey samples in this area at Northwest Middleground have been measured since 2010 (Figure A.23-6). Shell heights were also measured during the 2015 patent tong population survey (Figure A.23-7). Spat, small, and market-sized oysters were present in all years examined.

Biomass

Biomass was calculated from Fall Survey samples in this area on Northwest Middleground bar from 2010-2015. Biomass ranged from 21 to 162 g dry weight per bushel of material (Figure A.23-8).

Recruitment (Spatfall)

Based on Fall Survey samples, spatfall ranged from 0 to 948 spat per bushel. The highest spat fall was observed in 2002 (Figure A.20-3). There has been at least some spatfall each year from 2005 to 2015. Based on the patent tong population survey in 2015, the density of spat was $0.05 \pm 0.02\ m^{-2}$.

Mortality

Based on Fall Survey box counts, the average mortality from 2010 to 2015, after sanctuary establishment, was slightly higher than the average mortality before sanctuary establishment (Table A.20-2; Figure A.20-9). This pattern is driven by the high mortality of event of 2011.

Disease

Oysters in this area have been analyzed for disease since 2007 (Figure A.20-10). Dermo disease pressure has been high, with prevalence ranging from 83% to 100%. Although prevalence was high, dermo intensity never reached values greater than 5 which normally indicate lethal disease levels. MSX prevalence ranged from 0% to 27%.

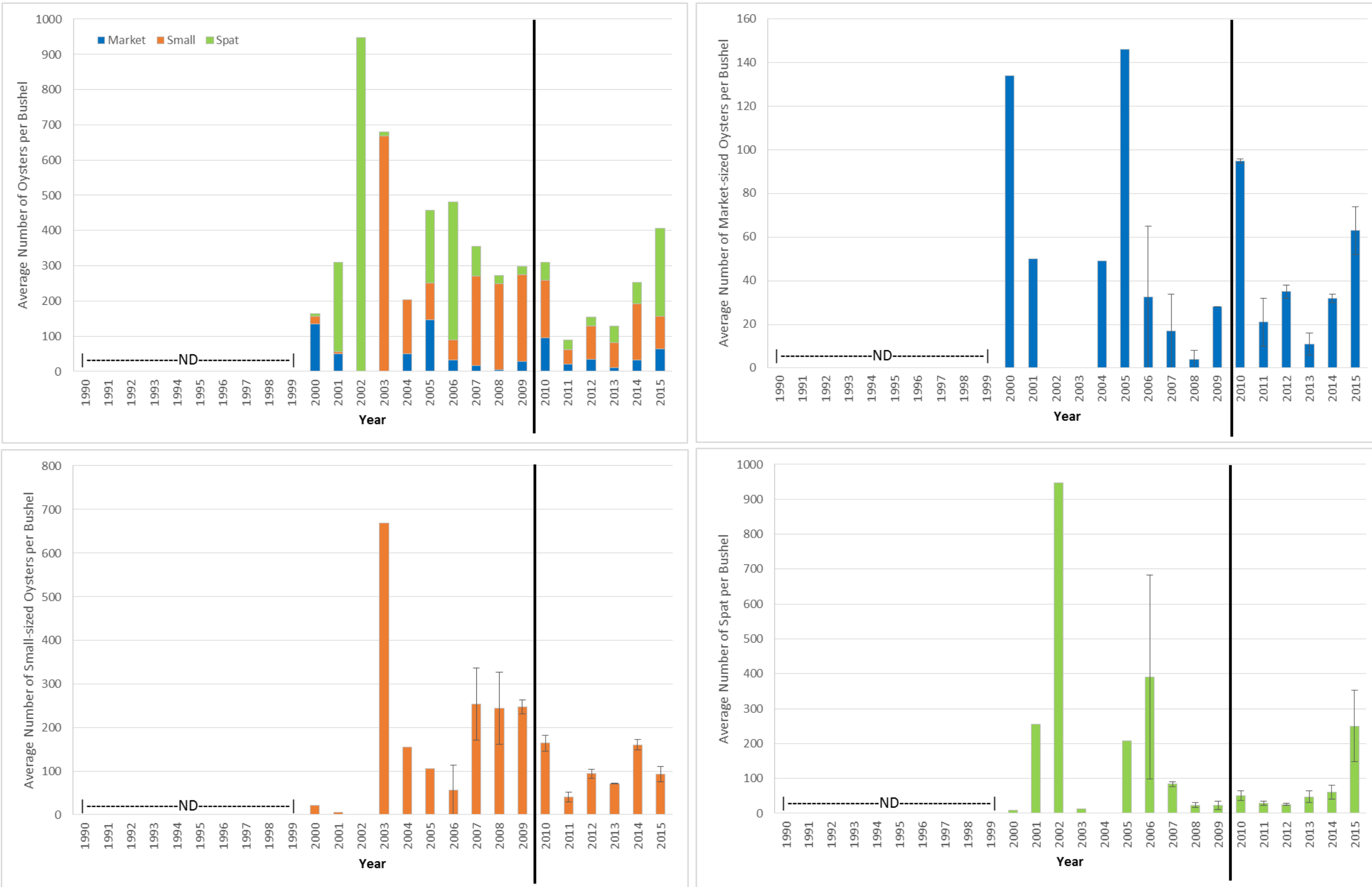


Figure A.20-3. Average number of live oysters per bushel of material by size class in the Lower Mainstem Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data.

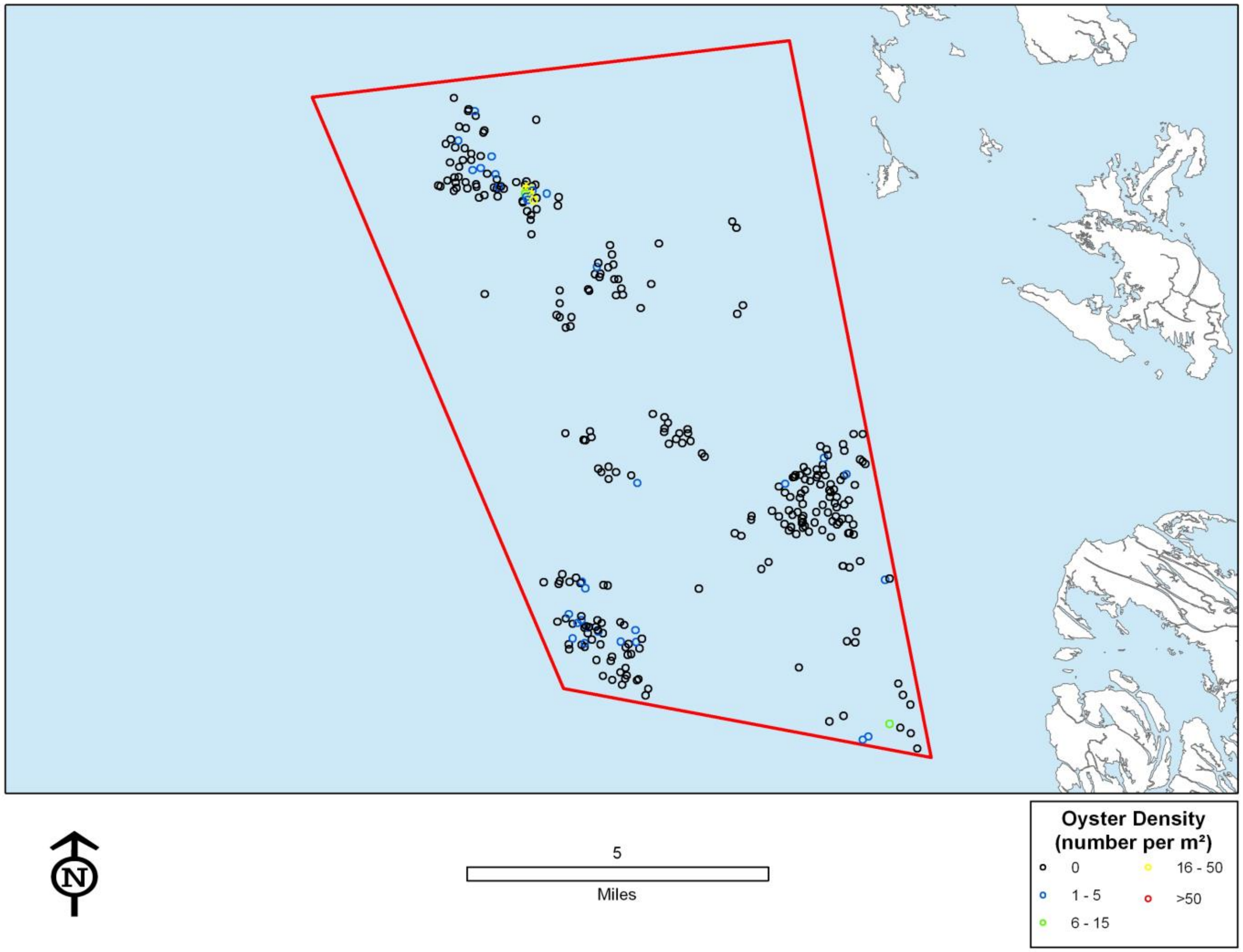


Figure A.20-4. Map of 2015 oyster density in the Lower Mainstem Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

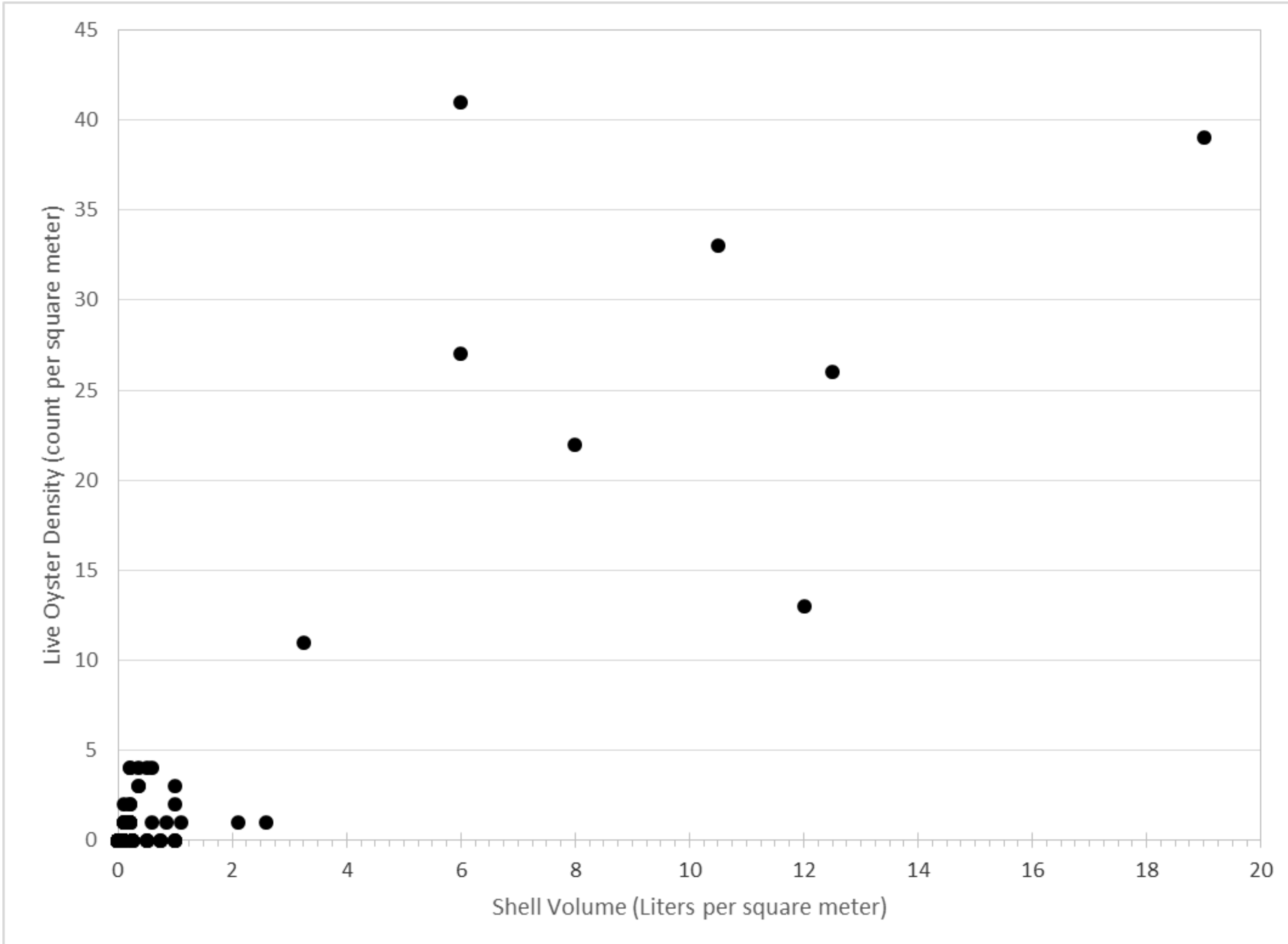


Figure A.20-5. 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Lower Mainstem Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

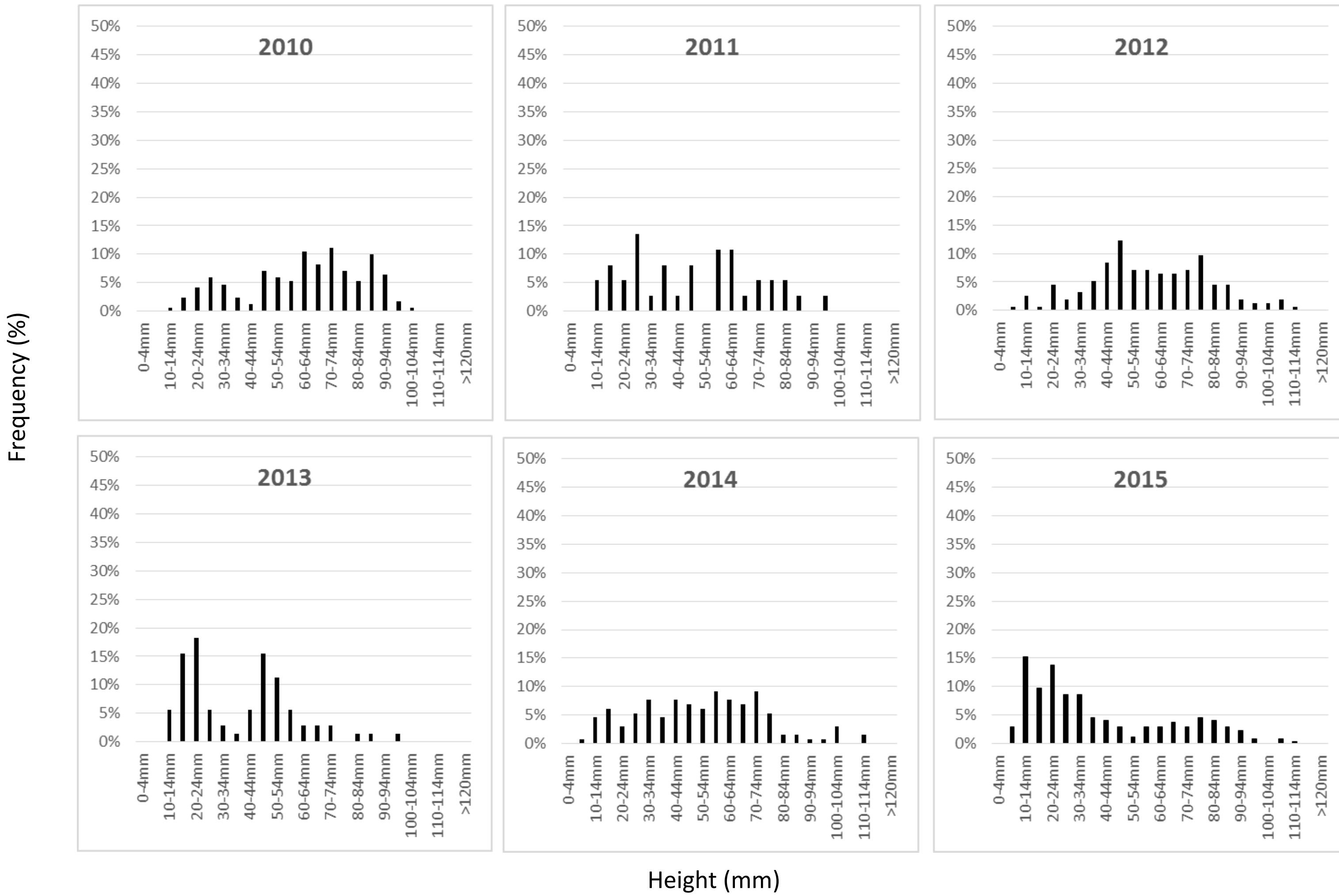


Figure A.20-6. Shell height frequencies of live oysters per bushel of material from 2010 to 2015 in the Lower Mainstem Sanctuary established in 2010. Data from Maryland's Annual Fall Oyster Dredge Survey on Northwest Middleground bar. Shell heights were not collected prior to 2010.

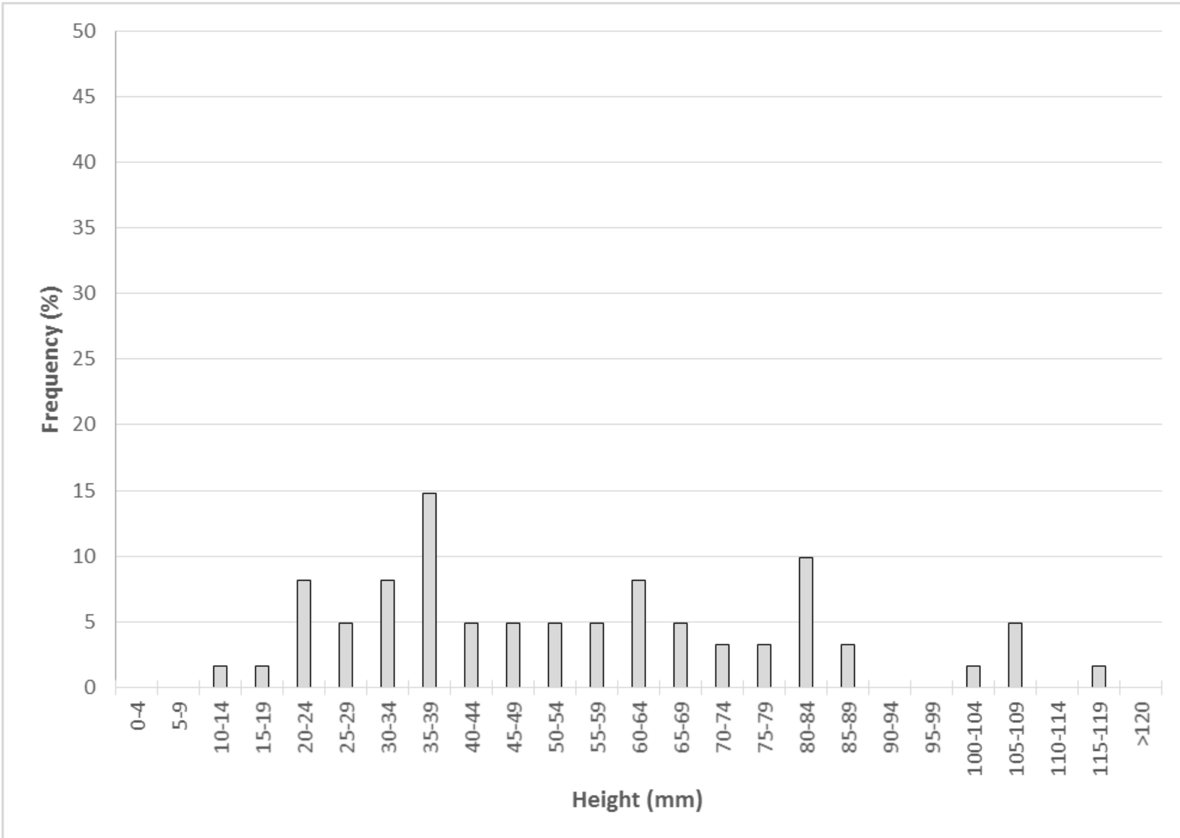


Figure A.20-7. Shell height frequencies of live oysters in the Lower Mainstem Sanctuary in 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

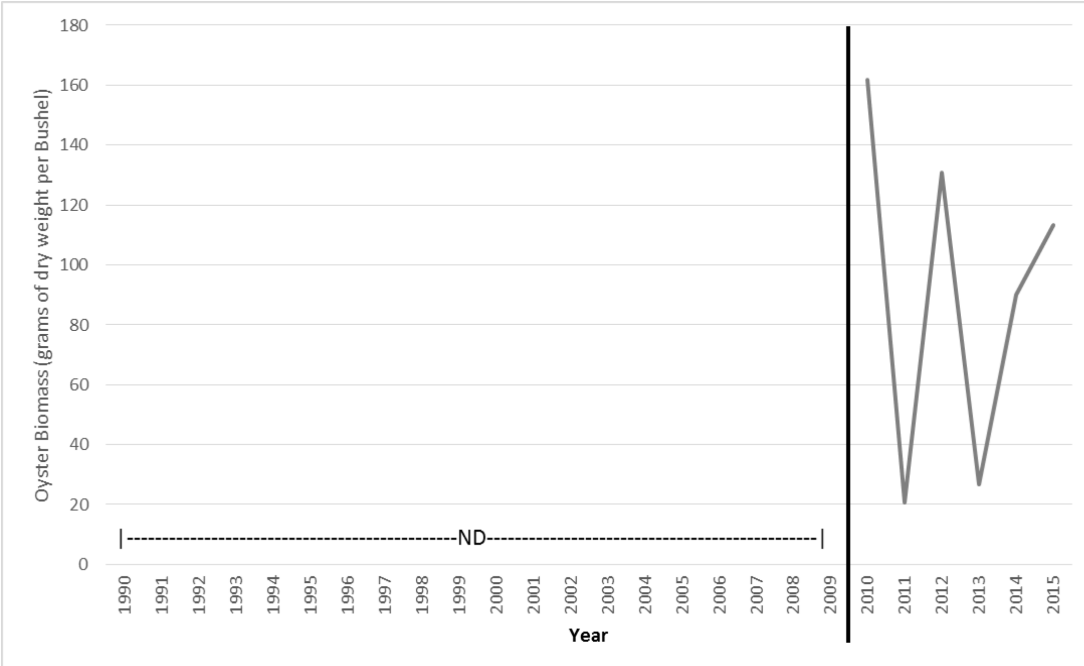


Figure A.20-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Lower Mainstem Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Northwest Middleground bar. Black line indicates the date the sanctuary was established. ND = No Data.

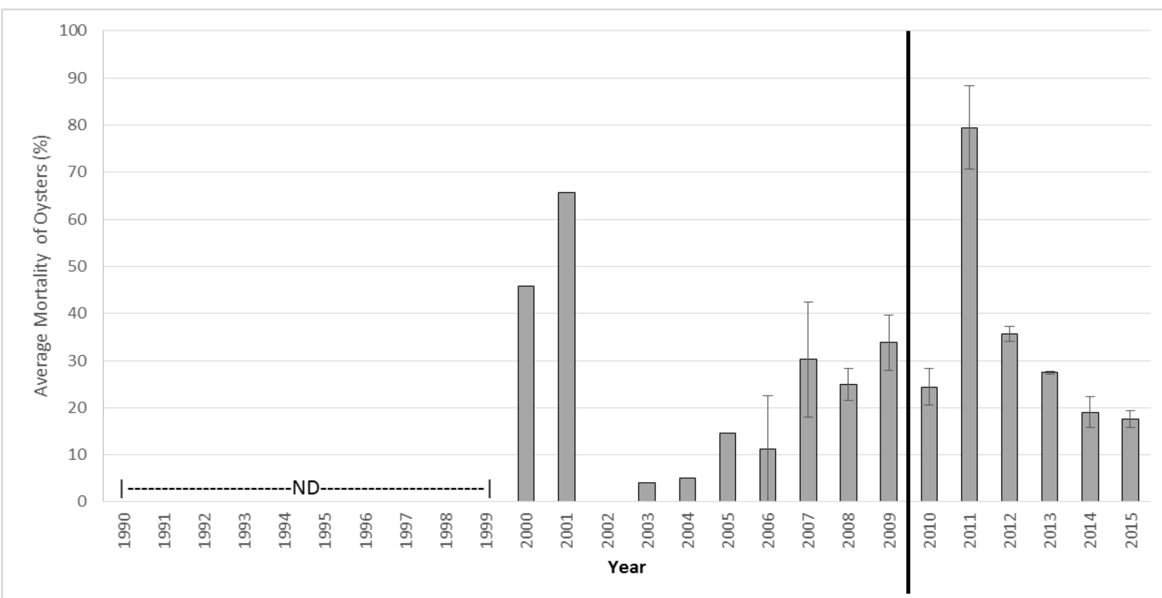


Figure A.20-9. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Lower Mainstem Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error. ND = No Data.

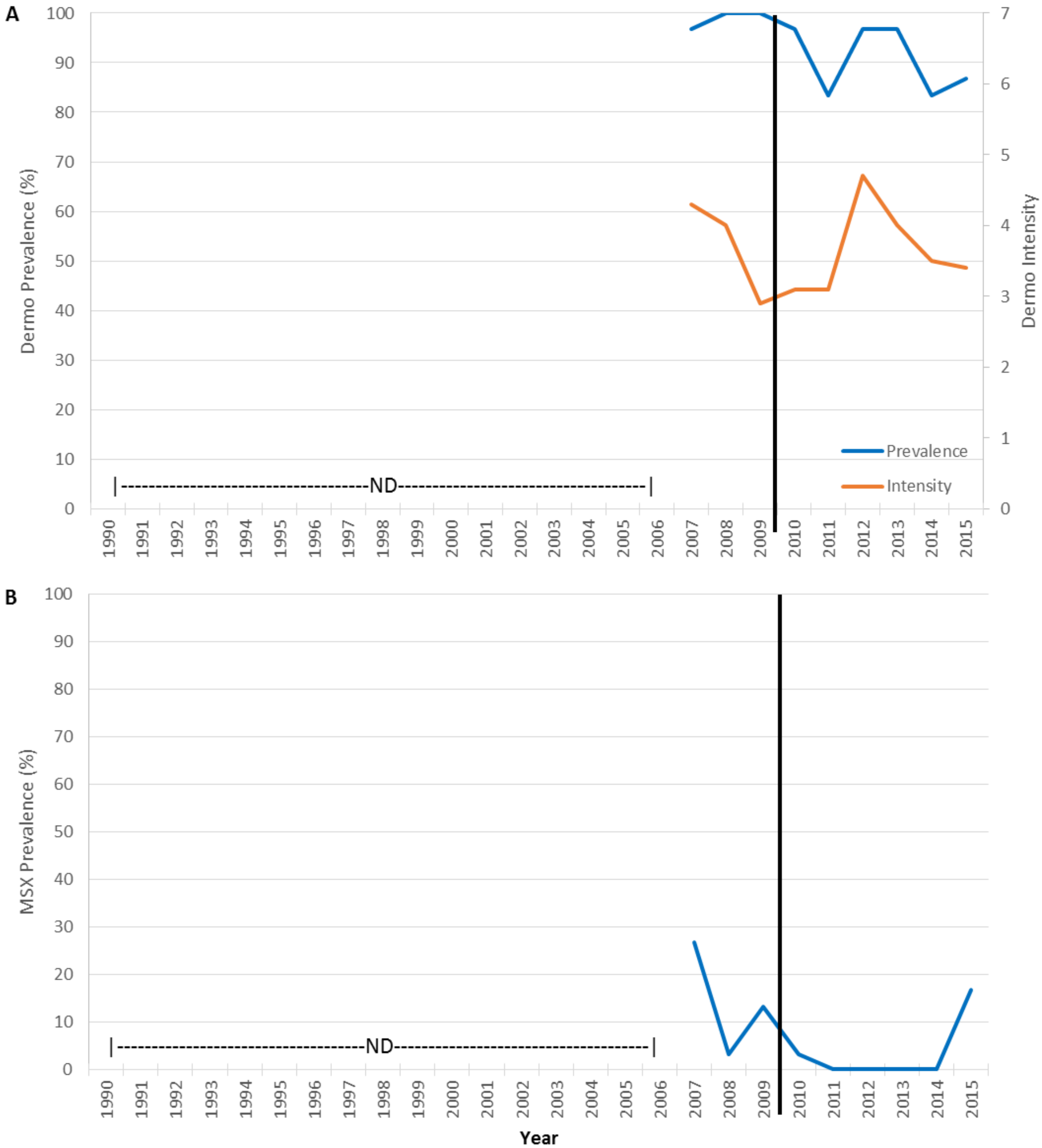


Figure A.20-10. Oyster disease prevalence and intensity from 1990 to 2016 in the Lower Mainstem Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey. ND = No Data.

Harvest

The sanctuary encompasses portions of three NOAA Code Areas (129, 192, and 292), but does not constitute the entirety of any one code area. Therefore, seafood dealer reports cannot be used to say anything about harvest in the sanctuary as the catch in a particular NOAA code may have come from areas outside the sanctuary. Commercial watermen reported no catch from the area that is now the sanctuary prior to its closure to harvest.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining oyster ecosystem services or environmental conditions (e.g. continuous water quality monitoring) in this area.

Section A.21: Lower Patuxent River Sanctuary

The Lower Patuxent River Sanctuary is located on the southern shore of the Patuxent River near the river's mouth, a medium salinity (12 to 14 ppt) region (Figure A.21-1). The sanctuary was created in 2010 and encompasses 335 acres of which 315 (94%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 2 historic oyster bars within the sanctuary.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.21-2). Of the 334 acres surveyed within the sanctuary, 247 (74%) were classified as oyster reef habitat. In 2011 Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 288 acres surveyed in 2011, 7.9 acres (3%) were classified as oyster reef habitat, indicating a substantial loss of habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

No replenishment or restoration activities have occurred in this area since 1990.

Oyster Population Characteristics

No Fall Survey samples have been collected in this area since 1990.

A patent tong population survey was conducted in the sanctuary 2015 (Figures A.21-3). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 1.38 ± 0.84 oysters m^{-2} (mean ± standard error, n= 26). Most of the samples (85%) had no live oysters or boxes. Live oyster density increased with volume of shell (Figure A.21.4).

Shell heights were measured during the patent tong population survey (Figure A.21-5). Spat, small, and market-sized oysters were all represented in the samples.

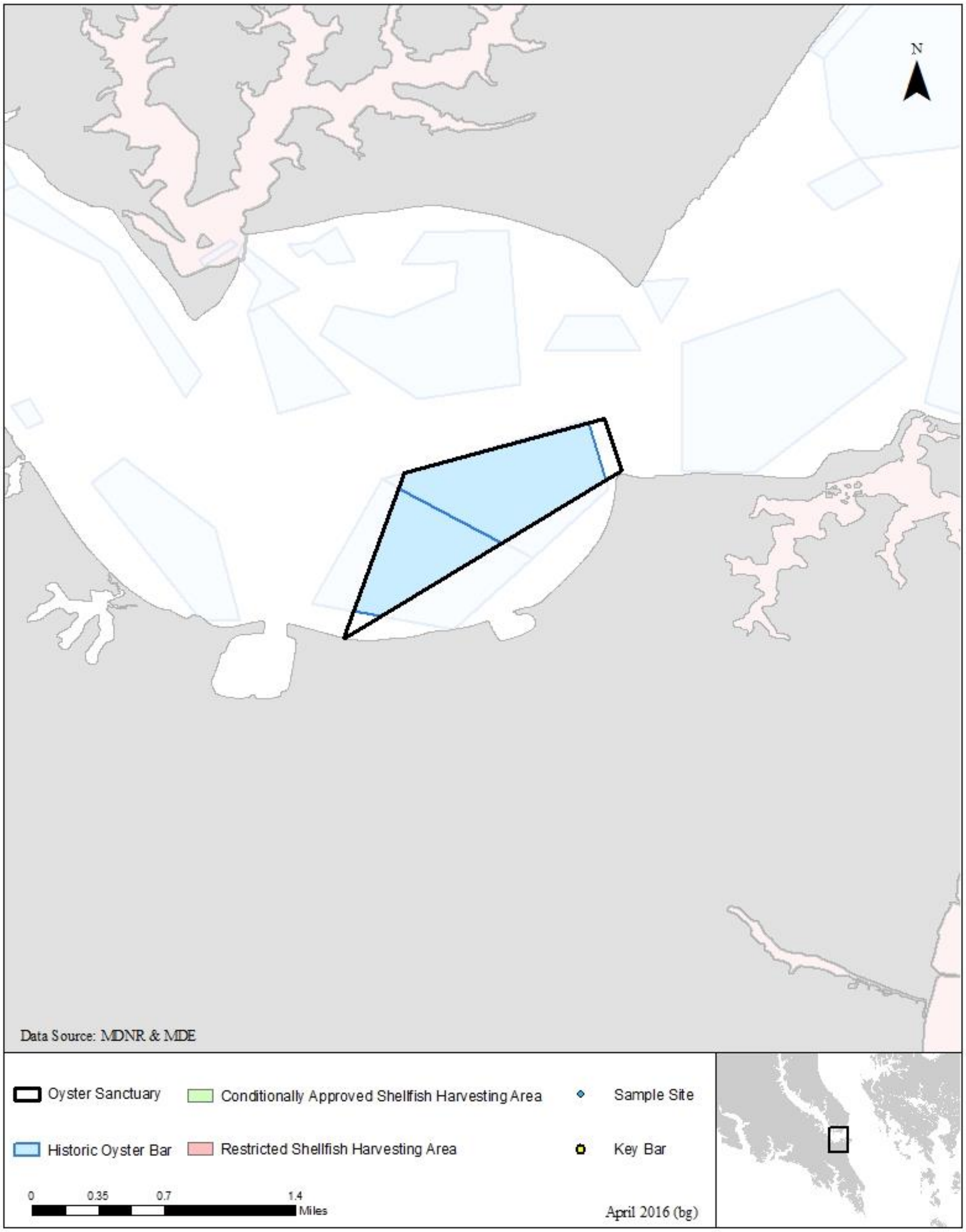
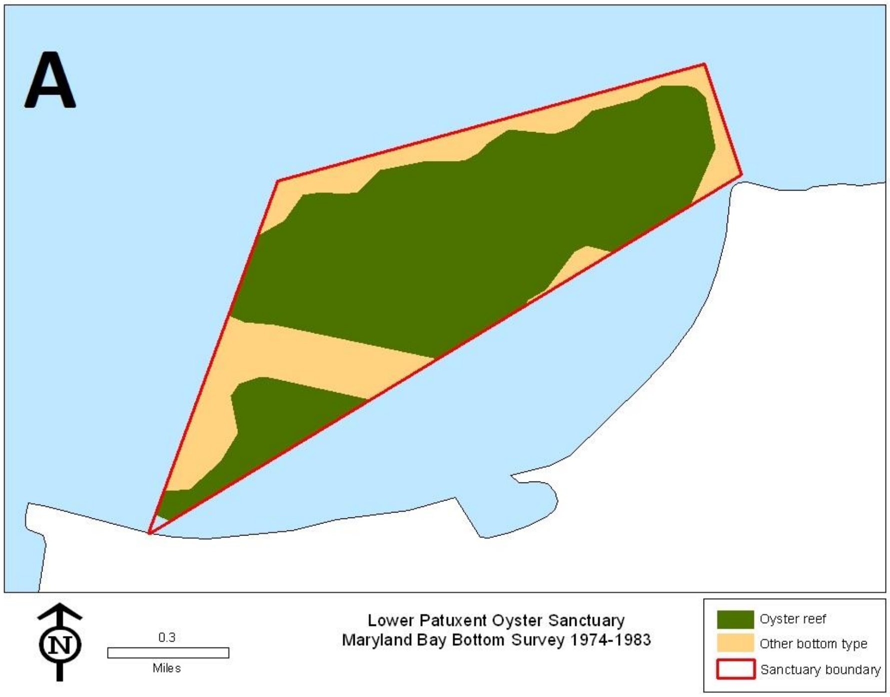


Figure A.21 -1. Lower Patuxent River Sanctuary.



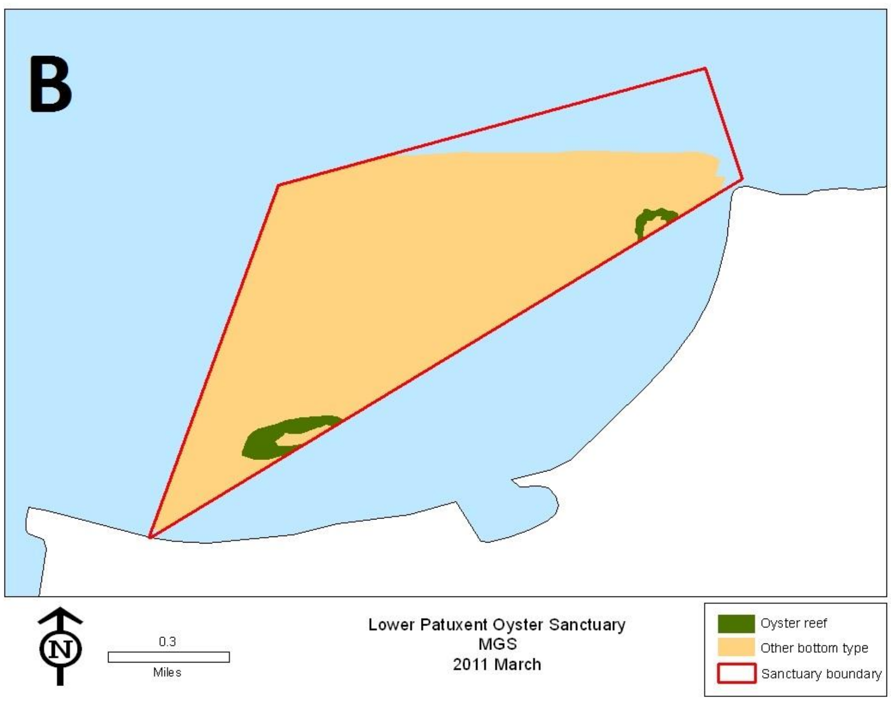


Figure A.21 -2. Lower Patuxent River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2011. Tan and green colored areas depict areas examined during the surveys.

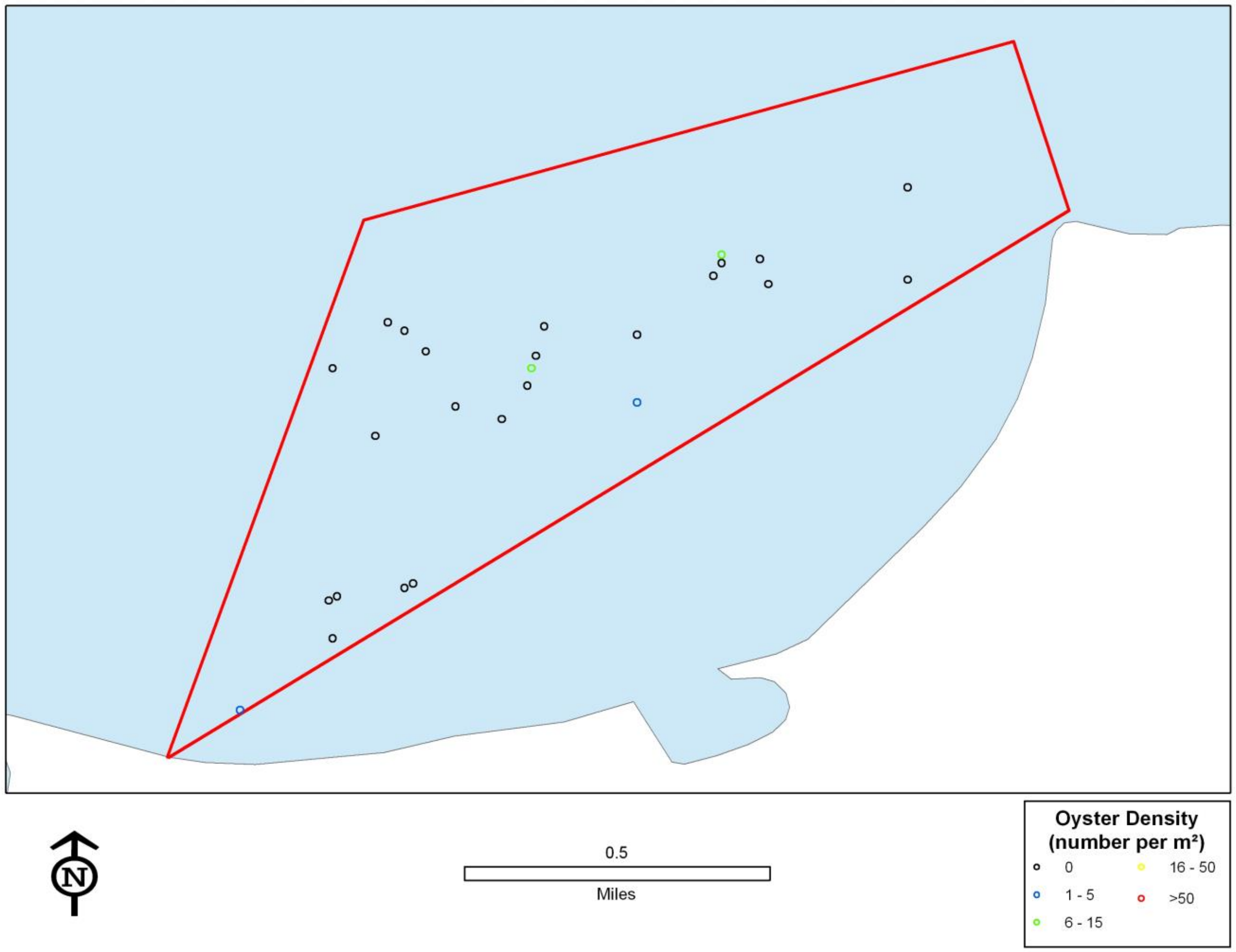


Figure A.21-3. Map of 2015 oyster density in the Lower Patuxent River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

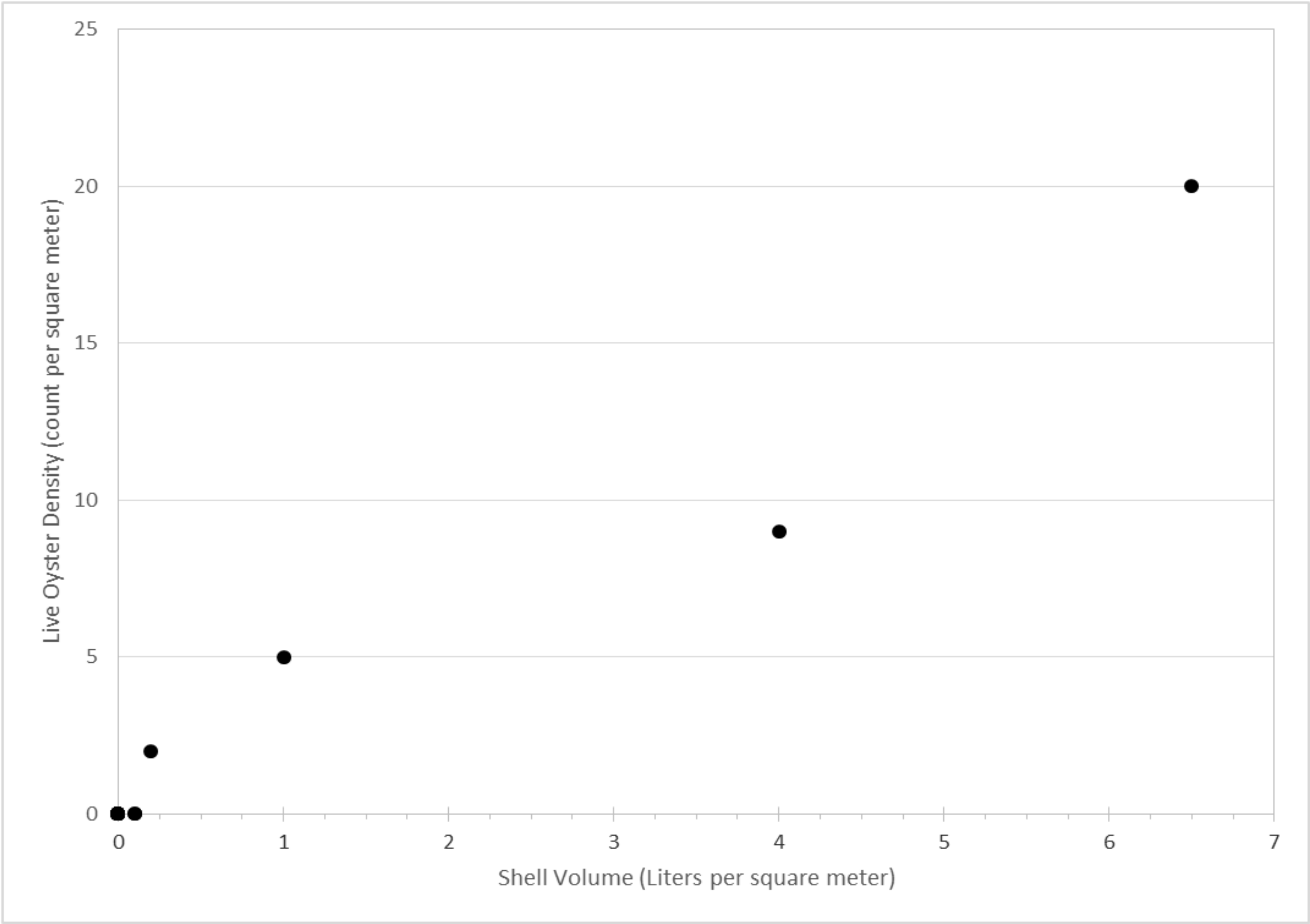


Figure A.21-4. 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Lower Patuxent River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

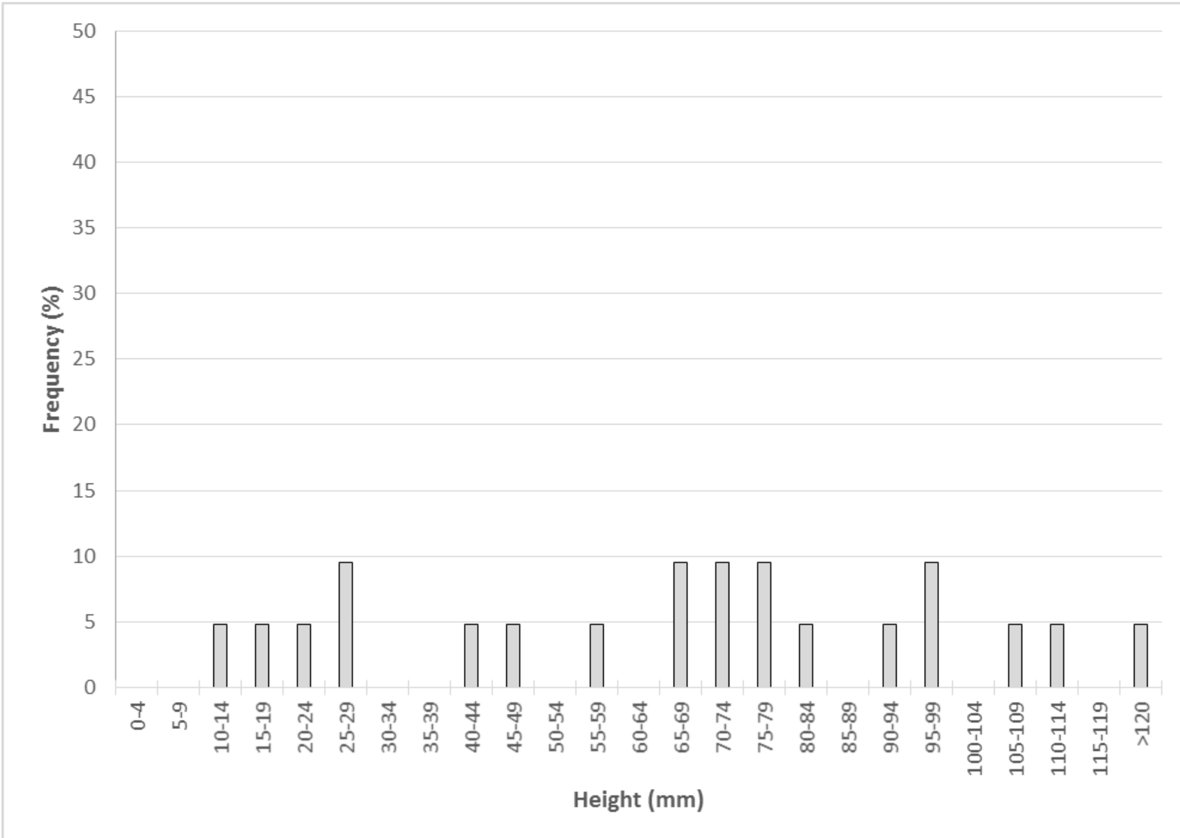


Figure A.21-4. Shell height frequencies of live oysters in the Lower Patuxent River Sanctuary in 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

Harvest

The sanctuary encompasses 4% of the 8,880 acres in NOAA Code 168. Because harvest reported for NOAA Code 168 may have from areas outside the sanctuary, seafood dealer reports cannot be used to assess harvest in this area. Oyster harvester reports show a catch of 29 bushels on bars in this area for the 2009-2010 season, the last season this area was open for harvest.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.22: Magothy River Sanctuary

The Magothy River Sanctuary is located in the Magothy River, a low salinity (less than 12 ppt) region. (Figure A.22-1). The sanctuary was created in 2010 and encompasses 5,607 acres of which 230 (4%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 8 historic oyster bars within the sanctuary[52].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.22-2). Of the 2,686 acres surveyed within the sanctuary, 2,257 (84%) were classified as oyster reef habitat. Between 2006 and 2008 NOAA conducted a sonar survey of the area. Of the 4,186 acres surveyed by NOAA, 544 acres (13%) were classified as oyster reef habitat. Comparing the areas examined by both surveys, there appears to be a substantial loss of habitat since the Bay Bottom Survey was conducted.

Restoration and Replenishment Activities

Replenishment efforts to enhance the public fishery occurred in this area prior to 2010 (Table A.22-1). Since 1990, approximately 94,000 bushels of dredged shell and 27.7 million hatchery spat-on-shell have been planted. No wild seed has been planted since 1990. The reserve was never opened to harvest, so all the plantings were effectively restoration efforts.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 550 cages and planted approximately 165,000 oysters.

Table A.22-1. Replenishment planting activities occurring since 1990 in the area of the Magothy River Sanctuary. ND = No Data.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1998	Dredged Shell	3.33	34.00	-
1999	Dredged Shell	8.34	60.12	-
1999	Hatchery Spat-on-Shell	6.3	-	4.21
2001	Hatchery Spat-on-Shell	0.46	15.86	1.31
2004	Hatchery Spat-on-Shell	ND	-	0.06
2006	Hatchery Spat-on-Shell	2.94	-	2.74
2008	Hatchery Spat-on-Shell	13.98	-	15.13
2009	Hatchery Spat-on-Shell	3.67	-	4.33

[52] See chart 6 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

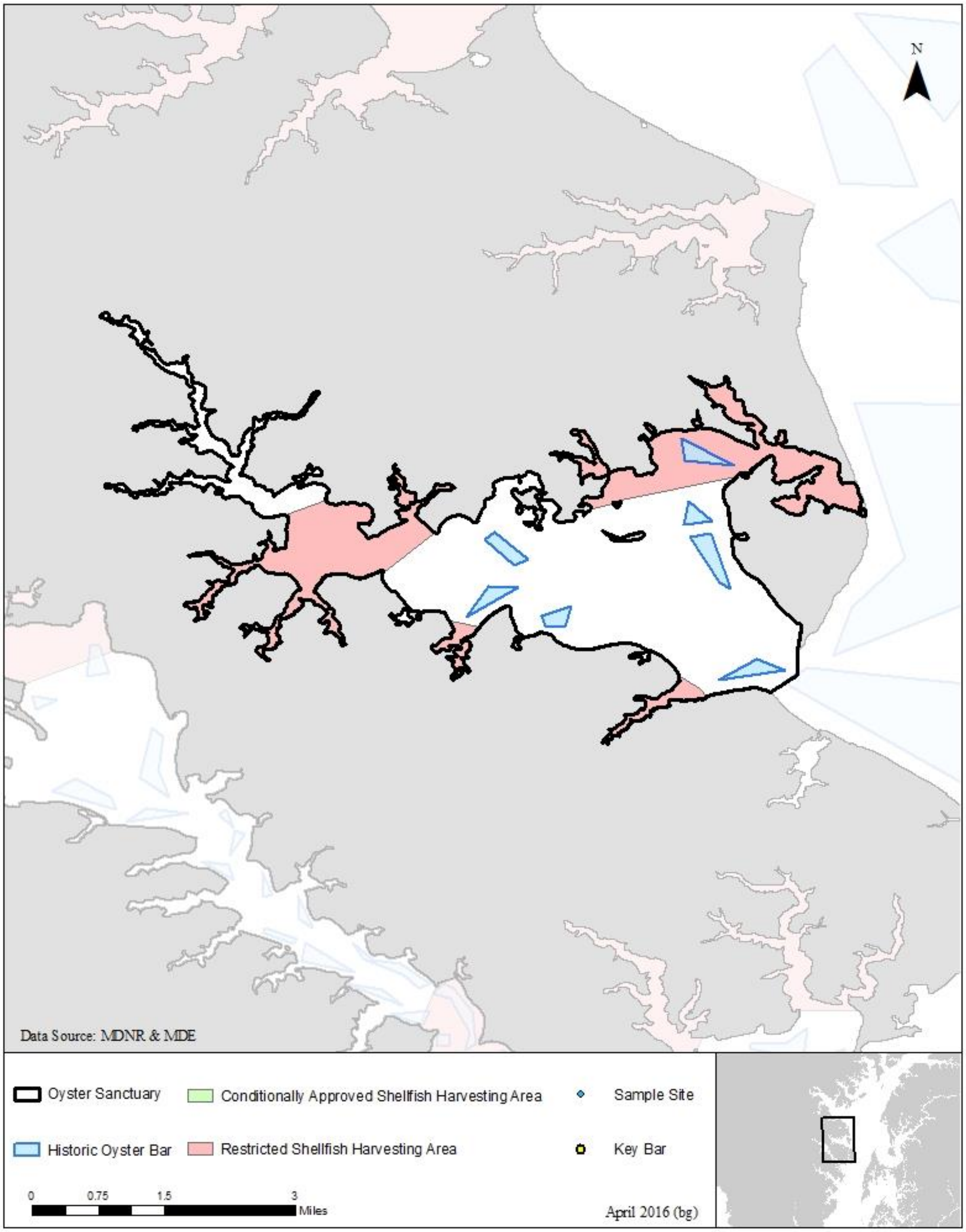


Figure A.22 -1. Magothy River Sanctuary.

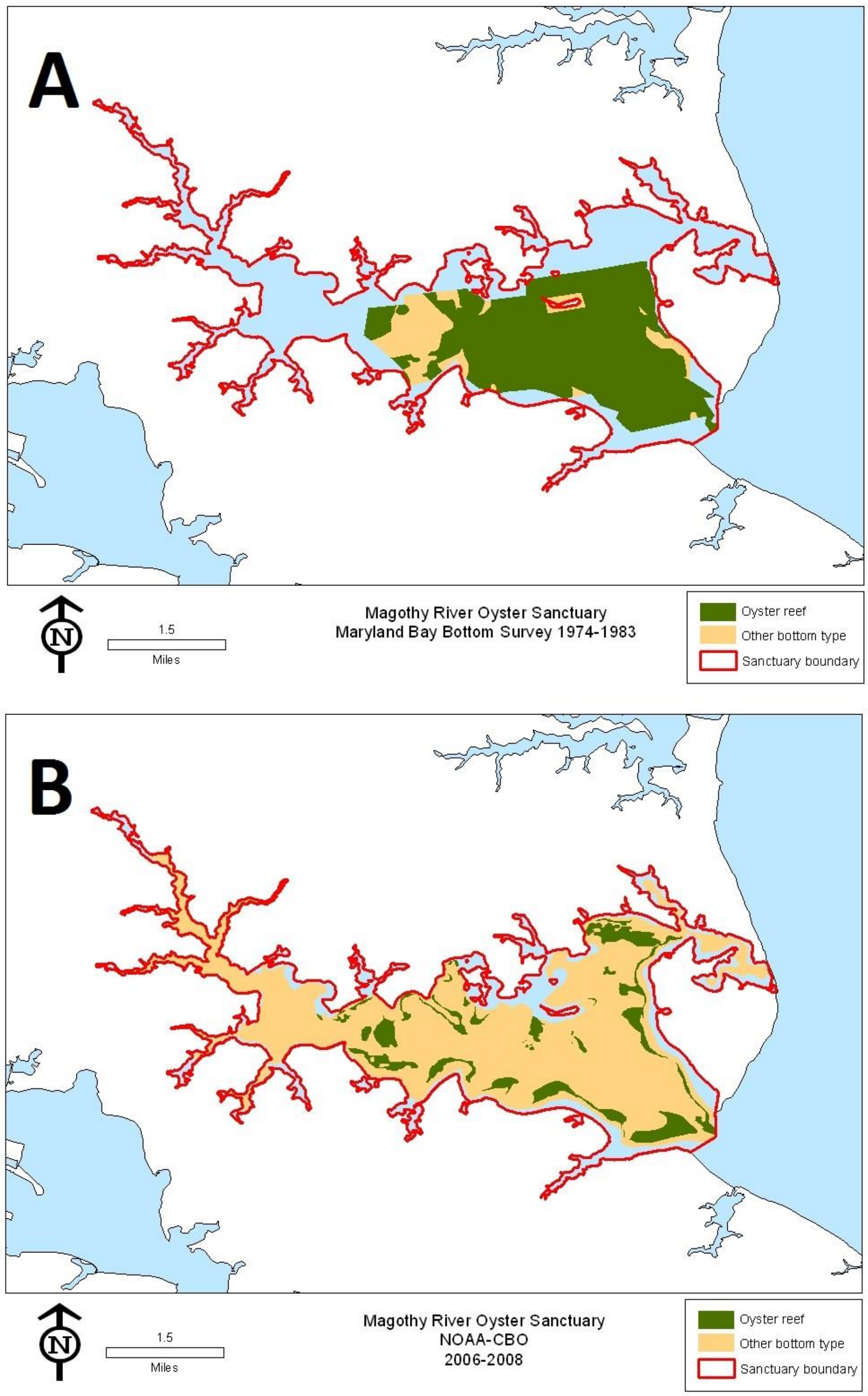


Figure A.22 -2. Magothy River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from NOAA Chesapeake Bay Office from 2006-2008. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has not sampled any oyster bars in this area since 1990, and no patent tong population surveys have been conducted by the Department.

Paynter and colleagues monitored hatchery plantings in the Magothy River and found densities as low as 2 and as high as 50.3 oysters m^{-2} two years after planting. They found a density of 16.6 oysters m^{-2} on a nine year old planting.[53,54,55]

Oyster Size Structure

Monitoring hatchery plantings, Paynter et al. found average oyster heights to be 65 mm one year post planting up to 128.4 mm nine years post-planting.

Biomass

Paynter et al. found an average biomass of 7 g m^{-2} on a hatchery planting five years after placement.[56]

Recruitment

We are unaware of any studies explicitly examining oyster recruitment in this area.

Mortality

We are unaware of any studies explicitly examining mortality services in this area.

Disease

Paynter and colleagues have been monitoring dermo disease on hatchery plantings. The highest dermo prevalence observed was 33.3% in 2010 on a one-year-old planting.

[53] Paynter, K.T. 2011. 2008 Sanctuary Assessment. Report to the U.S. Army Corps of Engineers, Baltimore District. 67 pp. http://www.nab.usace.army.mil/Portals/63/docs/Environmental/Oysters/2008SanctuaryAssessment.pdf

[54] H. Lane, A. Michaelis, and K.T. Paynter. 2011. Oyster Restoration Monitoring 2010. Report submitted to the Oyster Recovery Partnership.87 pp.

[55] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

[56] IBID

Harvest

The sanctuary encompasses 79% of the 7,098 acres in NOAA Code 055. Harvest reported by seafood dealers prior to the establishment of the sanctuary peaked in the 1999-2000 season at 133 bushels (Figure A.22-3). Watermen reported no catch from this area since the inception of harvester reporting in the 2009-2010 season.

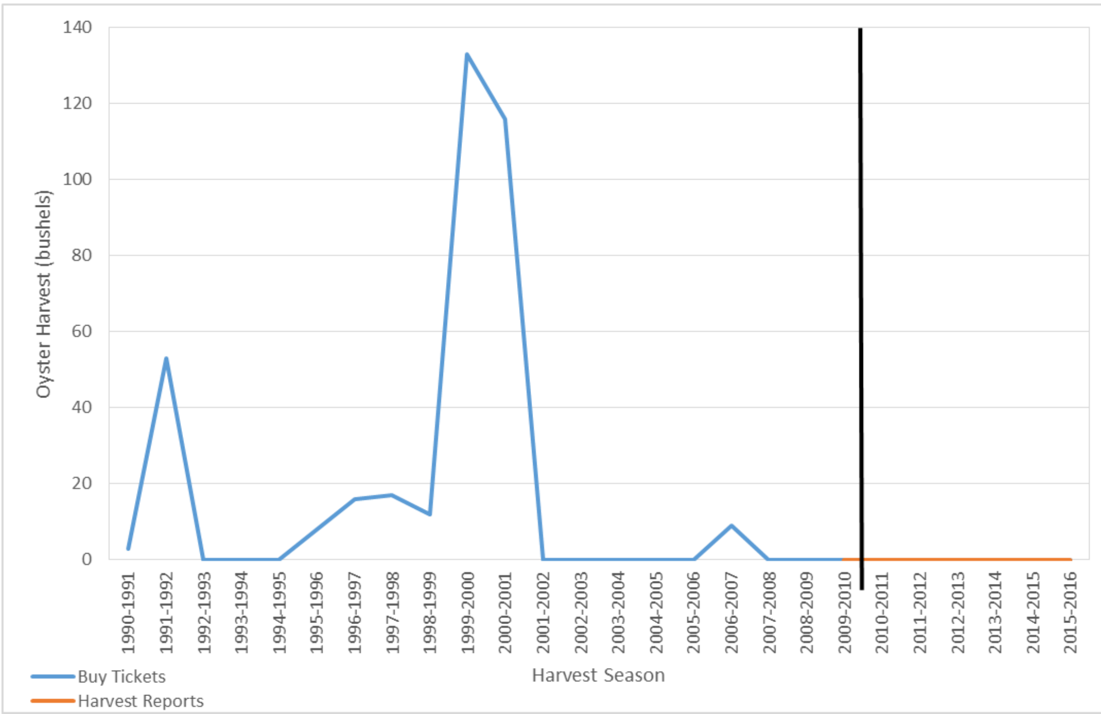


Figure A.22-3. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 055 (Magothy River). In 2010, 79% of NOAA Code became an oyster sanctuary (denoted by the black line) where harvest is prohibited.

Environmental Conditions and Ecosystem Services

Maryland's Eyes on the Bay Program monitors monthly water quality at station WT6.1 (39.07851, -76.51005) in this area (Figure A.22-4). Salinities were often too low for oyster reproduction.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

Figure A.22-4. Water quality data collected at Station WT6.1 in Magothy River. Black line denotes the date the sanctuary was established.

Section A.23: Manokin River Sanctuary

The Manokin River Sanctuary is located in the lower eastern portion of Maryland's Chesapeake Bay, a high salinity (greater than 14 ppt) region (Figure A.23-1). The mouth of the river empties into the Tangier Sound. The sanctuary was created in 2010 and encompasses 16,320 acres of which 11,040 (68%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 19 historic oyster bars within the sanctuary[57].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.23-2). Of the 9,360 acres surveyed within the sanctuary, 1,820 (19%) were classified as oyster reef habitat. In 2012 Maryland Geological Survey conducted a side scan sonar survey of a small portion of the Calvert Shore Sanctuary. Of the 5,851 acres surveyed in 2012, 391 acres (7%) were classified as oyster reef habitat. Different spatial coverage between the Bay Bottom Survey and Maryland Geological Survey's side scan sonar work in the Manokin River Sanctuary precludes comparison of the two surveys.

Restoration and Replenishment Activities

Since 1990, 48.5 acres have been planted with 215,507 bushels of dredged and fresh shell to enhance the public fishery. Wild seed was transplanted into Manokin River in 1999 (Table A.23-1). No restoration efforts have taken place in the sanctuary since it was established in 2010.

Table A.23-1. Replenishment planting activities occurring since 1990 in the area of the Manokin Sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Dredged Shell	11.3	59	-
1998	Dredged Shell	24.6	49	-
1999	Wild Seed	5.5	4	-
2001	Fresh Shell	12.6	107	-

[57] See chart 44 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

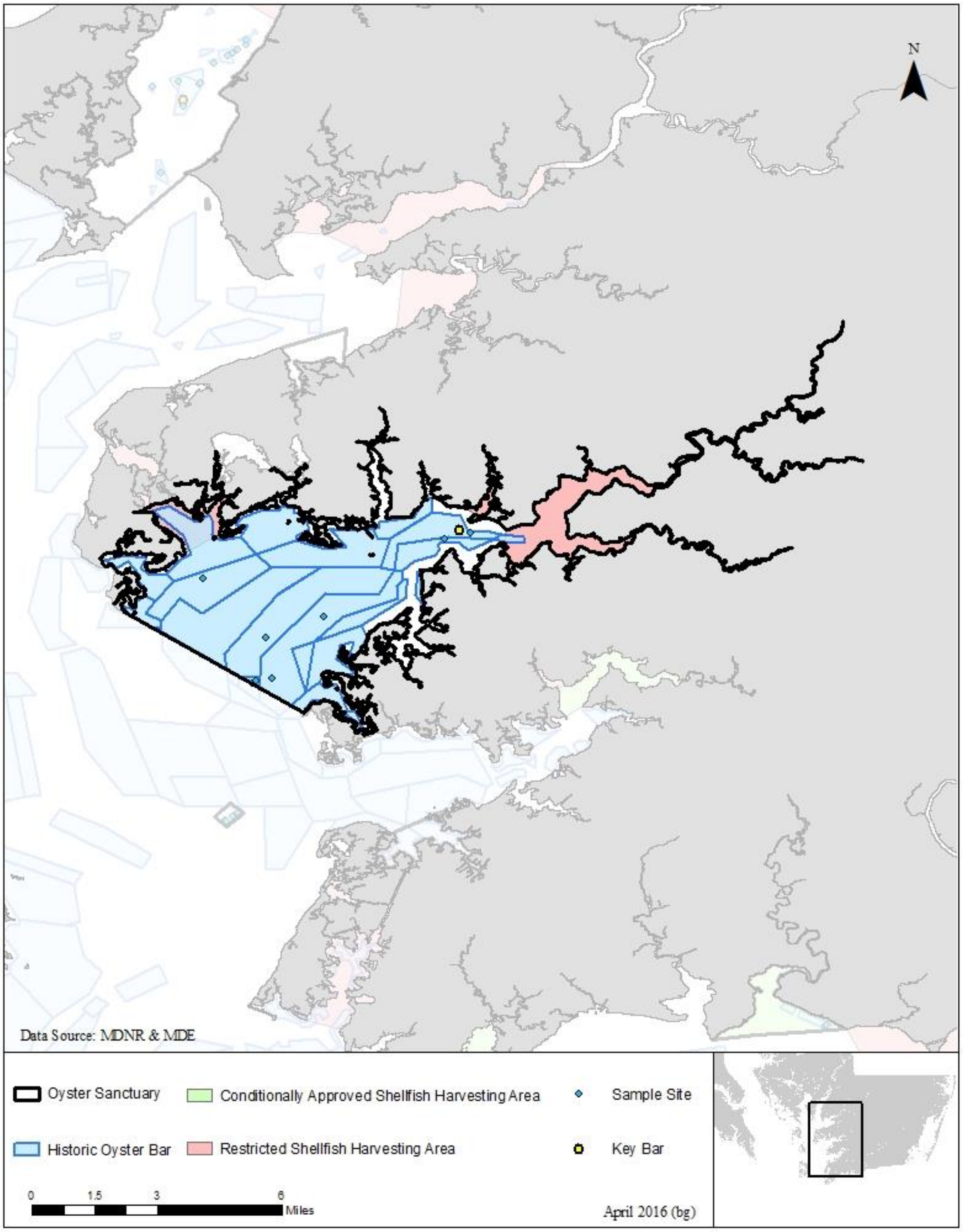


Figure A.23 -1. Manokin River Sanctuary.

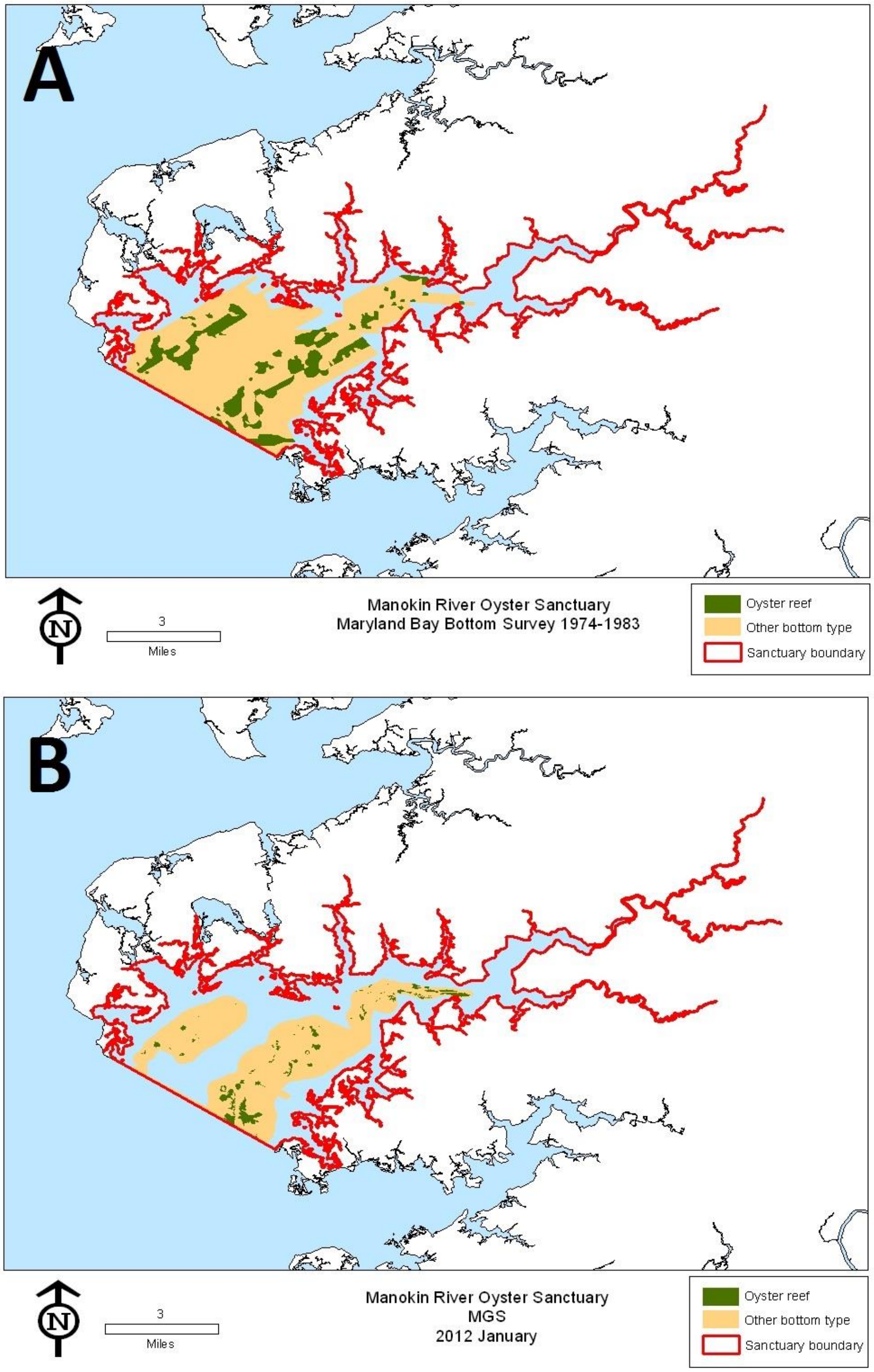


Figure A.23 -2. Manokin River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2012. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled five to eight oyster bars in this area since 1990 with an average of six oyster bars sampled annually. The average number of live oysters per bushel (market, small, and spat) was greater after sanctuary establishment than before (Figure A.23-3; Table A.23-2), with numbers of both small and market-sized oysters increasing There has been a steadily increasing number of market-sized oysters since 2010, with the average annual values from 2013-2015 exceeding the highest value from 1990-2009.

Table A.23-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Manokin River Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 124	6 / 38
Number of Live Oysters per Bushel	150 ± 15	400 ± 46
Number of Live Small-Sized Oysters per Bushel	73 ± 12	148 ± 28
Number of Live Market-Sized Oysters per Bushel	16 ± 3	61 ± 15
Live Oyster Biomass (g Dry Weight per Bushel)	52 ± 12	264 ± 56
Mortality (%)	32 ± 4.0	13 ± 1.6

Patent tong population surveys were conducted in 2012 and 2015 (Figures A.23-4 and A.23-5). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 16.03 ± 2.13 oysters m^{-2} (mean ± standard error, n=161) in 2012 and decreased to 9.67 ± 1.60 oysters m^{-2} (n=147). The average density of market-sized oysters increased from 1.29 ± 0.22 oysters m^{-2} in 2012 to 4.05 ± 0.67 oysters m^{-2} in 2015. The density of small-sized oysters decreased from 15.91 ± 2.14 m^{-2} to 4.81 ± 0.92 m^{-2} during the same time period. Oyster density increased with volume of shell present (Figure A.23.6). Half the samples from each survey had no live oysters or boxes.

Oyster Size Structure

The Fall Survey has measured oyster shell heights in this area at one bar (Georges Bar) since 1990 (Figure A.23-7). Shell heights were also measured during the two patent tong population surveys (Figure A.23-8). Shell heights collected at Georges Bar and collected during the two patent tong population surveys increased between 2012 and 2015, with a notable increase of oysters greater than the legal minimum harvest height of 76 millimeters. This increase in height is due to growth of oysters that settled in 2010 and 2012 coupled with the cessation of harvest.

Biomass

Biomass of oysters from Georges bar collected by the Fall Survey increased steadily since 2010, with the highest biomass of 385 grams dry weight per bushel occurring in 2015 (Table A.23-2; Figure A.23-9). The average biomass after sanctuary establishment is greater than before sanctuary establishment. This increase is due to the increase in both size and number of oysters.

Recruitment (Spatfall)

Based on the Fall Survey data, spatfall ranged from 6 to 454 spat per bushel (Figure A.23-4). From 1993 to 1998 there was an extended period of low spatfall. The highest spat counts since 1990 were observed in 2010 and 2012, years of high spat set throughout most of the bay.

Spat density was higher in the 2015 patent tong survey (0.82 ± 0.05 m^{-2}) than in the 2012 survey (0.12 ± 0.14 m^{-2}). Fall survey data show greater spat set in 2012 than 2015, however.

Mortality

Based on Fall Survey box counts, the average mortality before sanctuary establishment was higher than mortality after sanctuary establishment (Table A.23-2; Figure A.23-10).

Disease

From 1990 to 2015, dermo prevalence has ranged from 30% to 100% (Figure A.23-11), with periods of high prevalence (greater than80%) from 1995 to 2007 and 2013 to 2015. Dermo intensity reached 5.2 in 2001 (values greater than5 on a 0 to 7 scale can indicate a lethal level). MSX prevalence ranged from 0% to 40% from 1990 to 2015, and has been low since 2003.

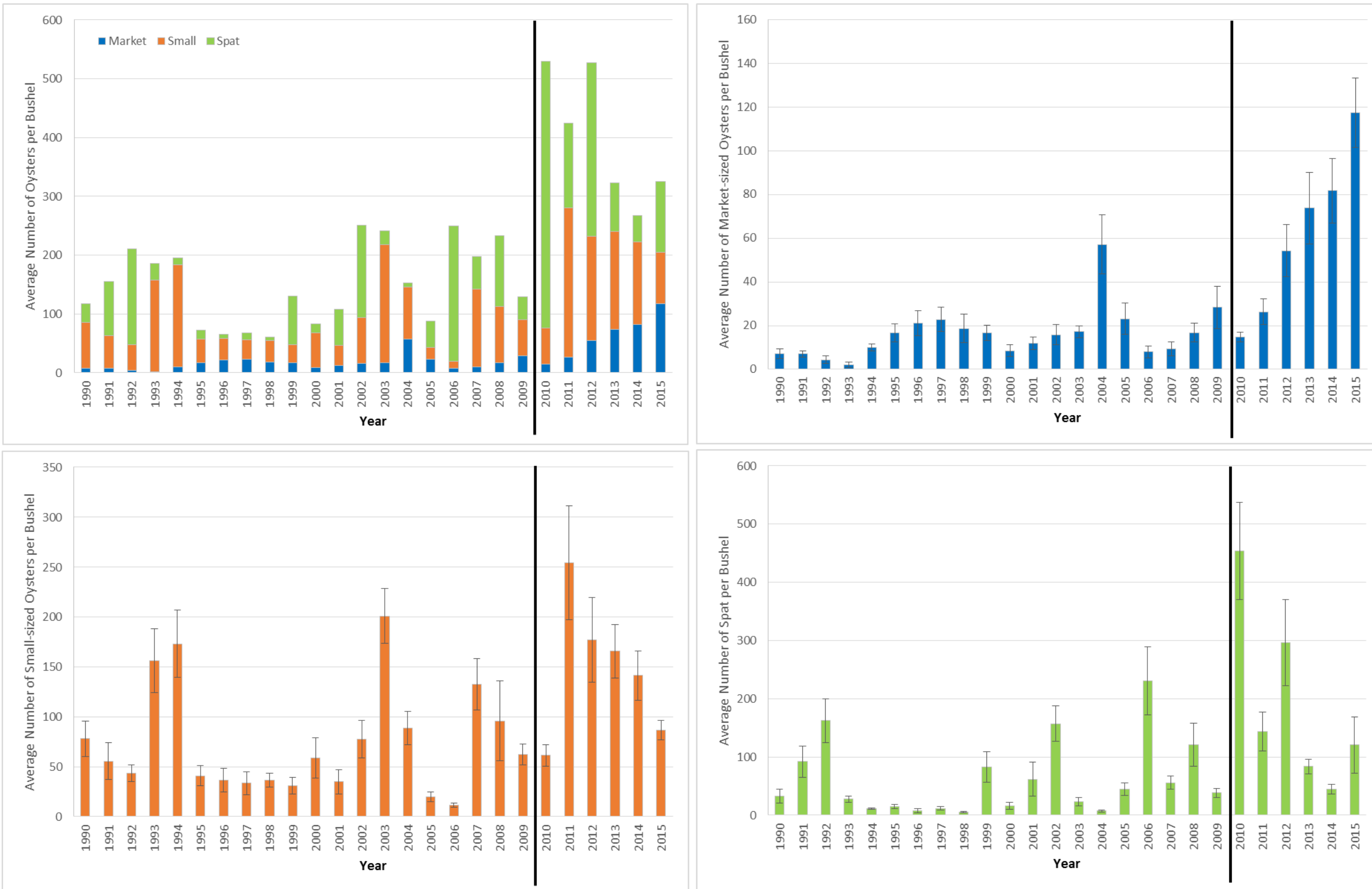


Figure A.23-3. Average number of live oysters per bushel of material by size class in the Manokin River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

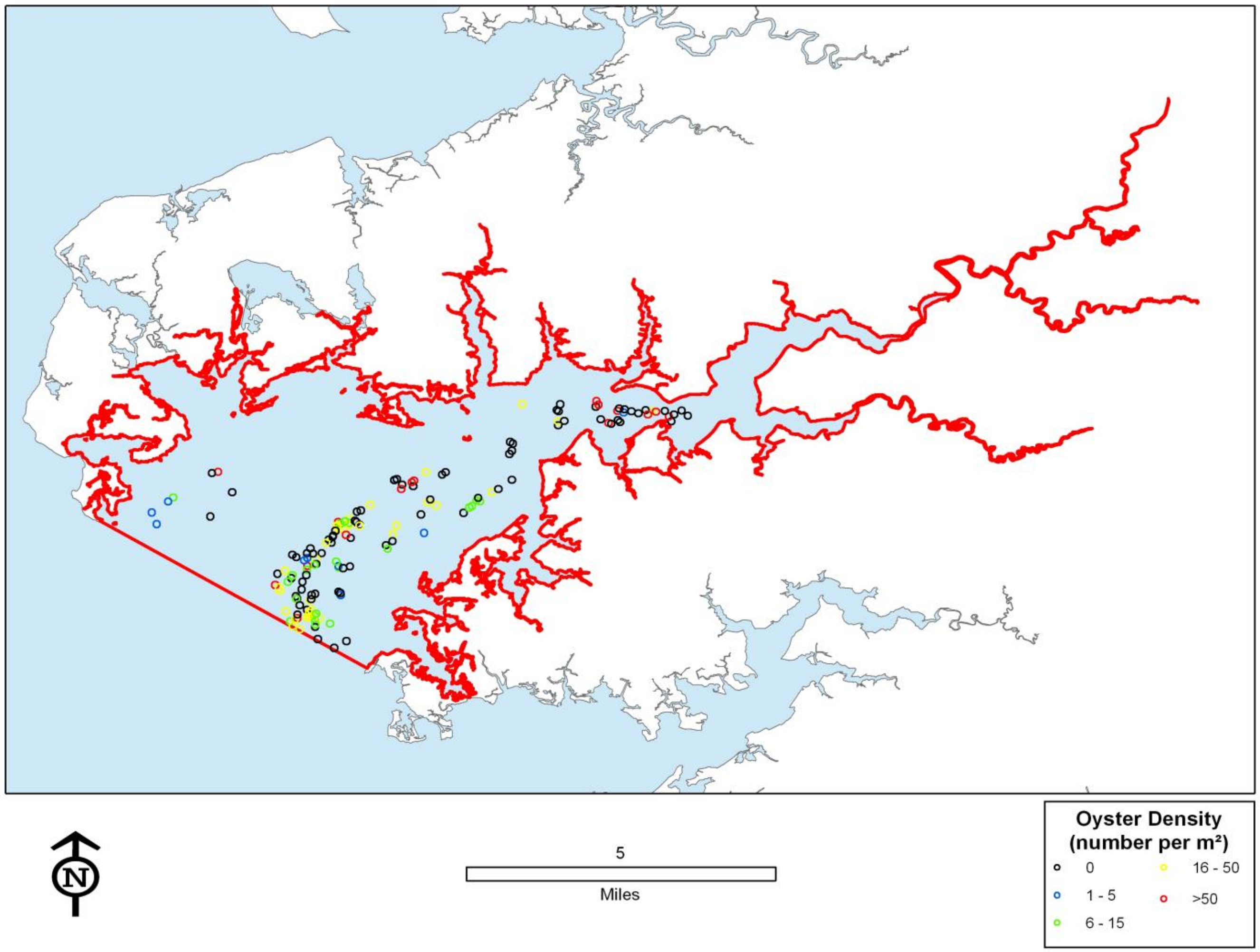


Figure A.23-4. 2012 oyster density in the Manokin River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

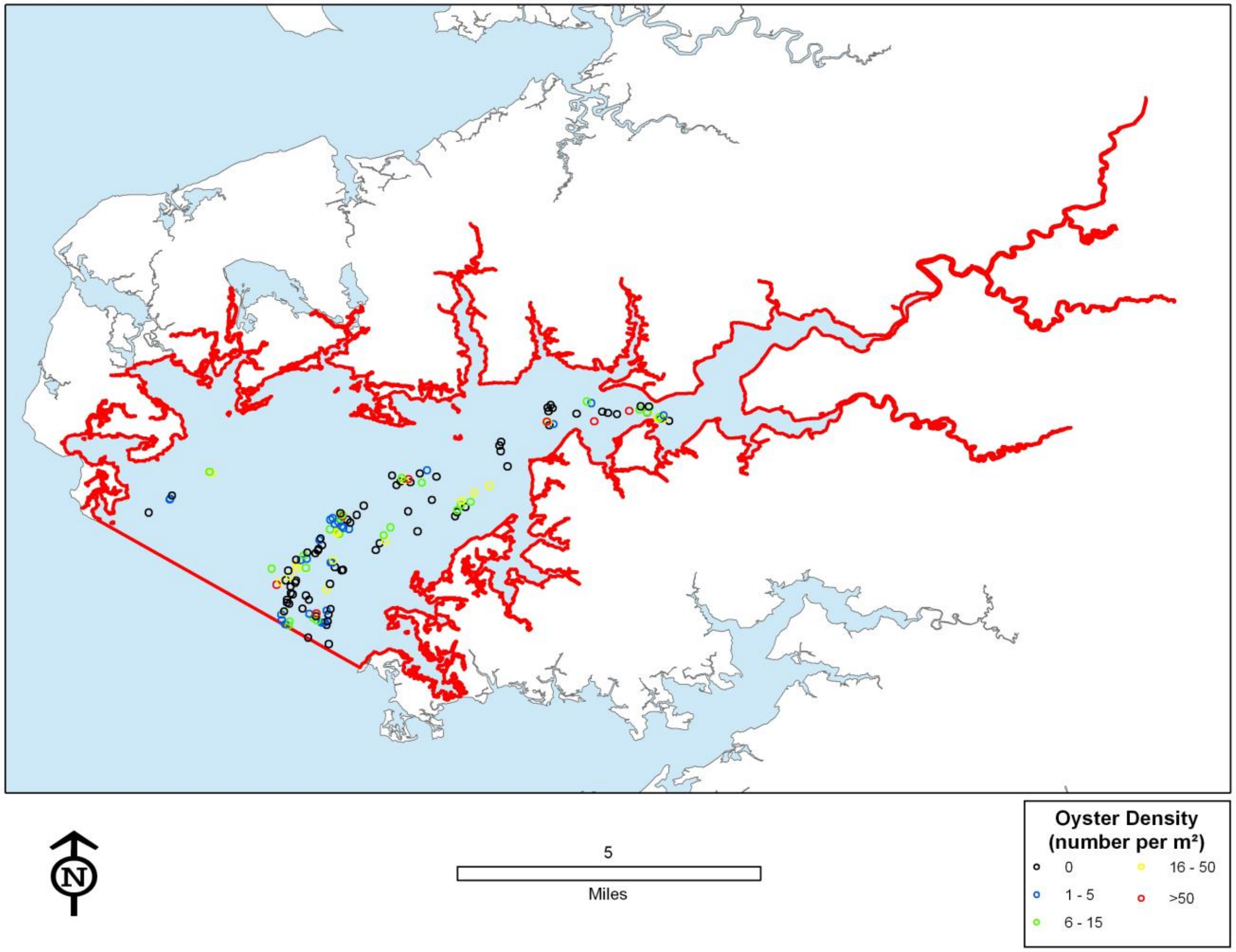


Figure A.23-5. 2015 oyster density in the Manokin River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

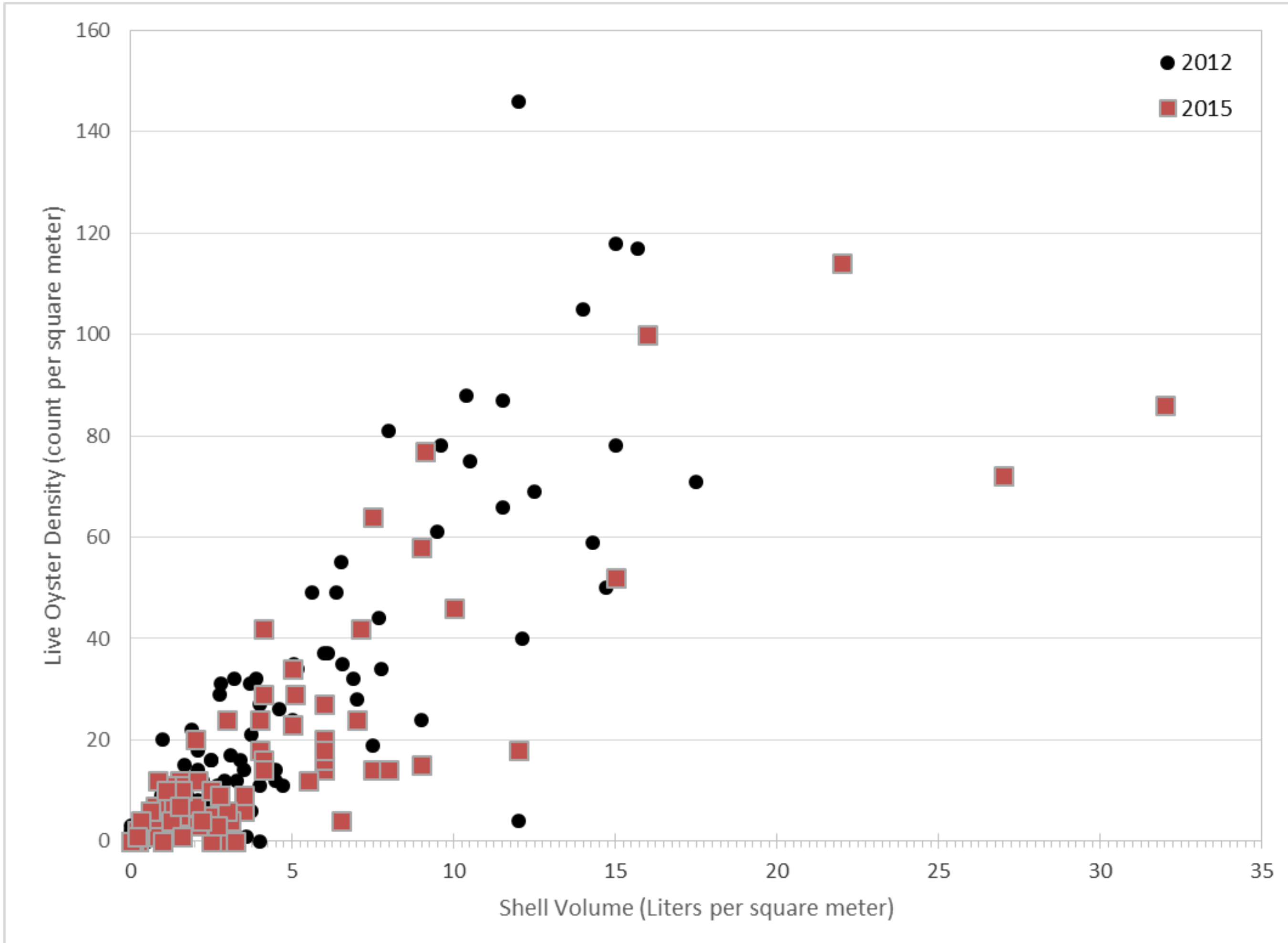


Figure A.23-6. 2012 and 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Manokin River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

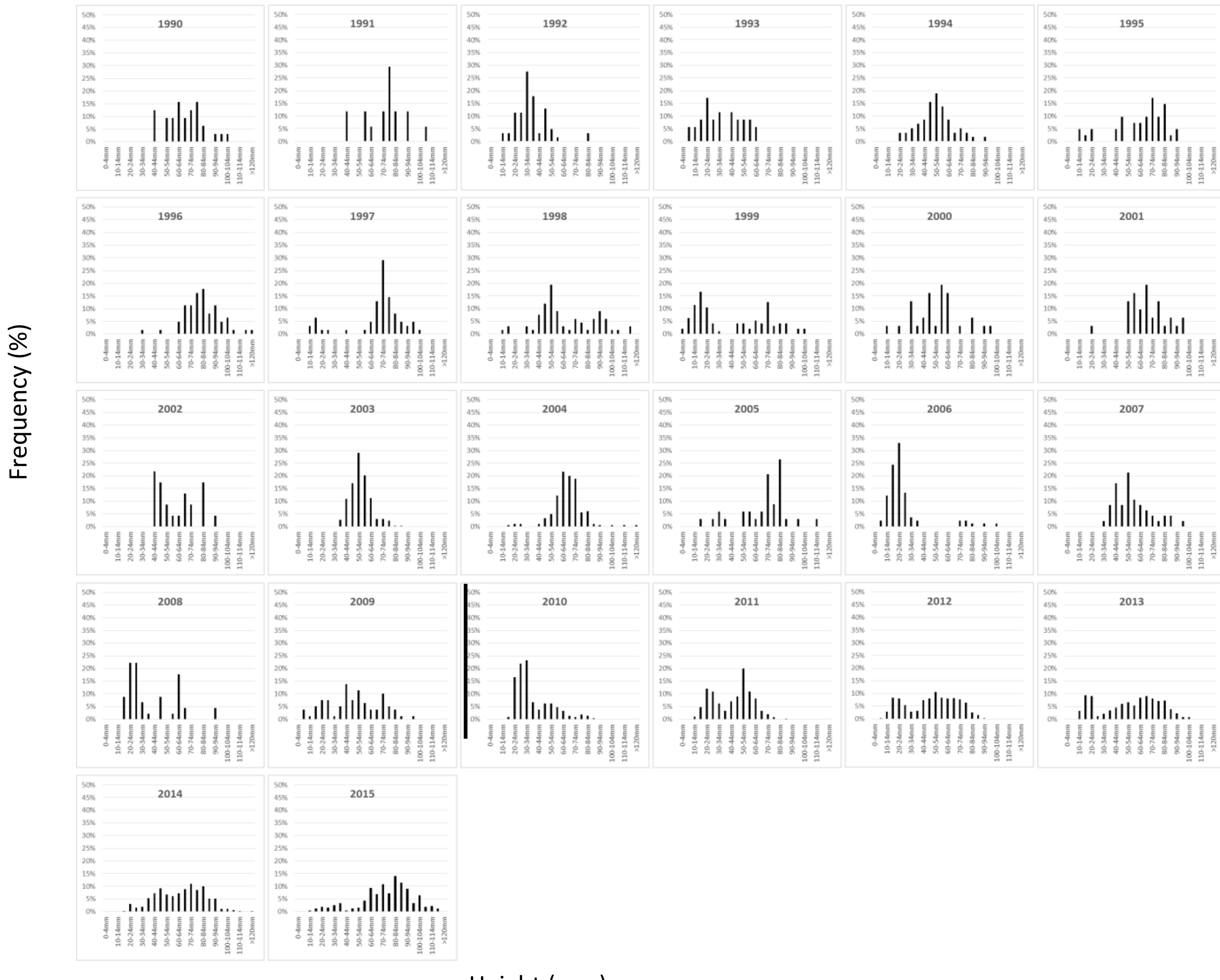


Figure A.23-7. Oyster shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the Manokin River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Georges oyster bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

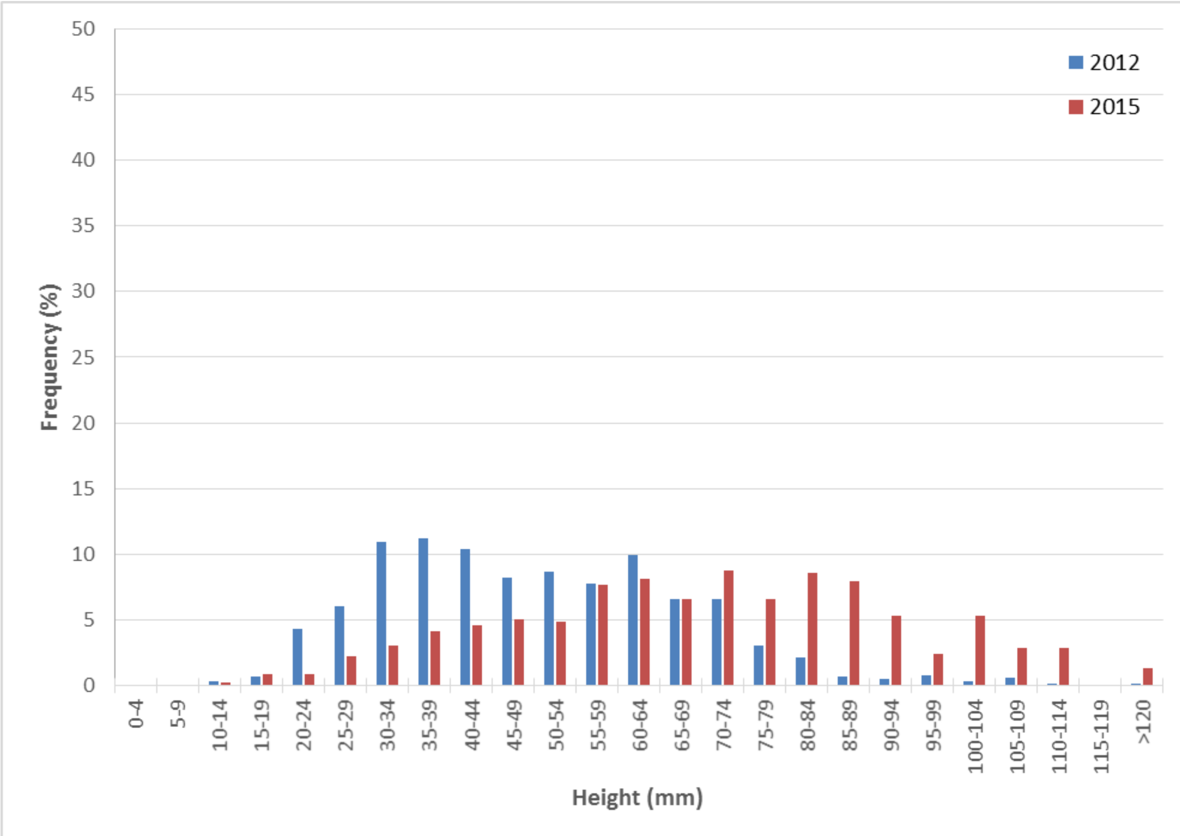


Figure A.23-8. Shell height frequencies of live oysters in the Manokin River Sanctuary, 2012 and 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

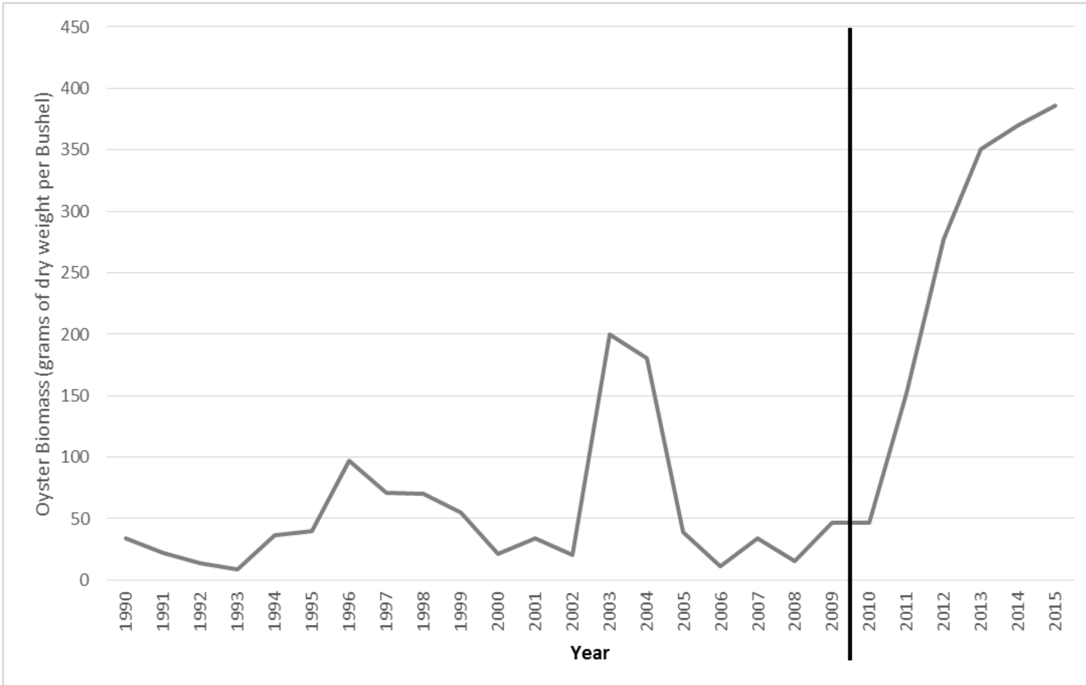


Figure A.23-9. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Manokin River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Georges oyster bar. Black line indicates the date the sanctuary was established.

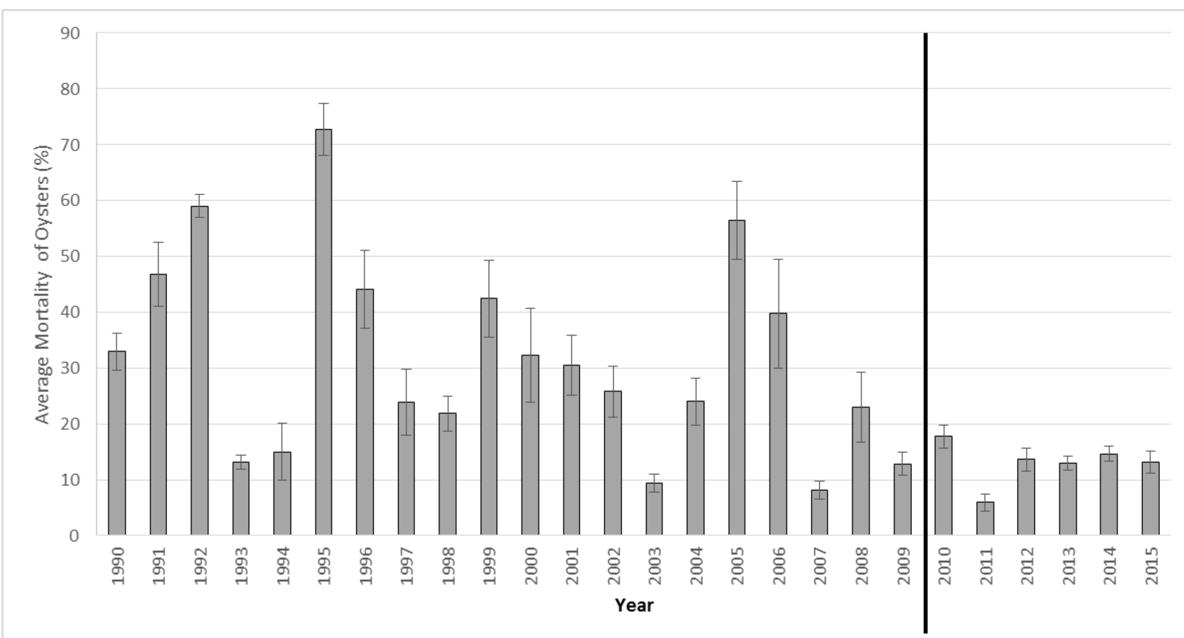


Figure A.23-10. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Manokin River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

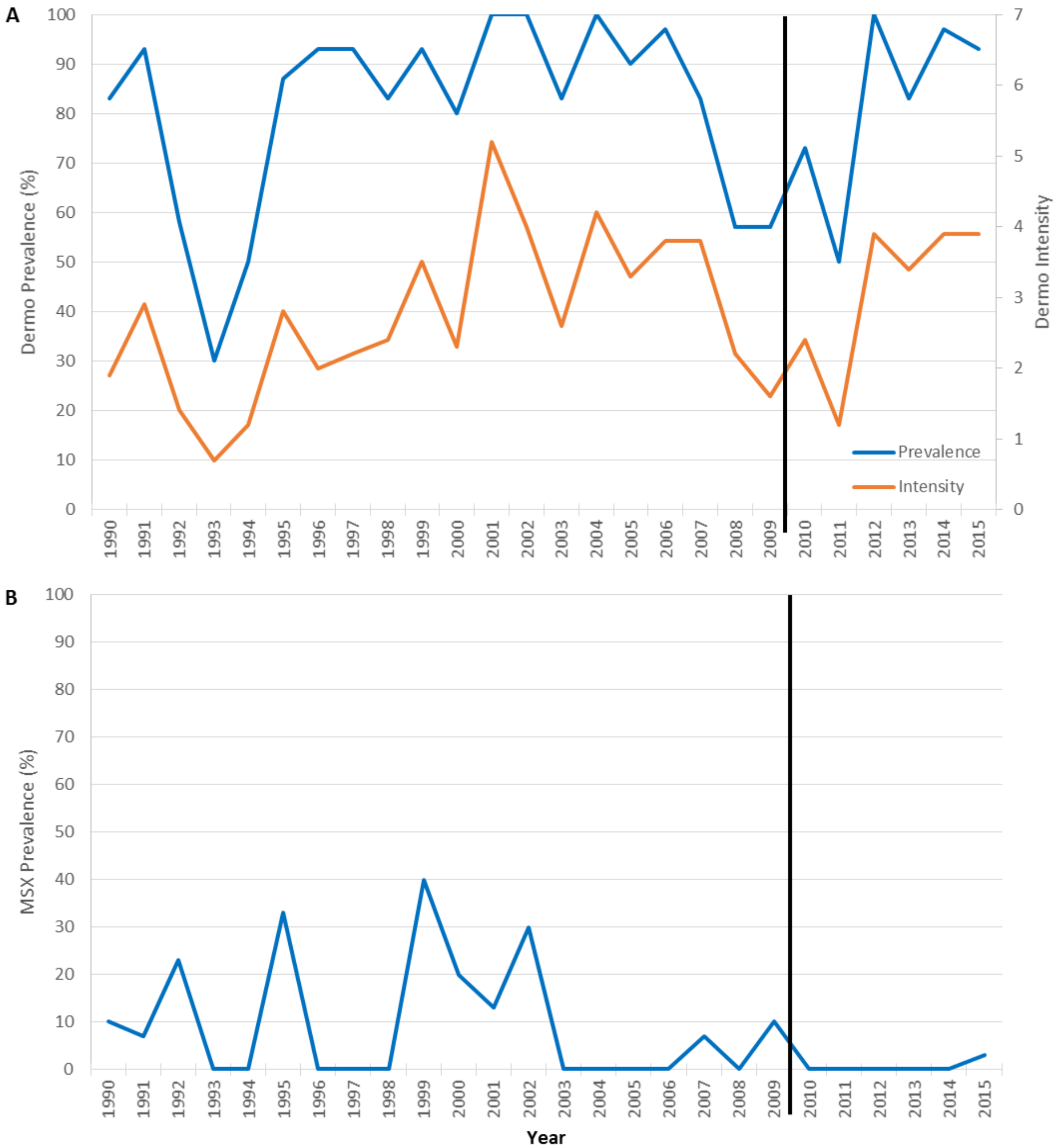


Figure A.23-11. Oyster disease prevalence and intensity from 1990 to 2015 in the Manokin River Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Georges oyster bar.

Harvest

The sanctuary encompasses 82% of the 19,909 acres in NOAA Code 057. Harvest reported by seafood dealers prior to the establishment of the sanctuary peaked in the 2001-2002 season at 4,003 bushels (Figure A.23-12). The average harvest per season from 1990 to 2009 was 700 bushels. In the 2009-2010 harvest season, commercial waterman reported a catch of 5, 490 bushels in the Manokin River.

After the 2009-2010 season, 82% of the NOAA Code area was a sanctuary where harvest is prohibited. In the 2014-2015 season, harvest from the non-sanctuary area peaked at between 3,010 bushels. Based on seafood dealer reports, this is the highest harvest since the 2000-2001 season.

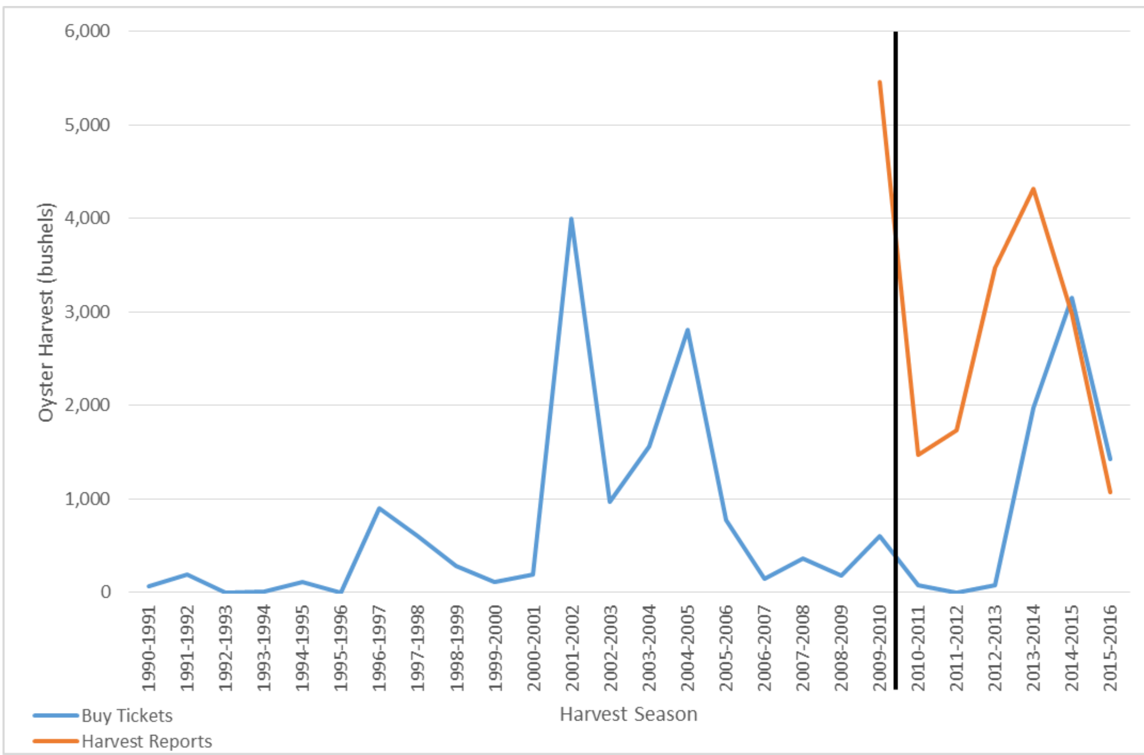


Figure A.23-12. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 057(Manokin River). In 2010, 82% of NOAA Code became an oyster sanctuary (denoted by the black line) where harvest is prohibited.

Environmental Conditions and Ecosystem Services

Maryland's Eyes on the Bay Program monitors monthly water quality at station ET8.1 (38.13794, -75.81411) in this area (Figure A.23-13). Salinity, water temperature and secchi depth minimum and maximum ranges have remained similar over the 25 year period. Variability of total nitrogen, chlorophyll a, and total suspended solids has decreased in more recent years. Water quality has been suitable for oysters during the time period examined.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

Figure A.23-14. Water quality data collected at Station ET8.1 in Manokin River. Black line denotes the date the sanctuary was established.

Section A.24: Man O War / Gales Lump Sanctuary

The Man O War / Gales Lump Sanctuary is located in upper Chesapeake Bay, a low salinity (less than 12 ppt) region (Figure A.24-1). Gales Lump (43 acres) constituted the original sanctuary area, created in 2003 as mitigation for shell dredging on Man O War Shoal. In 2010, the sanctuary was expanded to 4,704 acres, of which 2,310 (49%) is historic oyster bottom as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments. There are four historic oyster bars within the sanctuary[58].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.24-2). Of the 4,702 acres surveyed within the sanctuary, 3,218 acres (68%) were classified as oyster reef habitat. No recent bottom surveys using side scan sonar have been conducted.

Restoration and Replenishment Activities

Since 1990, this area has received one replenishment planting and one restoration activity (Table A.24-1). Wild seed was planted in 1995 to enhance the public fishery. Hatchery spat-on-shell was planted in 2003 for restoration purposes. (Table A.24-1).

Table A.24-1. Replenishment and restoration planting activities occurring since 1990 in area of the Man O War / Gales Lump Sanctuary. S = Planting occurring after the Gales Lump Sanctuary was established.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1995	Wild Seed	16.77	11.44	-
2003 (S)	Hatchery Spat-on-Shell	2.30	-	3.40

[58] See chart 4 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

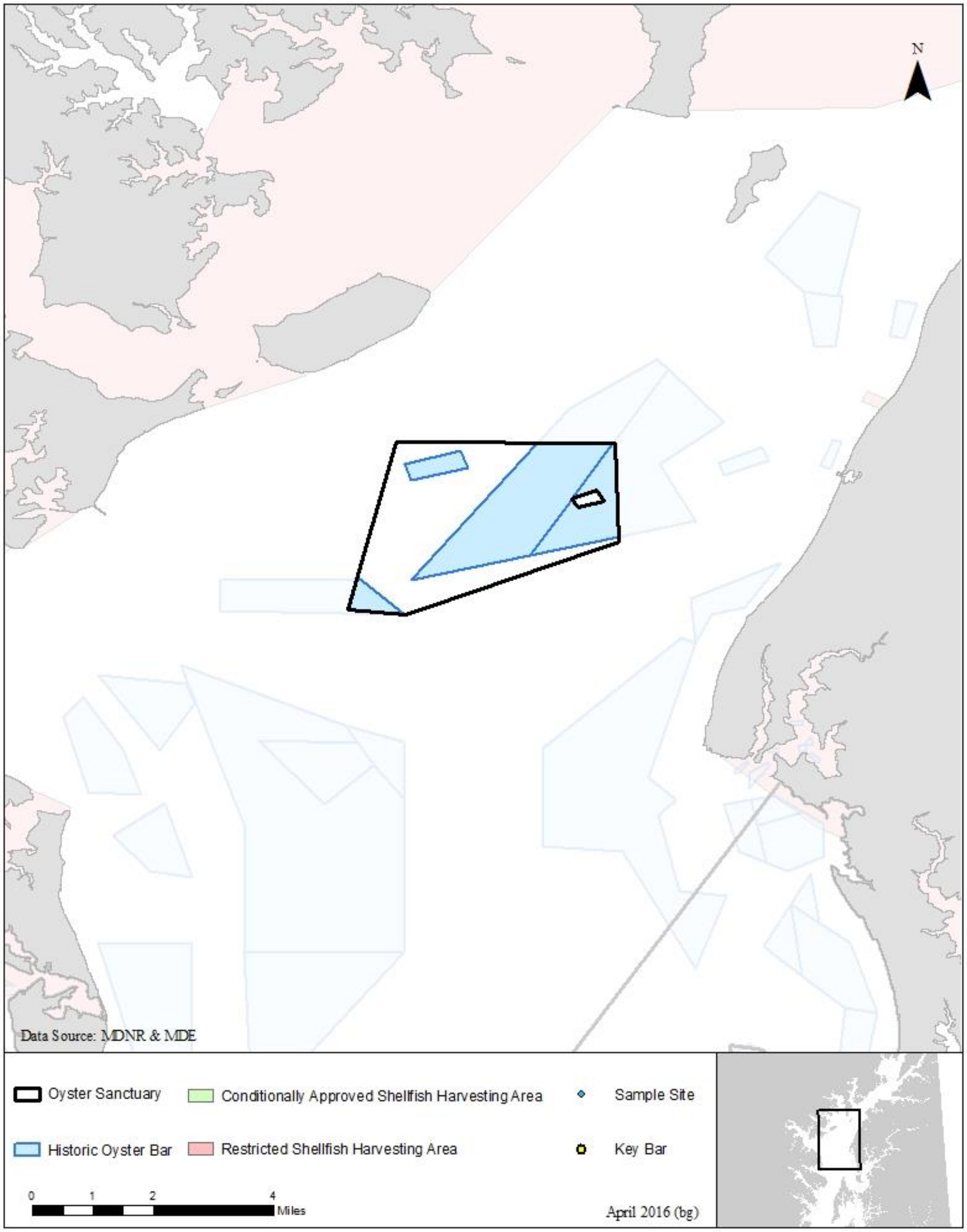


Figure A.24 -1. Man O War / Gales Lump Sanctuary. The smaller black box within the sanctuary represents the original Gales Lump Sanctuary (43 acres) created in 2003.

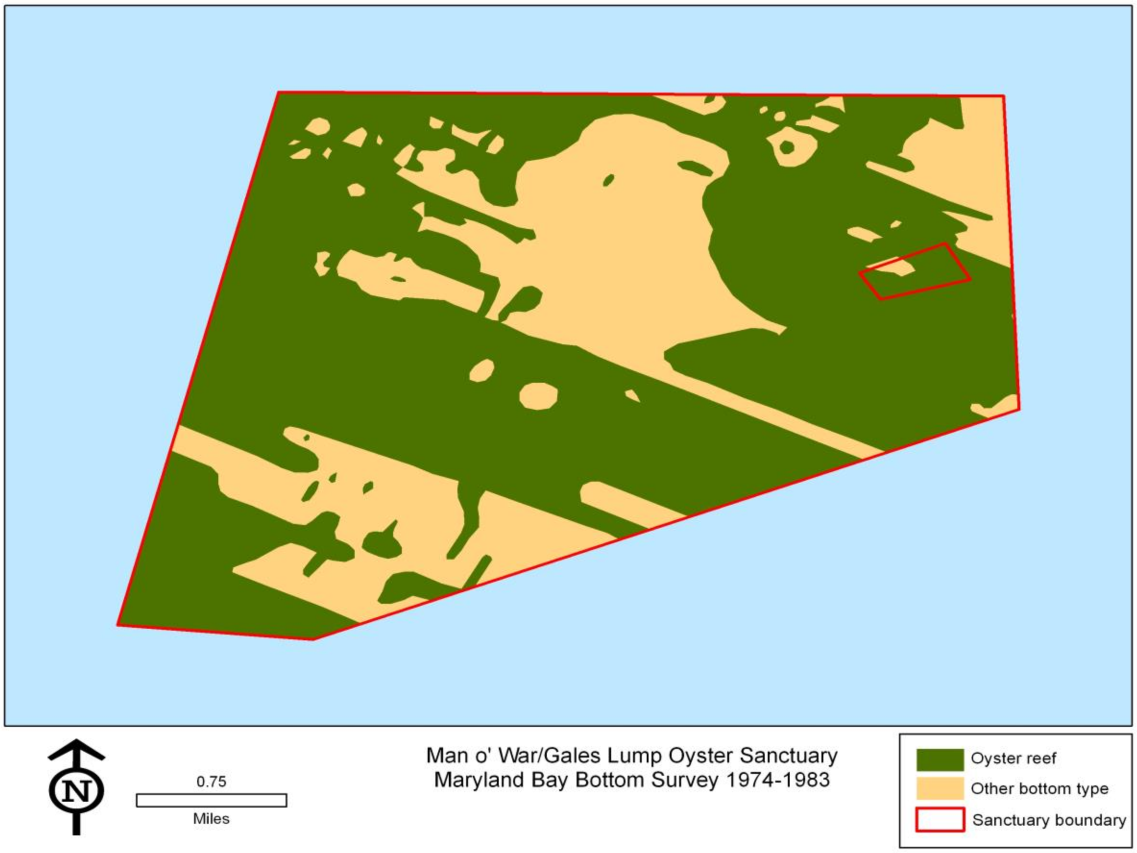


Figure A.24 -2. Man O War / Gales Lump Sanctuary bottom types. Data from Maryland Bay Bottom Survey of 1974-1983. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has not collected information within this area since 1990.

A patent tong population survey was conducted in 2015 (Figures A.24-3). No such population survey was conducted prior to the establishment of the sanctuary. Only two oysters were collected in 154 samples, yielding a live oyster density of 0.01 ± 0.01 oysters m^{-2}. Both oysters were small-sized oysters at 51 and 66 mm shell height. No spat were found. Given the large volume of shell in the sanctuary (Figure A.24.4), the low oyster density is likely due to something other than cultch availability.

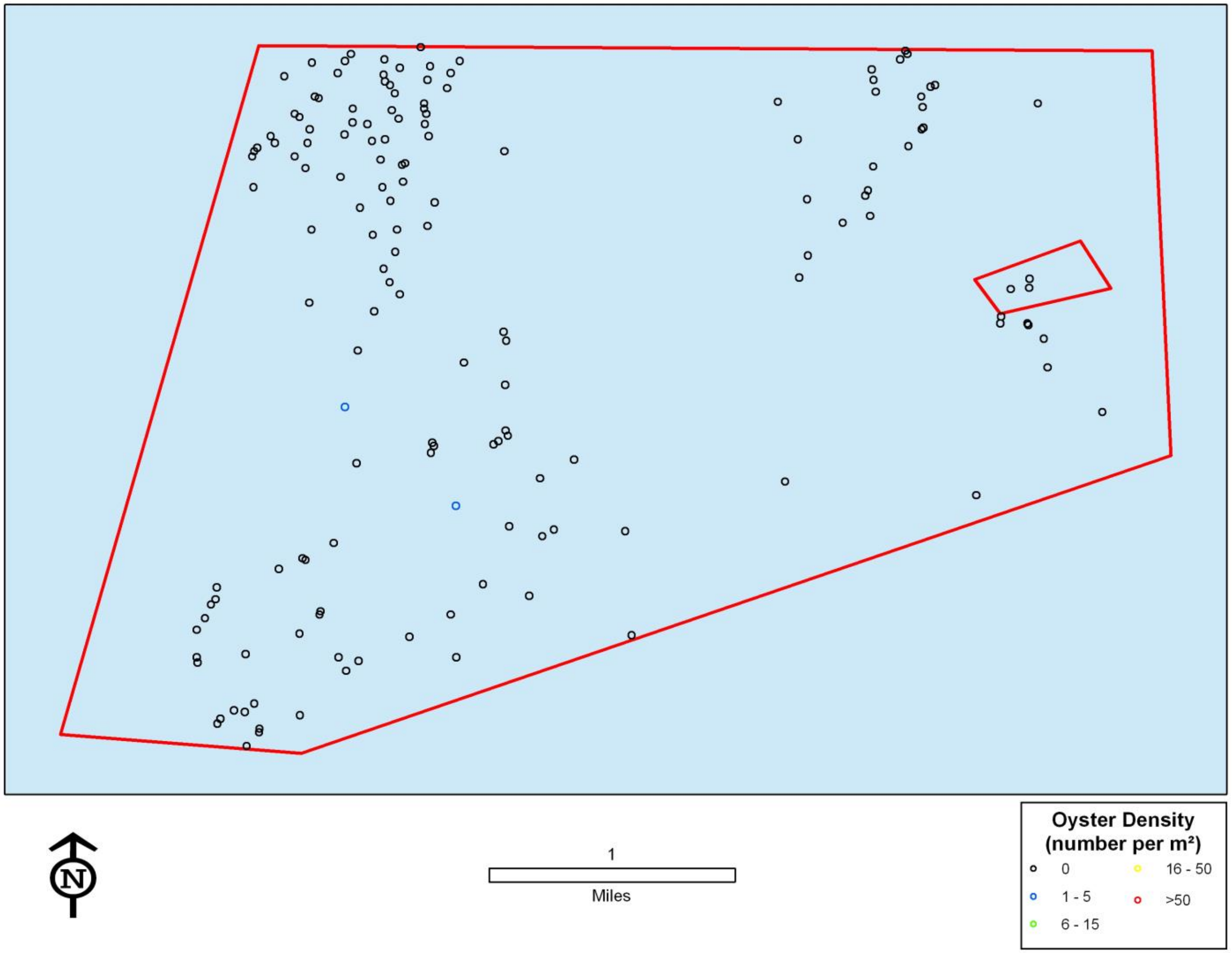


Figure A.24-3. Map of 2015 oyster density in the Man O War / Gales Lump Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

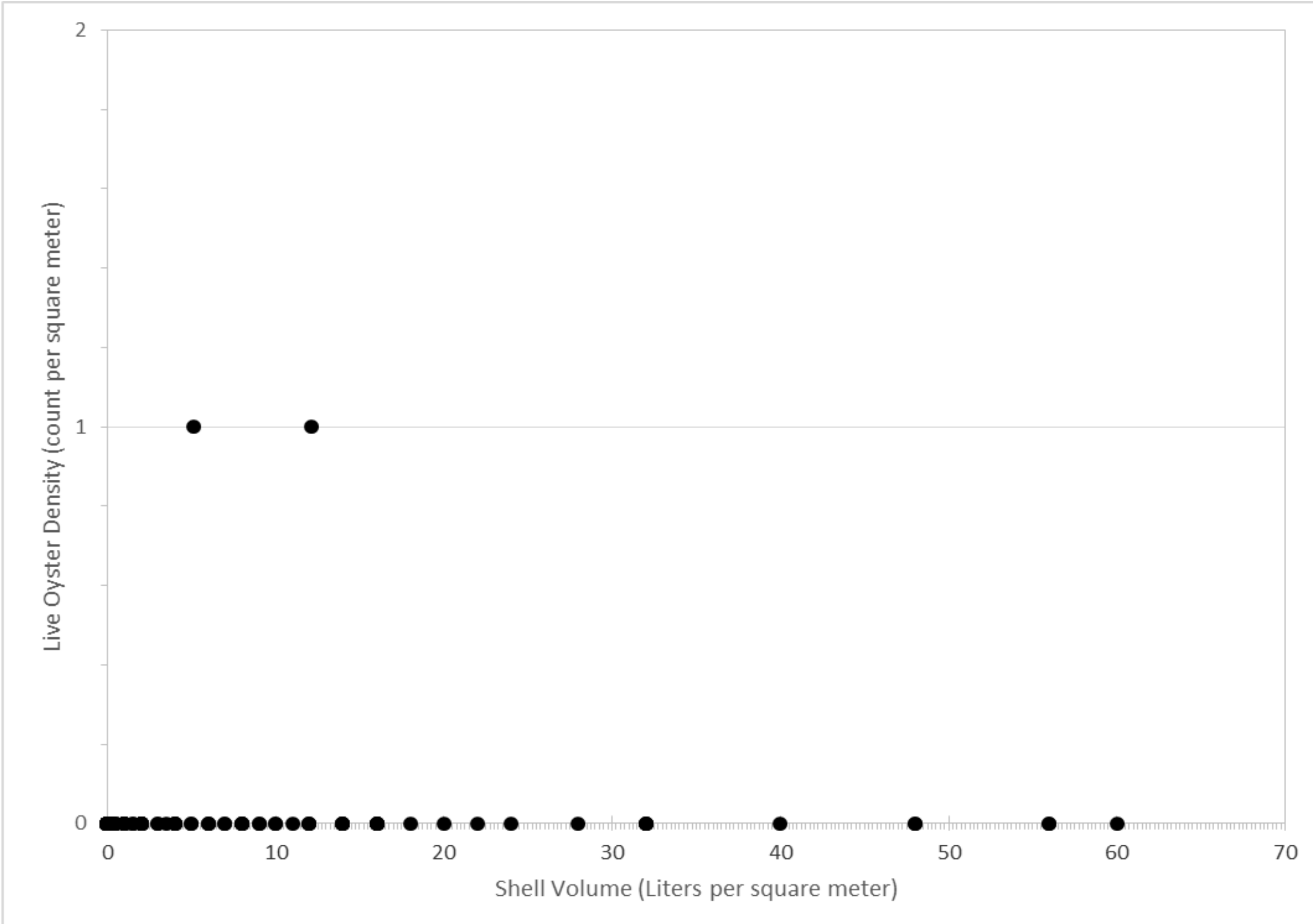


Figure A.24-4. 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Man O War / Gales Lump Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

Harvest

The sanctuary encompasses 3% of the 164,314 acres in NOAA Code 025. Because harvest from NOAA Code 025 may have come from areas outside the sanctuary, harvest reported by seafood dealers for the NOAA Code Area cannot be used to assess harvest in this area. Watermen reported a catch of 1,167 bushels from Man O War Shoals bar in the 2009-2010 season; however, only 18% of the bar falls within the existing sanctuary boundary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.25: Miles River Sanctuary

The Miles River Sanctuary is located in the upstream section of the Miles River, a tributary of Eastern Bay (Figure A.25-1). The sanctuary is in a low salinity (less than 12 ppt) region. The sanctuary was created in 2010 and encompasses 3,449 acres of which 373 (11%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 5 historic oyster bars within the sanctuary[59].

Bottom Habitat Characteristics

Although the area that is now the sanctuary may have been surveyed during the Bay Bottom Survey (1974 to 1983), the chart covering this area has been lost[60]. In 2011, NOAA Chesapeake Bay Office conducted a side scan sonar survey of the area (Figure A.25-2). Of the 1,335 acres surveyed, 103 acres (8%) were classified as oyster reef habitat.

Restoration and Replenishment Activities

No active restoration efforts have taken place in the sanctuary since its establishment in 2010; however, replenishment efforts occurred while the area was still open for oyster harvest (Table A.25-1). Since 1990, approximately 13,000 bushels of wild seed has been planted.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 150 cages and planted approximately 45,000 oysters.

Table A.25-1. Replenishment planting activities occurring since 1990 in area of the Miles Sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1998	Wild Seed	12.09	7.92	-
1999	Wild Seed	5.79	5.94	-

[59] See chart 12 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

[60] Smith, G.F., K.N. Greenhawk, D.G. Bruce, E.B. Roach, and S.J. Jordan. 2001. A digital presentation of the Maryland oyster habitat and associated bottom types in the Chesapeake Bay (1974–1983). Journal of Shellfish Research 20:192–206.

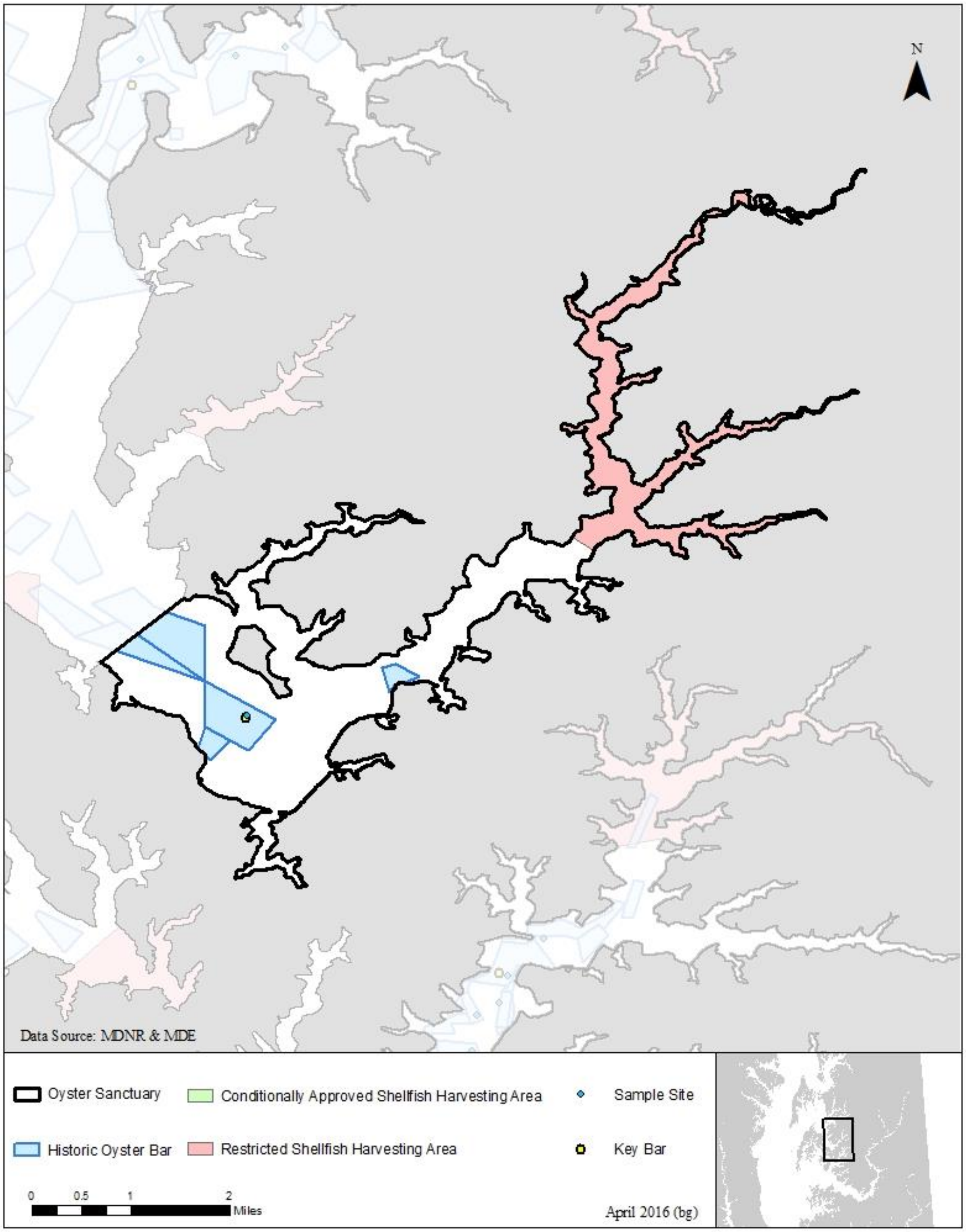


Figure A.25 -1. Miles River Sanctuary.

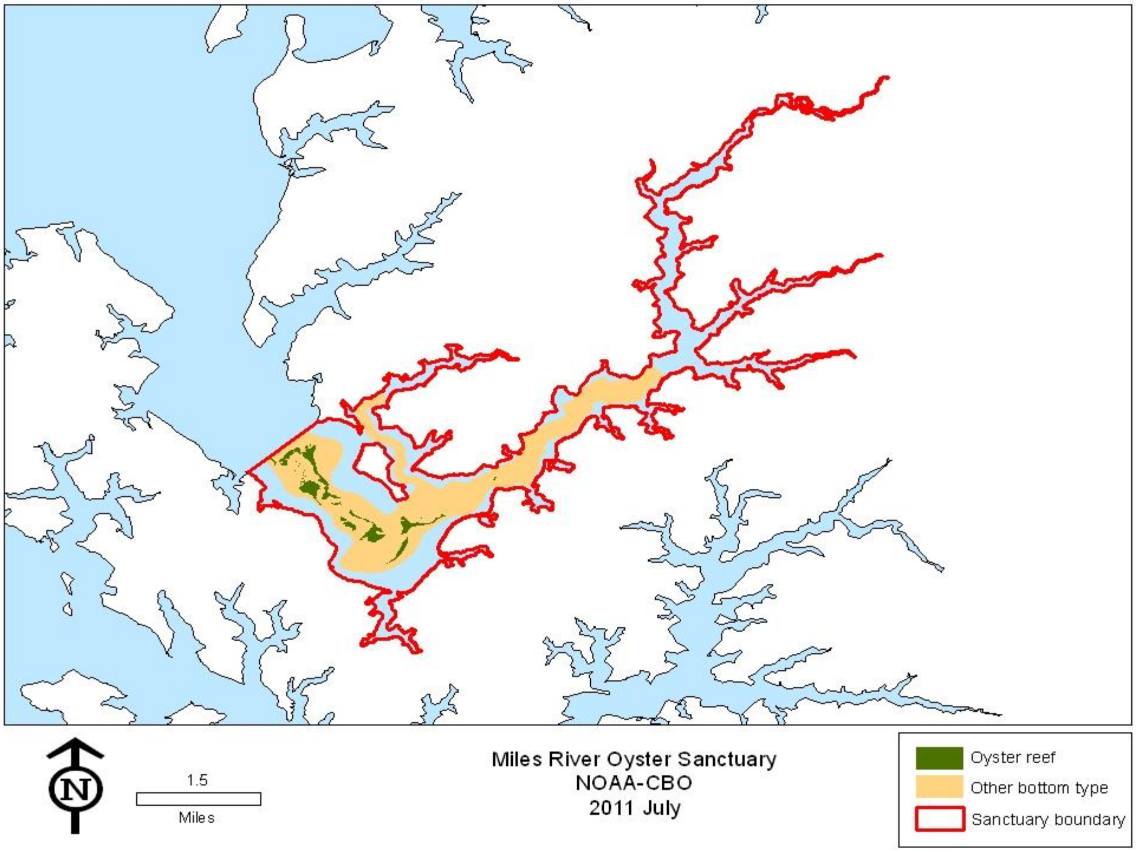


Figure A.25 -2. Miles River Sanctuary bottom types. Data from NOAA Chesapeake Bay Office in 2011. Tan and green colored areas depict areas examined during the survey.

Oyster Population Characteristics

The Fall Survey has sampled one oyster bar annually in this area since 1990. The average number of live oysters per bushel (market, small, and spat) was lower after sanctuary creation than before (Table A.25-2; Figure A.25-3). Both small and market-sized oysters showed a similar trend. The decrease may be due to poor recruitment since the late 1990s.

Table A.25-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Miles River Sanctuary in 2010. Values are given as mean ± standard error.		
	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 20	6 / 6
Number of Live Oysters per Bushel	70 +/- 20	10 +/- 5
Number of Live Small-Sized Oysters per Bushel	30 +/- 16	2 +/- 0
Number of Live Market-Sized Oysters per Bushel	36 +/- 6	8 +/- 4
Live Oyster Biomass (g Dry Weight per Bushel)	107 +/- 20.5	21 +/- 10.1
Mortality (%)	28.4 +/- 4.8	14.4 +/- 6.8

A patent tong population survey was conducted in 2014 (Figure A.25-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 0.04 ± 0.02 oysters m^{-2} (mean ± standard error, n=152). The percentage of samples having no oysters was 96%. Given the presence of shell in the sanctuary, the low oyster density is likely due to something other than cultch availability (Figure A.25.5).

Oyster Size Structure

Oysters collected by the Fall Survey in this area at Long Point Bar have been measured since 1990 (Figure A.23-6). The Fall Survey time series shows strong recruitment in 1995 and 1997 and the growth of these cohorts over time. The lack of additional recruitment has resulted in a population dominated by large oysters since 2000.

Shell heights were also measured during the 2014 patent tong population survey (Figure A.23-7). Small and market-sized oysters were found, but no spat.

Biomass

Biomass of oysters from Long Point Bar was calculated based on the number and size of oysters from Fall Survey samples. Biomass was higher before the sanctuary was established than after (Table A.25-2; Figure A.25-8). The reduction in biomass was likely due to an extended period of high dermo disease pressure from 1998-2008.

Recruitment (Spatfall)

Fall Survey spat counts from 1990-2105 ranged from 0 to 65. Recruitment is generally sporadic and low (Figure A.25-3). An anomalous high spat set occurred in 1995 which led to the increase in market-sized oysters from 1997 to 2001. No spat were collected in the 2014 patent tong population survey.

Mortality

Based on Fall Survey box counts, the average mortality after sanctuary establishment was lower than the average mortality before sanctuary establishment (Table A.25-2; Figure A.25-9). Mortality ranged from 0% to 72% from 1990 to 2015.

Disease

Disease pressure from dermo has fluctuated widely since 1990, with prevalence levels ranging from 10% to 100% (Figure A.25-10). There was an extended period of high (greater than 80%) dermo prevalence from 1998 to 2008, during which time infection intensity peaked at 4.6, slightly below the lethal level of 5 on a 0-7 scale. MSX prevalence was low from 1990-2015, ranging from 0% to 3% (Figure A.25-10).

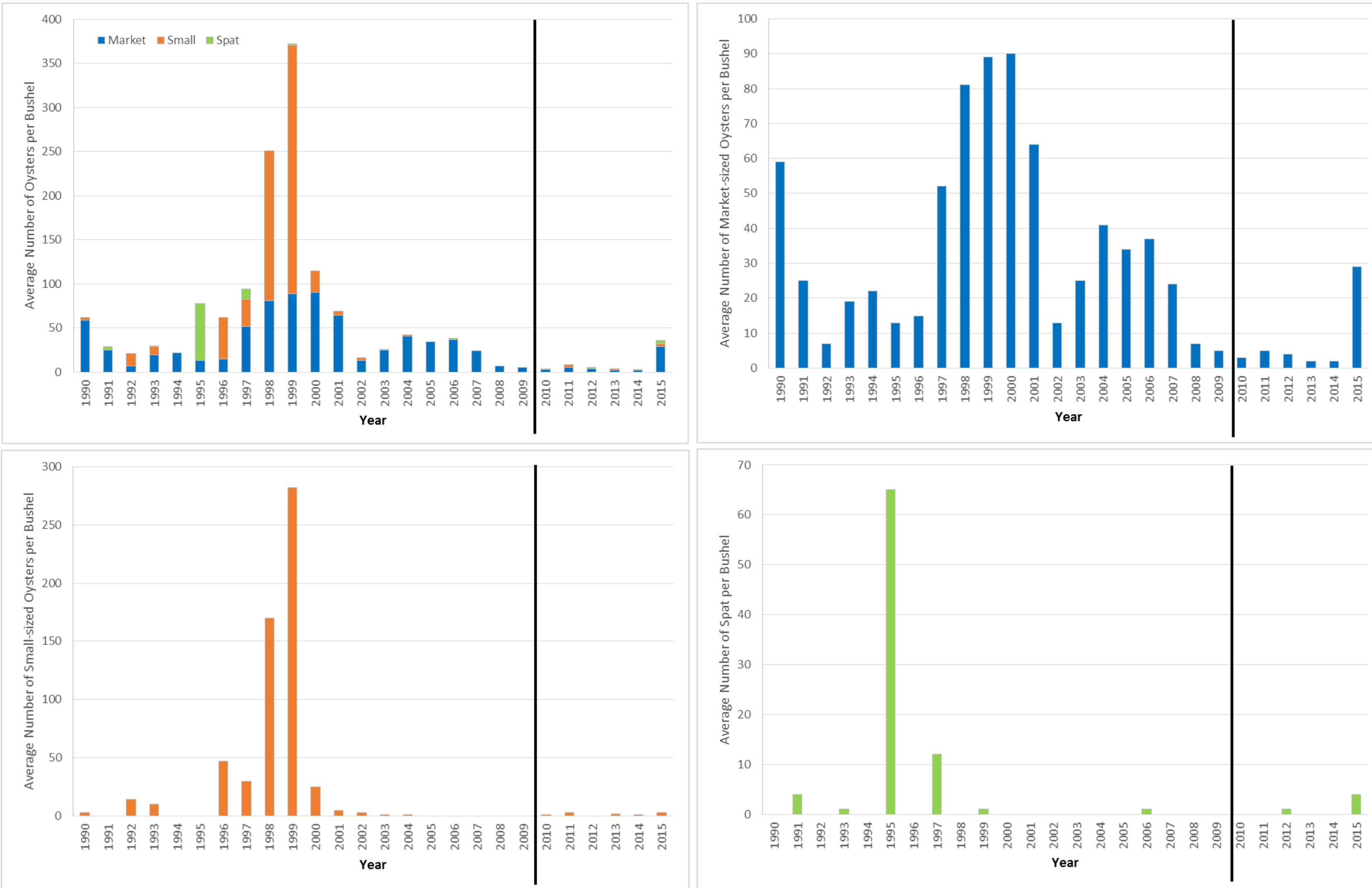


Figure A.25-3. Average number of live oysters per bushel of material by size class in the Miles River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

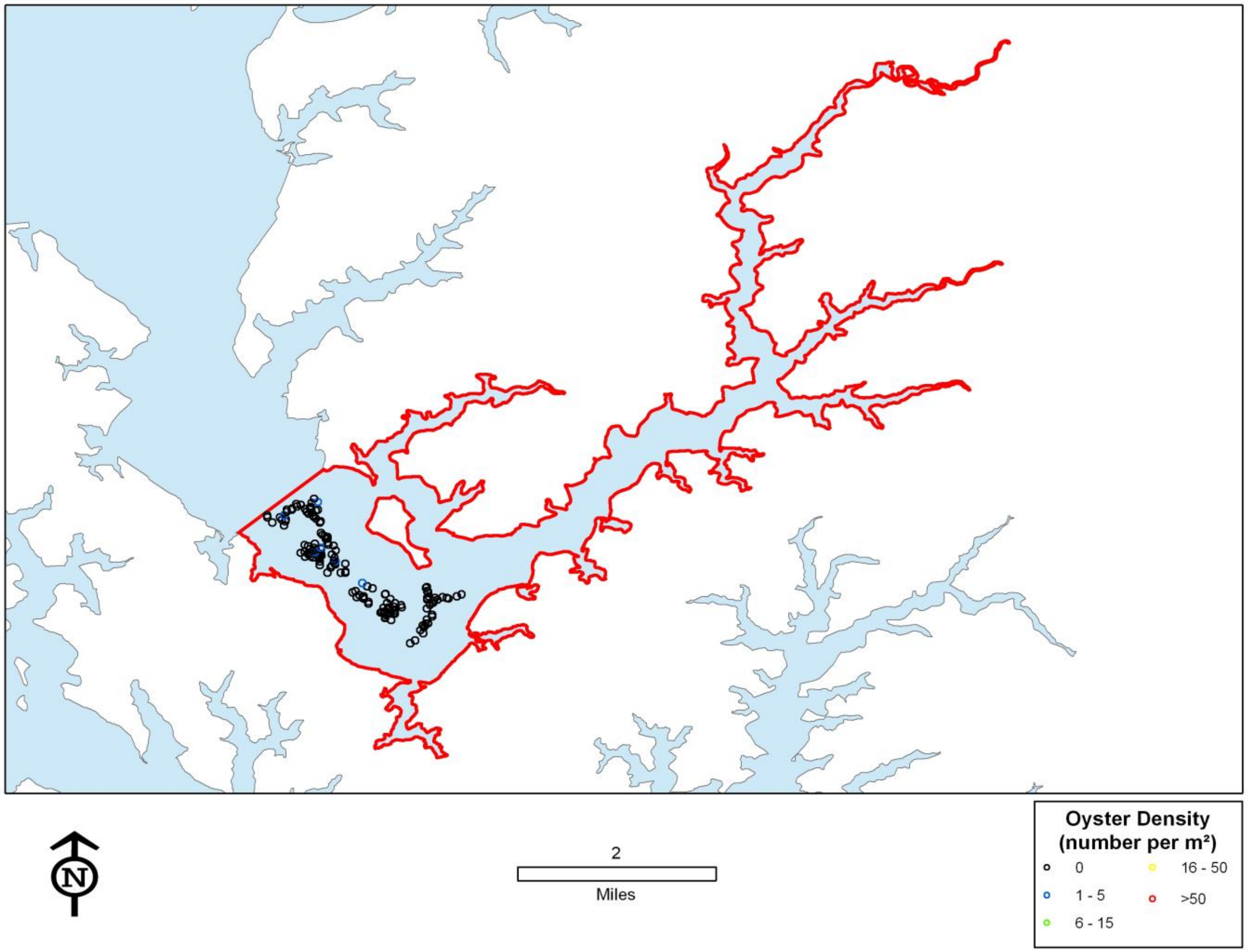


Figure A.25-4. Map of 2014 oyster density in the Miles River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

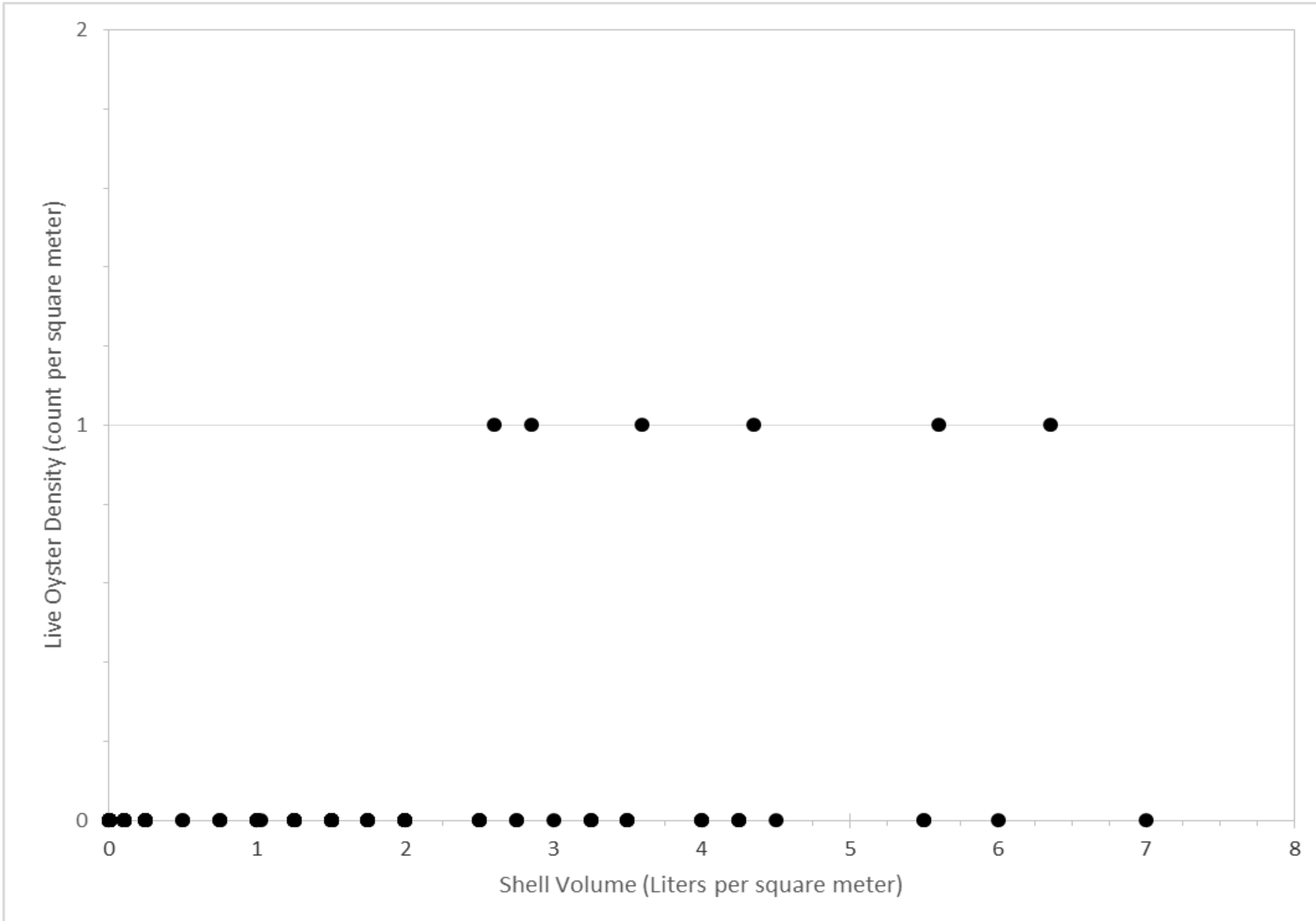


Figure A.25-5. 2014 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Miles River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

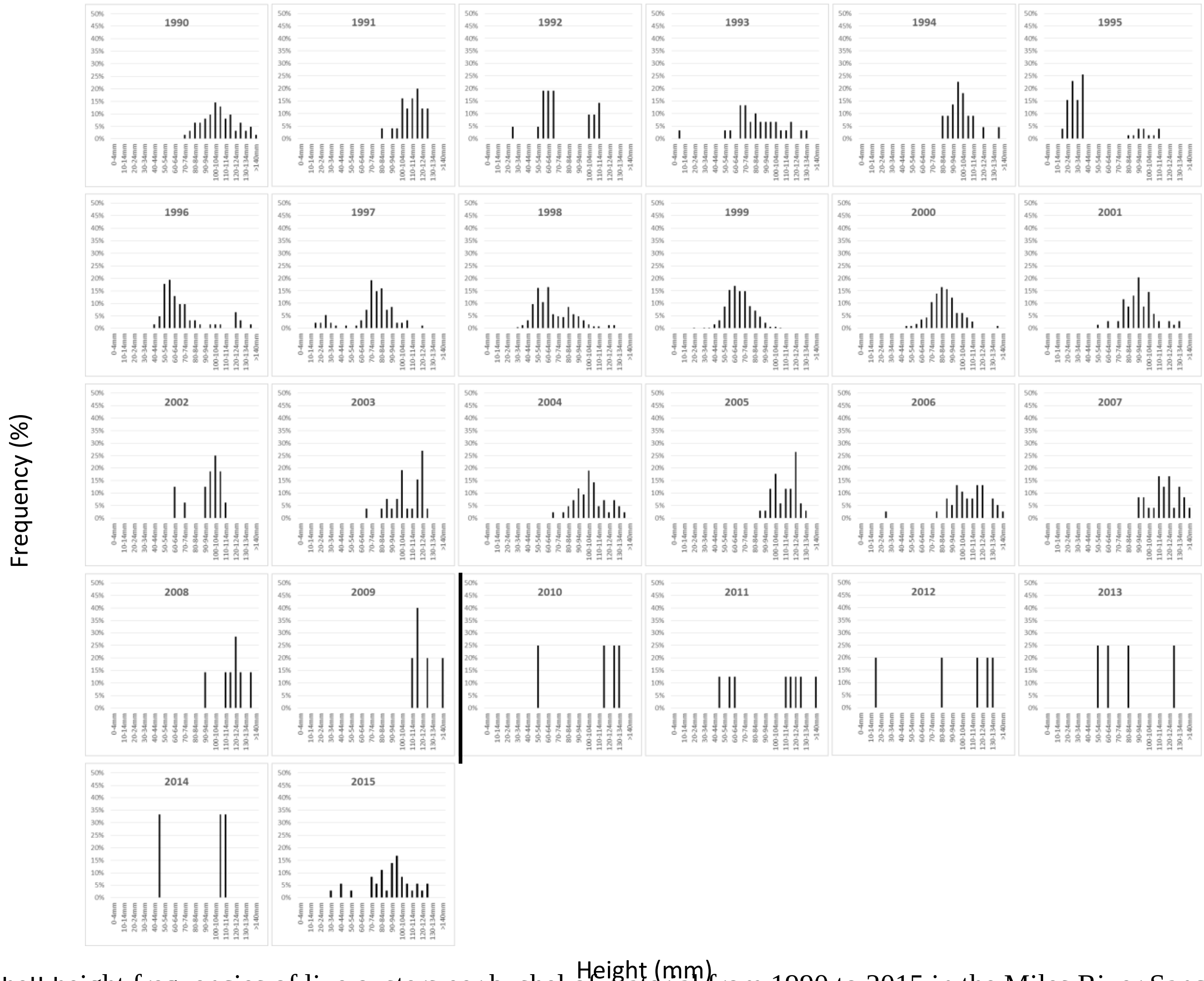


Figure A.25-6. Shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the Miles River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Long Point bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

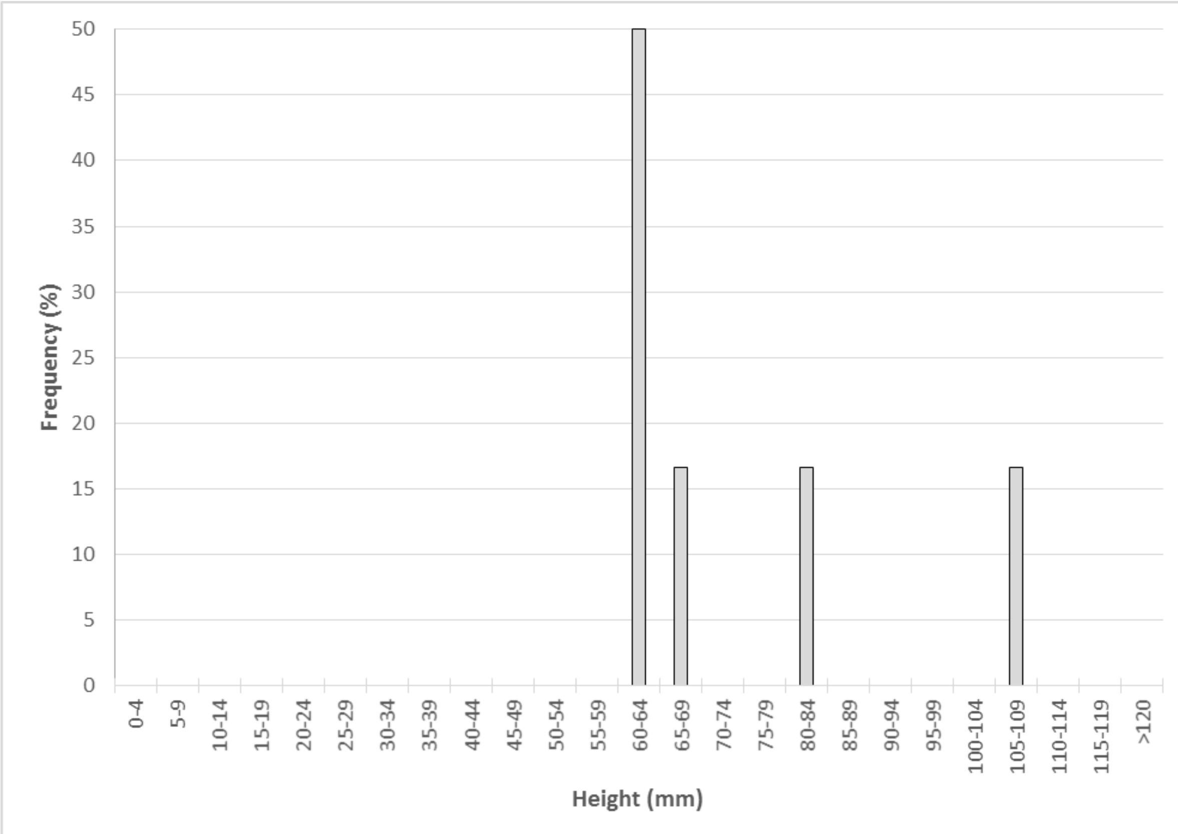


Figure A.25-7. Shell height frequencies of live oysters in the Miles River Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

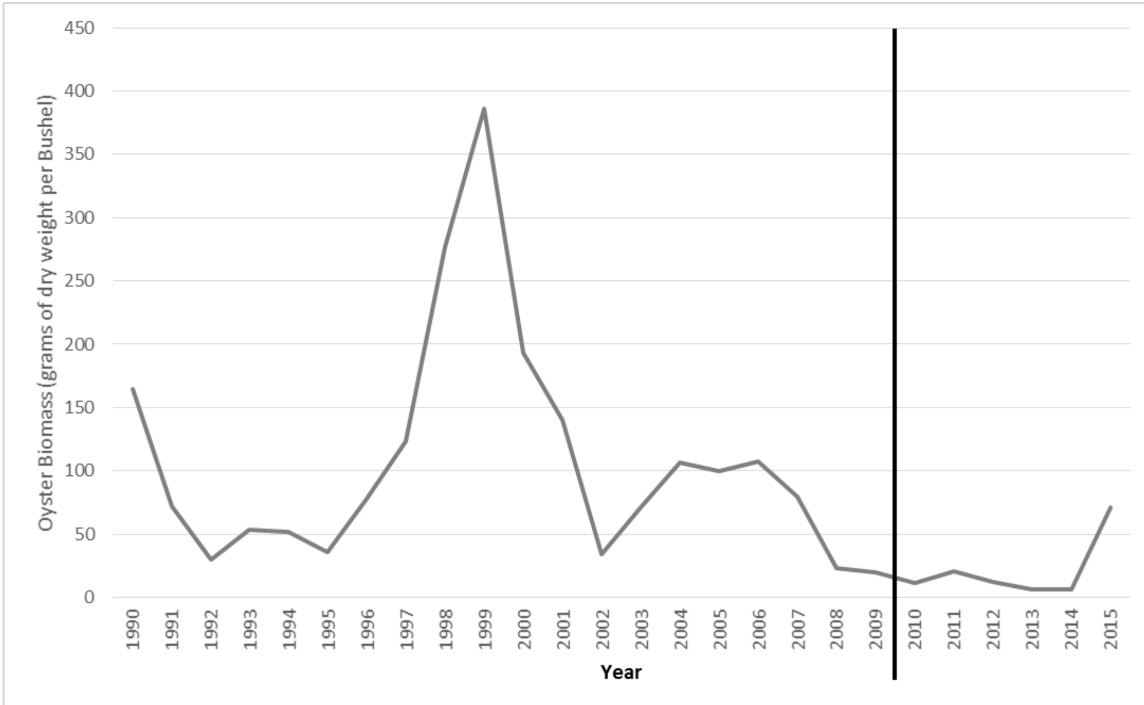


Figure A.25-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Miles River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Long Point bar. Black line indicates the date the sanctuary was established.

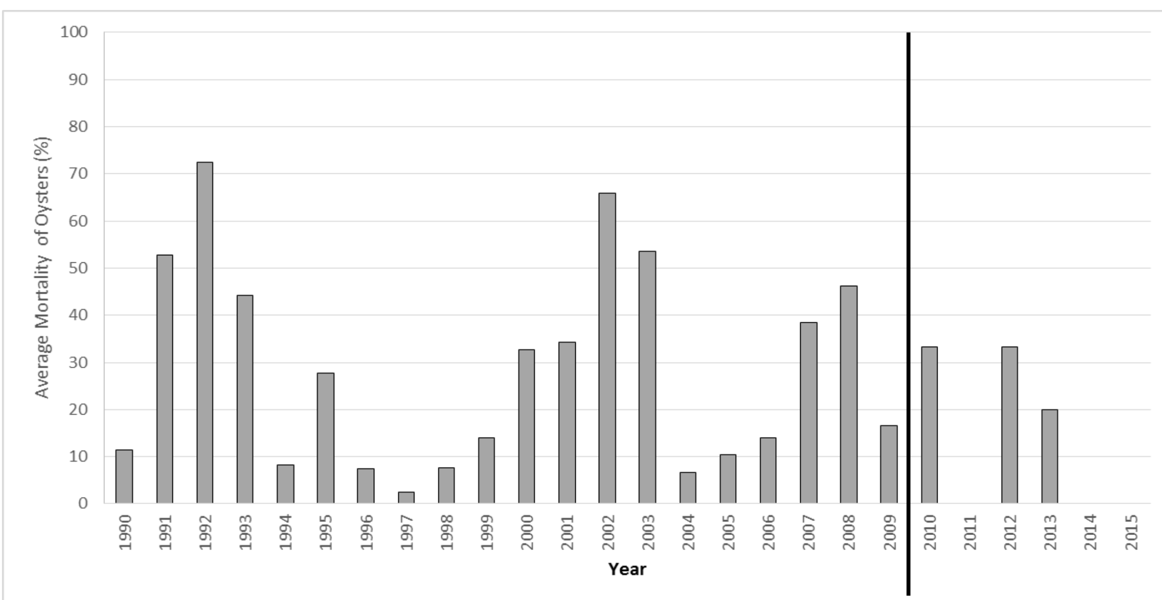


Figure A.25-9. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Miles River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

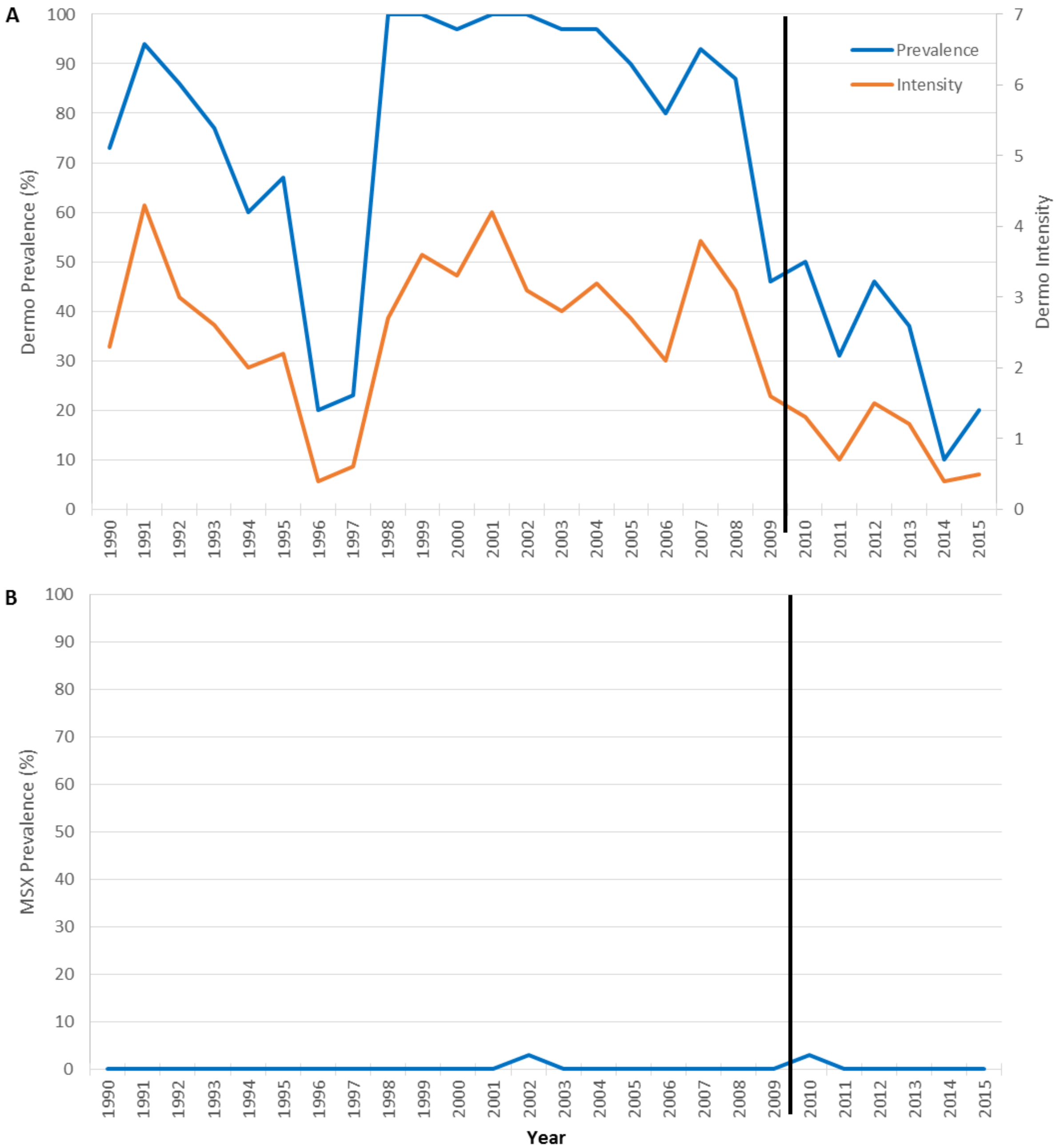


Figure A.25-10. Oyster disease prevalence and intensity from 1990 to 2015 in the Miles River Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Long Point bar.

Harvest

The sanctuary encompasses 27% of the 12,778 acres in NOAA Code 060. Because harvest from NOAA Code 060 may have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area. Watermen reported no catch in the 2009-2010 season on bars in the area that became the sanctuary.

Environmental Conditions and Ecosystem Services

Chesapeake Bay Program Data Hub recorded monthly water quality at station XFH7523 (38.7926, -76.1282) in this area. Data were collected from 2004 to 2006; no water quality data are available for the area after sanctuary establishment (Figure A.25-9). Surface water was analyzed for salinity, water temperature, secchi disk depth, total suspended solids, total nitrogen, and chlorophyll a. Water quality was suitable for oysters during the period examined.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

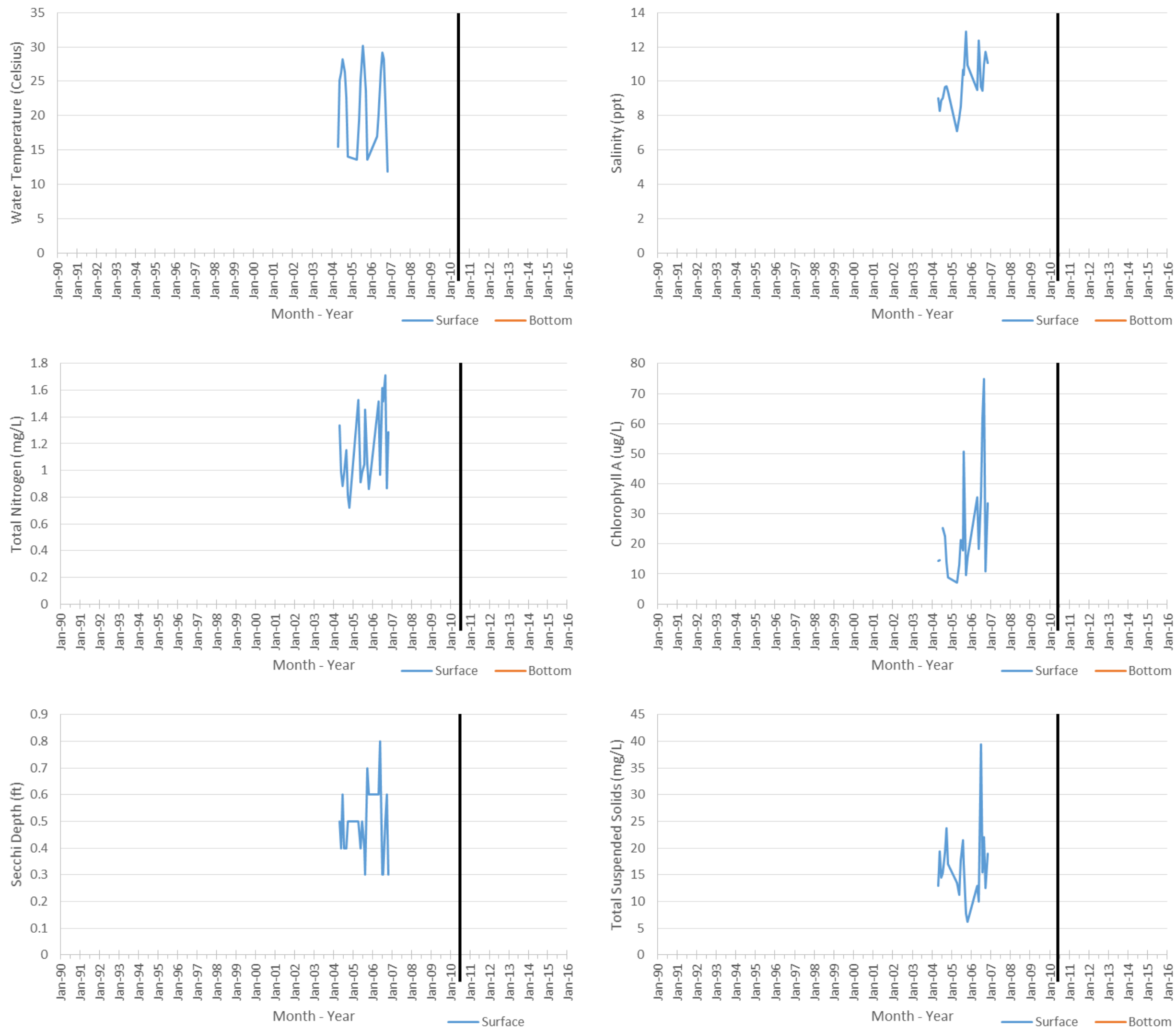


Figure A.25-9. Water quality data collected at Station XFH7523 within the area now established as Miles River Sanctuary from 2004 to 2006. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.

Section A.26: Mill Hill Sanctuary

The Mill Hill Sanctuary is located in Eastern Bay, a low salinity (less than 12 ppt) region (Figure A.26-1). The sanctuary was created in 2000 for a US Environmental Protection Agency (EPA) project examining mounded habitat and alternative materials for oysters. The sanctuary encompasses 295 acres of which 188 (64%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 2 historic oyster bars within the sanctuary although neither bar has the majority of its area within the sanctuary (Mill Hill 31% and Saw Mill Creek 9%).

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.26-2). Of the 218 acres surveyed within the sanctuary, 18.2 (8%) were classified as oyster reef habitat. In 2012 NOAA Chesapeake Bay Office conducted a sonar survey of the area. Of the 215 acres surveyed in 2012, 39 acres (18%) were classified as oyster reef habitat. The increase in area is likely due to construction of 20 acres experimental reefs in 2000.

Restoration and Replenishment Activities

No replenishment efforts have taken place in this area since 1990. The sanctuary has received restoration activities, including the placement of over 57,000 bushels of dredge shell, over 140,000 bushels of wild seed, and 83.52 million hatchery spat-on-shell (Table A.26-1). Experimental reefs made of crushed stone, slag, concrete, and shell were constructed in 2002. Reef balls with oyster seed were also placed in the sanctuary in 2002.

Table A.26-1. Restoration planting activities occurring since 1990 in the area of the Mill Hill Sanctuary. S = planting activity occurring after the area was established as a sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
2000 (S)	Dredged Shell	76.24	32.32	-
2000 (S)	Wild Seed	1.56	140.11	-
2002 (S)	Dredged Shell	2.02	25.34	-
2002 (S)	Reef Balls	1	-	-
2002 (S)	Shell, Stone, Concrete, Slag	10.4	-	-
2008 (S)	Hatchery Spat-on-Shell	28.56	-	40.80
2009 (S)	Hatchery Spat-on-Shell	33.03	-	42.72

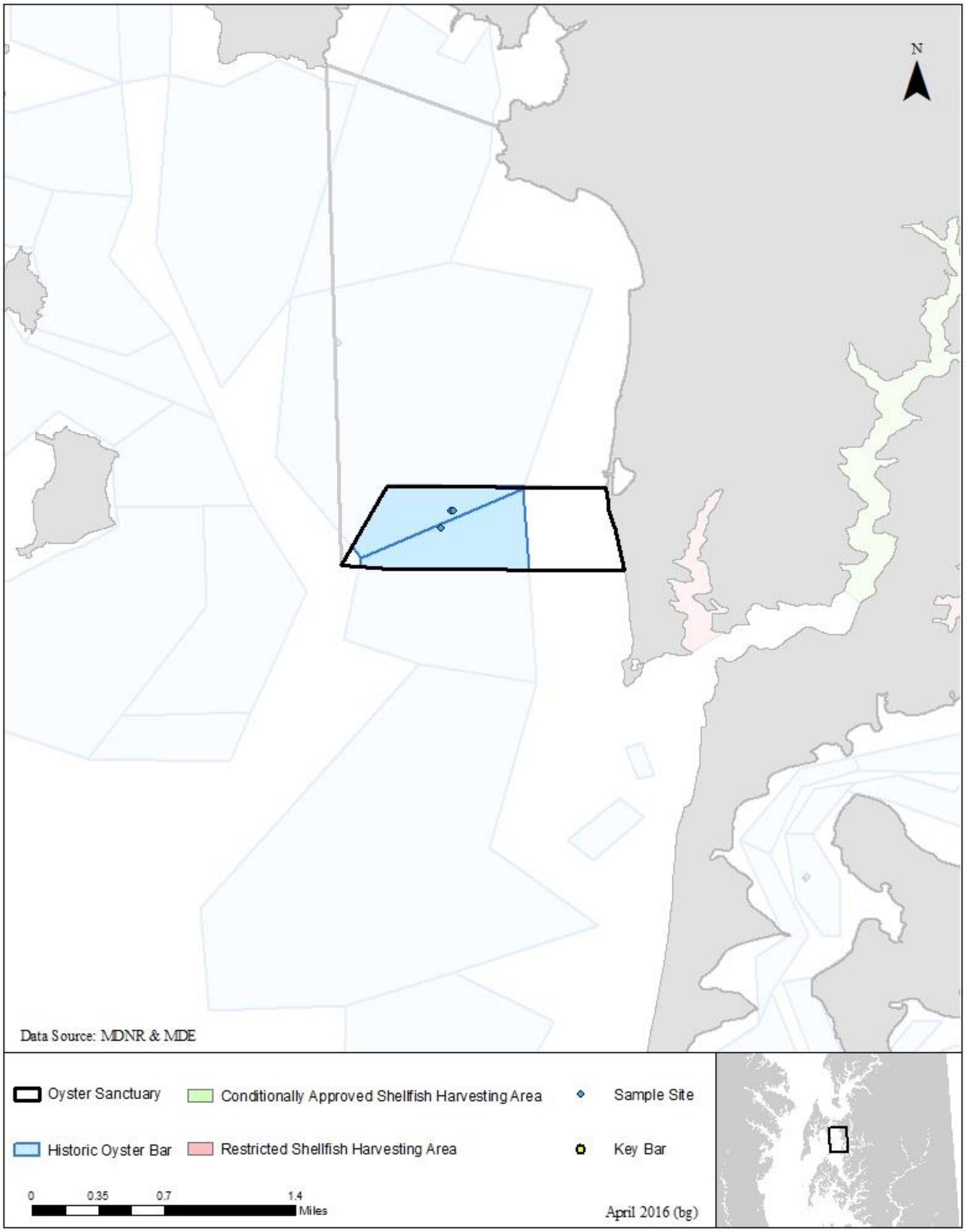


Figure A.26 -1. Mill Hill Sanctuary.

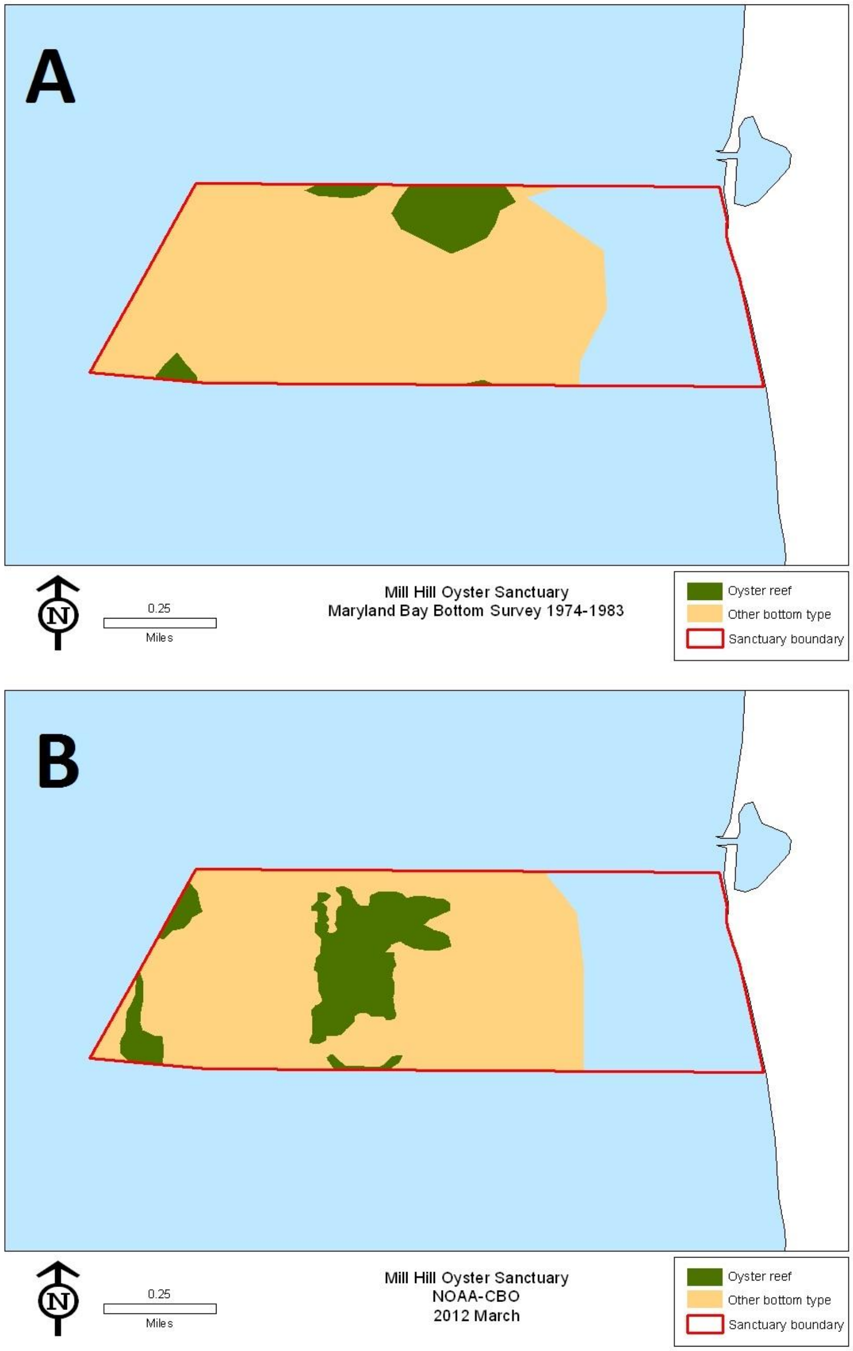


Figure A.26 -2. Mill Hill Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1983. (B) Data from NOAA Chesapeake Bay Office in 2012. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled the same one oyster bar annually in this area since 1990. The average number of live oysters per bushel (market, small, and spat) decreased after sanctuary establishment (Table A.26-2; Figure A.26-3). The greater number of oysters prior to sanctuary creation is a result of the high 1997 spatfall which increased the number of small-sized oysters in 1998 and 1999. While the average number of small oysters was greater than the average number of market-sized oysters before sanctuary creation, this pattern is reversed after sanctuary creation as a result of the 1997 cohort reaching market size around 2000.

Table A.26-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Mill Hill Sanctuary in 2000. ND = No Data. Values are given as mean ± standard error.

	1990-1999	2000-2015
Number of Years Sampled / Number of Samples	20 / 20	6 / 6
Number of Live Oysters per Bushel	380 ± 172	88 ± 12
Number of Live Small-Sized Oysters per Bushel	154 ± 64	31 ± 7
Number of Live Market-Sized Oysters per Bushel	33 ± 6	43 ± 7
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	15.8 ± 3.8	18.8 ± 4.4

Oyster densities on the constructed reefs one year after placement (2003) were highest on reefs made of concrete (32 oysters m^{-2}) and slag (44 oysters m^{-2}). Densities on other substrates (stone, shell, concrete capped with shell, slag capped with shell, stone capped with shell, and reef balls) were less than15 oysters m^{-2} (EA 2012)[61].

A patent tong population survey was conducted in the sanctuary 2013 (Figures 4.26-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 1.65 ± 0.56 m^{-2} (mean ± standard error, n=40). The density of small-sized oysters was less than the density of market-sized oysters (0.40 ± 0.14 and 0.75 ± 0.36 oysters m^{-2}, respectively). Sixty-five percent of the samples collected contained no live oysters or boxes. Oyster density increased with shell volume (Figure A.26.5).

Oyster Size Structure

The Fall Survey has not measured shell height in this area since 1990.

[61] EA Engineering, Science, and Technology. 2012. USACE Chesapeake Bay Oyster Recovery, MD and VA: Initial Screening of Oyster Reefs Constructed Using Alternate Substrate. Report to the U.S. Army Corps of Engineers, Baltimore District. 159 pp.

On the constructed reefs, nine years after placement (in 2011), oyster heights ranged from 53 to 137 mm across all substrates, whereas heights at a reference location on Mill Hill bar ranged from 122 to 183 mm (average = 98 mm). The greatest average height (96 mm) occurred on oyster shell, whereas the smallest average height (73 mm) occurred on slag capped with shell (EA 2012)[62].

The size distribution of oysters from the 2013 patent tong survey shows sizes ranging from spat to very large markets (greater than 120 mm shell height) (Figure A.26-6).

Biomass

The Fall Survey has not measured biomass in this area since 1990.

Recruitment (Spatfall)

Fall Survey spat counts from 1990 to 2015 ranged over four orders of magnitude (Figure A.26-3). An anomalously high spat set (1,176 spat per bushel) occurred in 1997. The second highest spat set since 1990 (147 spat per bushel) occurred in 2008. The longest consecutive period of annual spatfall occurred from 1997 to 2001. Spat density from the 2013 patent tong survey was $0.50 \pm 0.15\ m^{-2}$.

Mortality

Based on Fall Survey box counts, the average mortality was similar before and after sanctuary establishment (Table A.26-2; Figure A.26-7). Mortality ranged from 0% to 58% from 1990 to 2015.

Disease

The Fall Survey has not measured disease in this area since 1990.

[62] EA Engineering, Science, and Technology. 2012. USACE Chesapeake Bay Oyster Recovery, MD and VA: Initial Screening of Oyster Reefs Constructed Using Alternate Substrate. Report to the U.S. Army Corps of Engineers, Baltimore District. 159 pp.

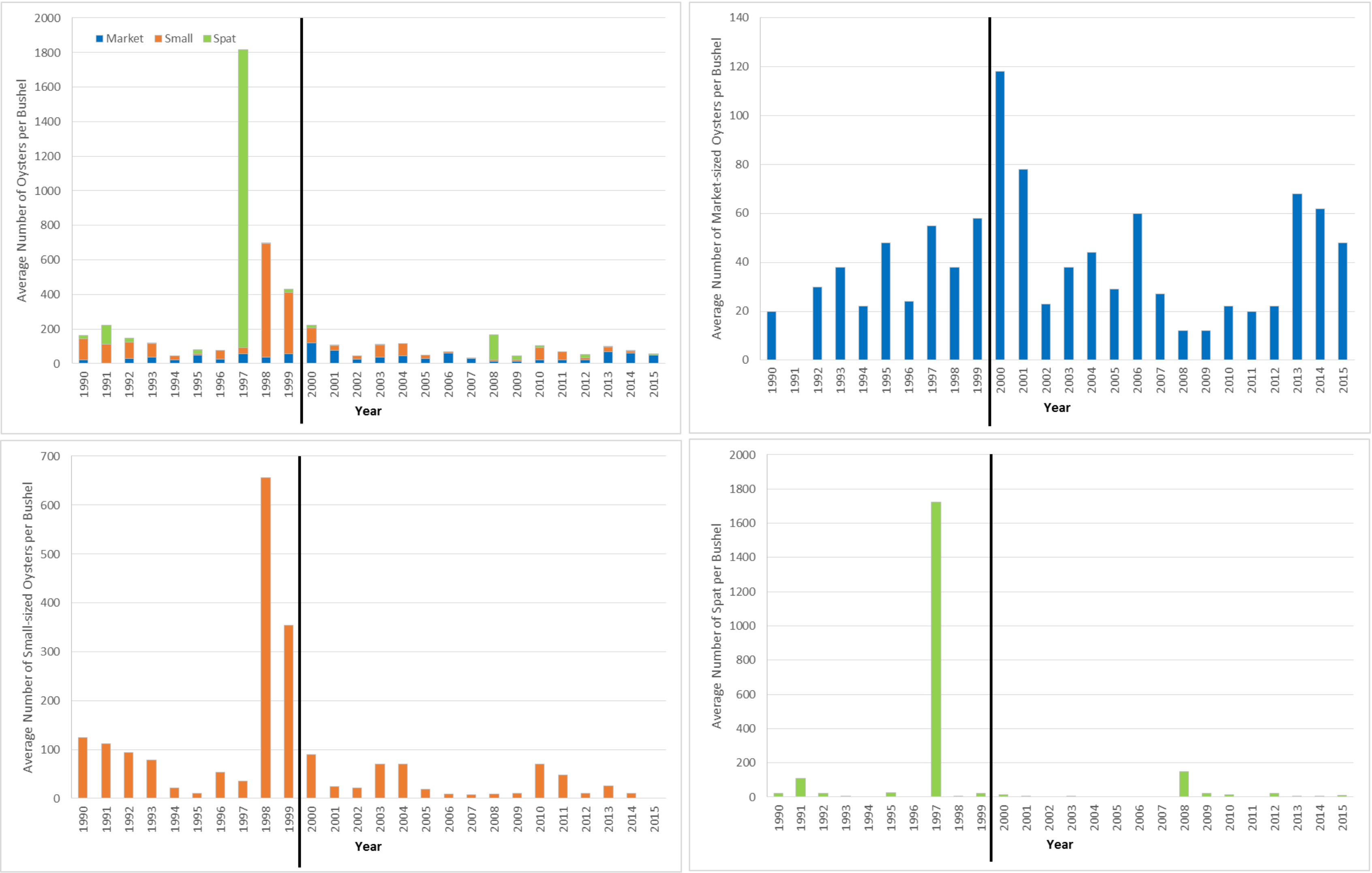


Figure A.26-3. Average number of live oysters per bushel of material by size class in the Mill Hill Sanctuary. The black line denotes the year the sanctuary was established. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

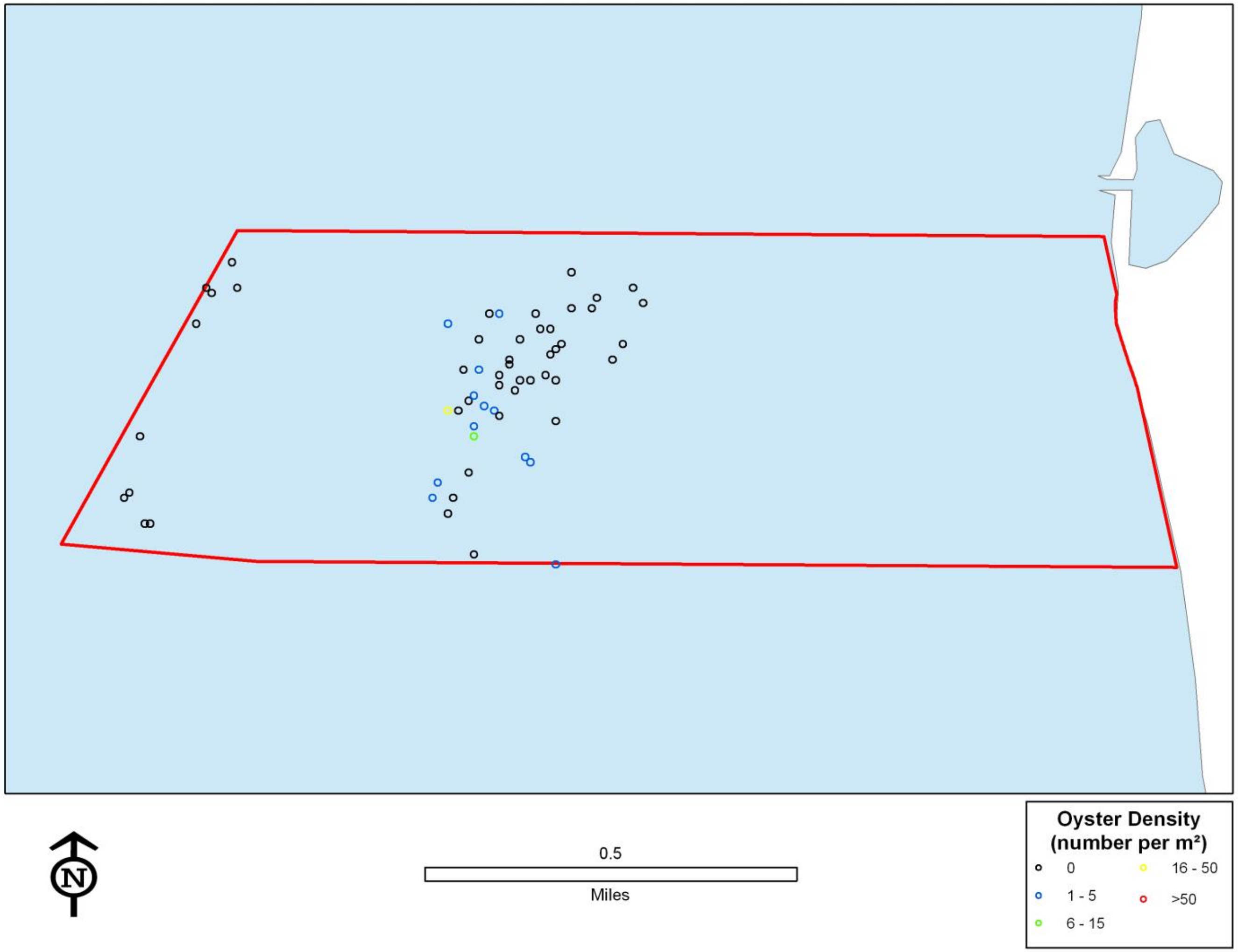


Figure A.26-4. Map of 2013 oyster density in the Mill Hill Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

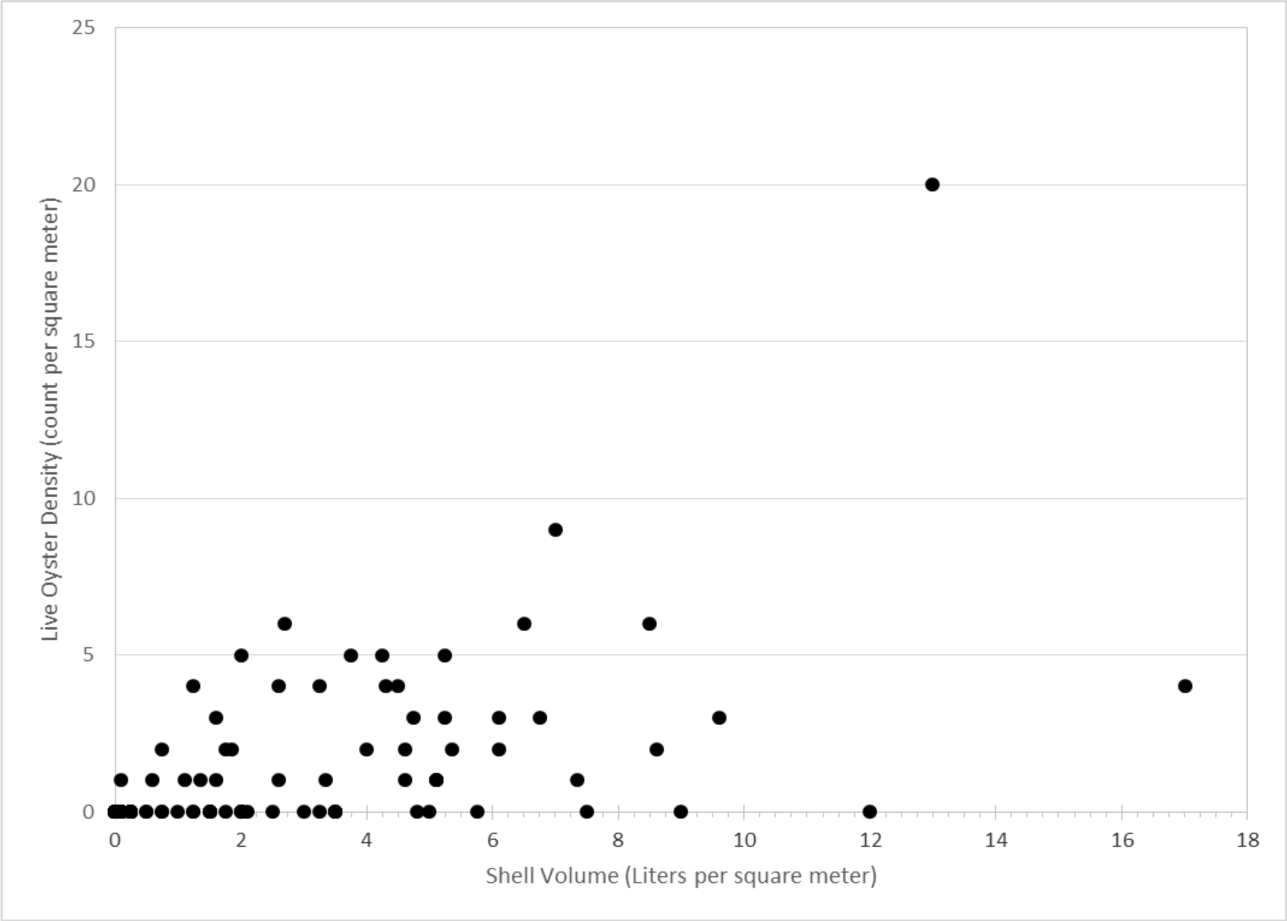


Figure A.26-5. 2014 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Mill Hill Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

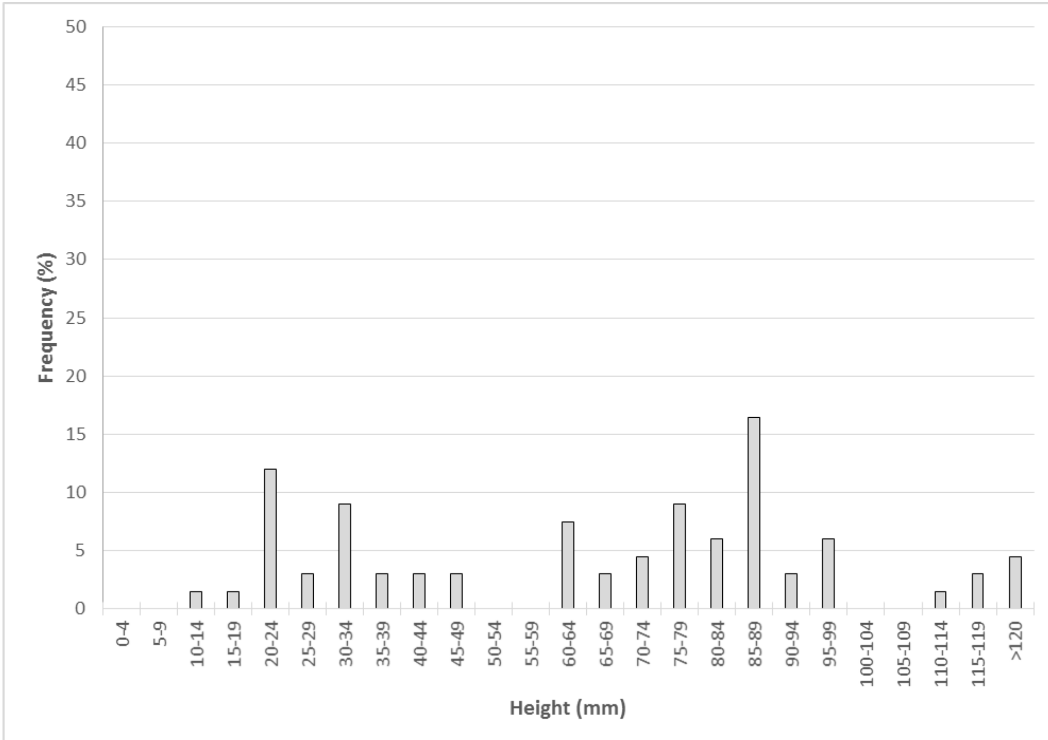


Figure A.26-6. Shell height frequencies of live oysters in the Mill Hill Sanctuary in 2013. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

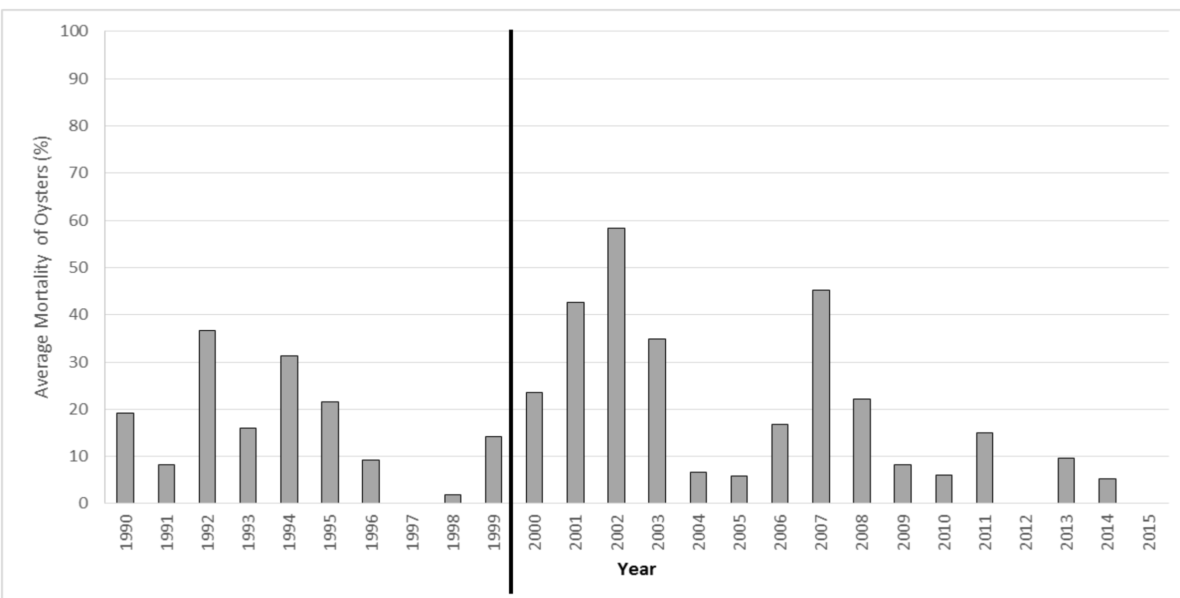


Figure A.26-7. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Mill Hill Sanctuary in Maryland's portion of the Chesapeake Bay. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established.

Harvest

The sanctuary encompasses 0.9% of the 33,334 acres in NOAA Code 039. Because harvest for NOAA Code 039 is likely to have come from places other than the area that became the sanctuary, harvest reported by seafood dealers prior to sanctuary establishment cannot be used to assess harvest in this area.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.27: Nanticoke River Sanctuary

The Nanticoke River Sanctuary is located in the Nanticoke River, a low salinity (less than 12 ppt) region (Figure A.27-1). The sanctuary was created in 2010 and encompasses 16,699 acres of which 576 (3.4%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 19 historic oyster bars within the sanctuary[63].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.27-2). Of the 1,309 acres surveyed within the sanctuary, 619 (47%) were classified as oyster reef habitat. In 2011 Maryland Geological Survey conducted a more thorough side scan sonar survey of the Nanticoke River Sanctuary. Of the 5,558 acres surveyed in 2011, 709 acres (13%) were classified as oyster reef habitat. Differences between the coverage areas of the Bay Bottom Survey and Maryland Geological Survey's side scan sonar work precludes comparison of the two surveys.

Restoration and Replenishment Activities

Since 1990 and prior to sanctuary establishment, approximately 199,000 bushels of shell and 244,000 bushels of wild seed were planted to enhance the wild fishery (Table A.27-1). The sanctuary has not received any active restoration efforts since it was established in 2010.

[63] See chart 31 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

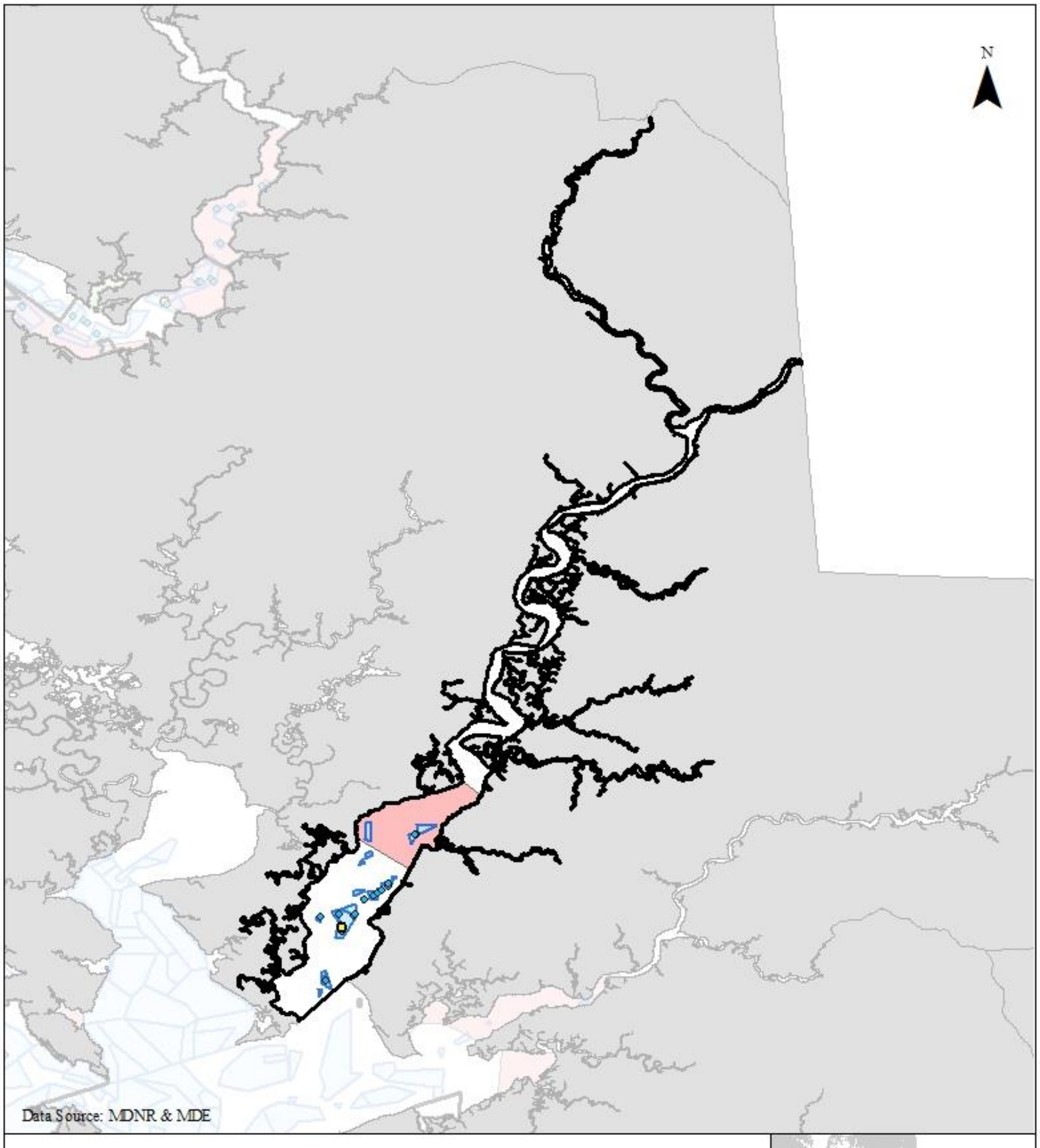
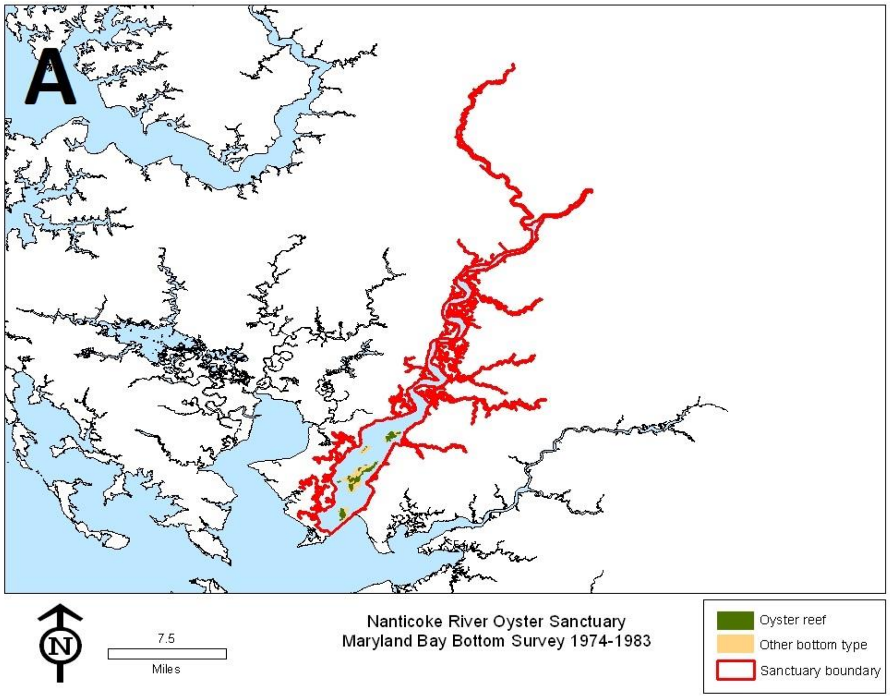


Figure A.27 -1. Nanticoke River Sanctuary.



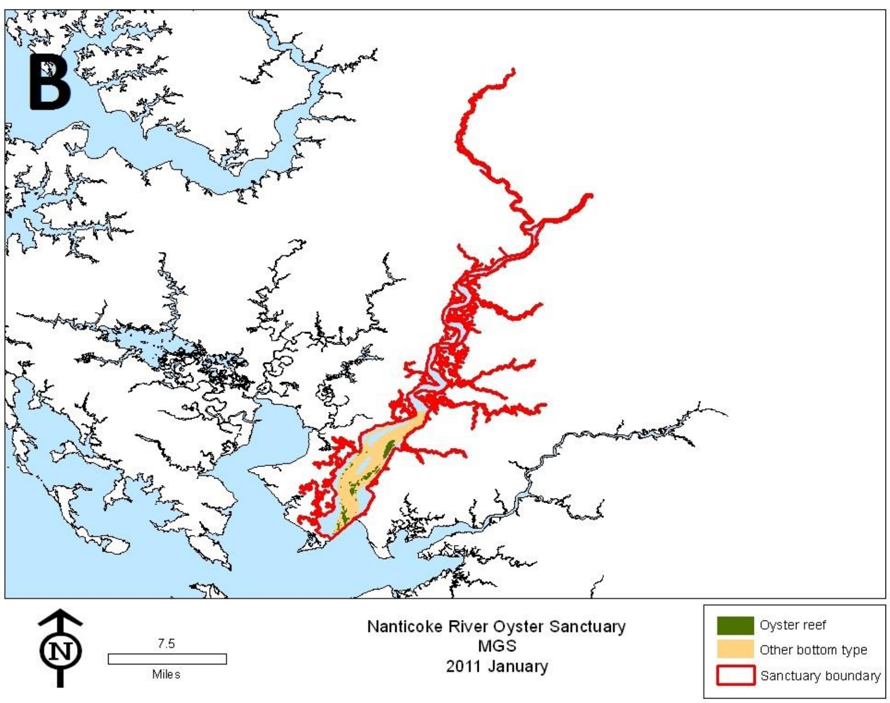


Figure A.27 -2. Nanticoke River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey of 1974-1883. (B) Data from Maryland Geological Survey from 2011. Tan and green colored areas depict areas examined during the surveys.

Table A.27-1. Replenishment planting activities occurring since 1990 in the area that is now established as Nanticoke River Sanctuary.				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Fresh Shell	2.32	8.56	-
1990	Wild Seed	9.18	20.31	-
1991	Wild Seed	30.06	23.79	-
1992	Wild Seed	43.78	16.85	-
1993	Wild Seed	5.14	3.81	-
1994	Dredged Shell	3.75	48.19	-
1995	Dredged Shell	11.02	31.02	-
1995	Fresh Shell	5.13	22.35	-
1995	Wild Seed	24.37	18.97	-
1996	Fresh Shell	8.39	30.97	-
1996	Wild Seed	9.88	32.03	-
1997	Fresh Shell	14.84	27.00	-
1997	Wild Seed	25.13	49.87	-
1998	Wild Seed	27.98	24.05	-
1999	Fresh Shell	6.86	31.50	-
1999	Wild Seed	5.98	7.71	-
2000	Wild Seed	12.07	13.28	-
2002	Wild Seed	7.50	11.38	-
2003	Wild Seed	10.13	12.06	-
2004	Wild Seed	4.45	4.14	-
2007	Wild Seed	5.94	4.05	-
2008	Wild Seed	5.49	2.00	-

Oyster Population Characteristics

The Fall Survey has sampled seven to twelve oyster bars in this area since 1990 with an average of nine sampled annually. The average number of live oysters per bushel (market, small, and spat) increased after sanctuary creation (Table A.27-2; Figure A.27-3) due to the increase in market-sized oysters and spat. The average number of market-sized oysters has increased steadily since 2010 with 2014 and 2015 counts the two highest since 1990 (61 and 97 oysters per bushel, respectively). The increase in market-sized oysters is most likely due to the cessation of harvest coupled with consistently strong spat sets.

Table A.27-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Nanticoke River Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.		
	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 184	6 / 53
Number of Live Oysters per Bushel	75 ± 9	97 ± 10
Number of Live Small-Sized Oysters per Bushel	38 ± 6	29 ± 3
Number of Live Market-Sized Oysters per Bushel	31 ± 3	54 ± 10
Live Oyster Biomass (g Dry Weight per Bushel)	100 ± 9.8	193 ± 48.8
Mortality (%)	18.3 ± 3.2	5.0 ± 0.7

Paynter et al. (2012)[64] conducted a patent tong survey in the Nanticoke River Sanctuary in 2012. They found densities of 3.1 oysters m^{-2} on exposed shell and a 1.3 oysters m^{-2} on shell mixed with other substrates. Oyster density increased with volume of shell.

Oyster Size Structure

Oysters collected by the Fall Survey in this area on Wilson Shoal bar have been measured since 1990 (Figure A.27-4). There has been in increase in large oysters since sanctuary establishment. The most recent year for which data are available (2015) shows the presence of spat, small, and market-sized oysters. Shell height data from Paynter et al. (2012) agree well with the Fall Survey data.

Biomass

Biomass of oysters from Wilson Shoal was calculated based on the number and size of oysters collected during the Fall Survey. Average biomass after sanctuary creation was greater than biomass before sanctuary creation (Table A.27-2; Figure A.27-5). Biomass has increased steadily since 2010, with the highest biomass of 405 grams dry weight per bushel occurring in 2015. This gain is due to the increasing number and size of oysters in the population.

Paynter et al. (2012)[65] estimated biomass density to be 3.2 g m^{-2} on shell substrate and 0.9 g m^{-2} on shell mixed with other substrates.

[64] Paynter, K. H. Lane, and A. Michaelis. 2012. Oyster Population and Habitat Assessment, Nanticoke River. Draft report to The Nature Conservancy. 26 pp.
[65] IBD

Recruitment (Spatfall)

Based on Fall Survey data, average spatfall has ranged from 0 to 43 spat per bushel, with the highest spatset occurring in 1994 (Figure A.27-3). The longest period of consecutive annual spatfall occurred from 2006 to 2015.

Mortality

Based on Fall Survey box counts, the average mortality after sanctuary establishment was lower than mortality before sanctuary establishment (Table A.27-2; Figure A.27-6). The highest mortality was seen in 2002, a year of high mortality throughout the bay.

Disease

From 1990 to 2015, dermo prevalence has ranged from 40% to 100% (Figure A.27-7). Dermo prevalence has been generally high, greater than 80% in 21 of the 26 years that disease information was collected. Dermo intensity ranged from 0.9 to 4.8, slightly lower than the lethal level of 5 on a 0 to 7 scale.

In October 2012, Paynter et al. (2012)[66] found a dermo prevalence of 80% in the northern part of the river and 100% in the southern part of the river. These data agree well with the department's data showing high dermo prevalence in 2012. Dermo intensity (0 to 5 scale) in the northern part of the river was 1.01, and in the southern part of the river 2.54.

MSX prevalence ranged from 0% to 57% from 1990 to 2015 (Figure A.27-7). From 1999 to 2002, there was an extended period of low-level MSX prevalence.

[66] Paynter, K. H. Lane, and A. Michaelis. 2012. Oyster Population and Habitat Assessment, Nanticoke River. Draft report to The Nature Conservancy. 26 pp.

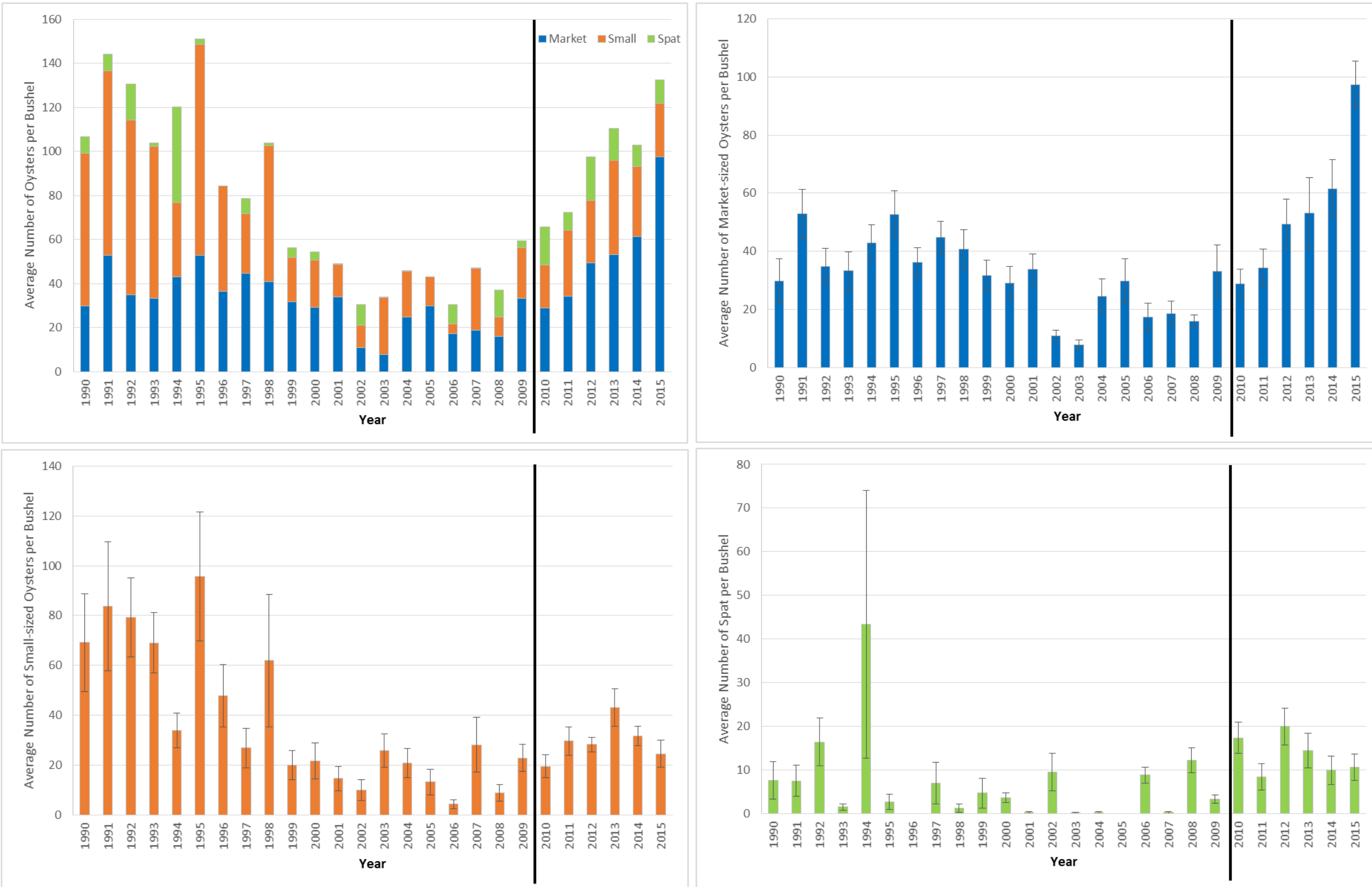
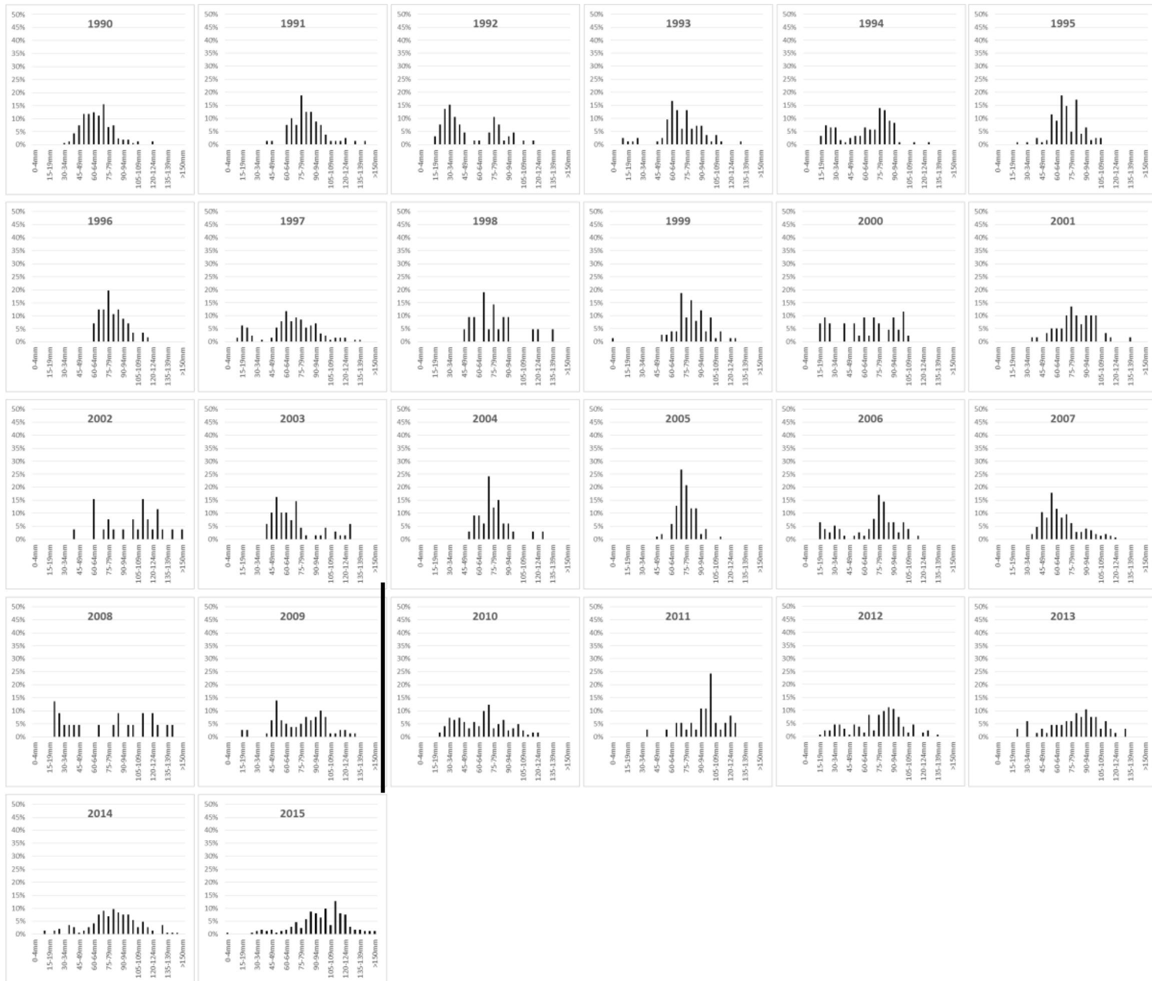


Figure A.27-3. Average number of live oysters per bushel of material by size class in the Nanticoke River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

Frequency (%)



Height (mm)

Figure A.27-4. Shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the Nanticoke River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Wilson Shoal bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

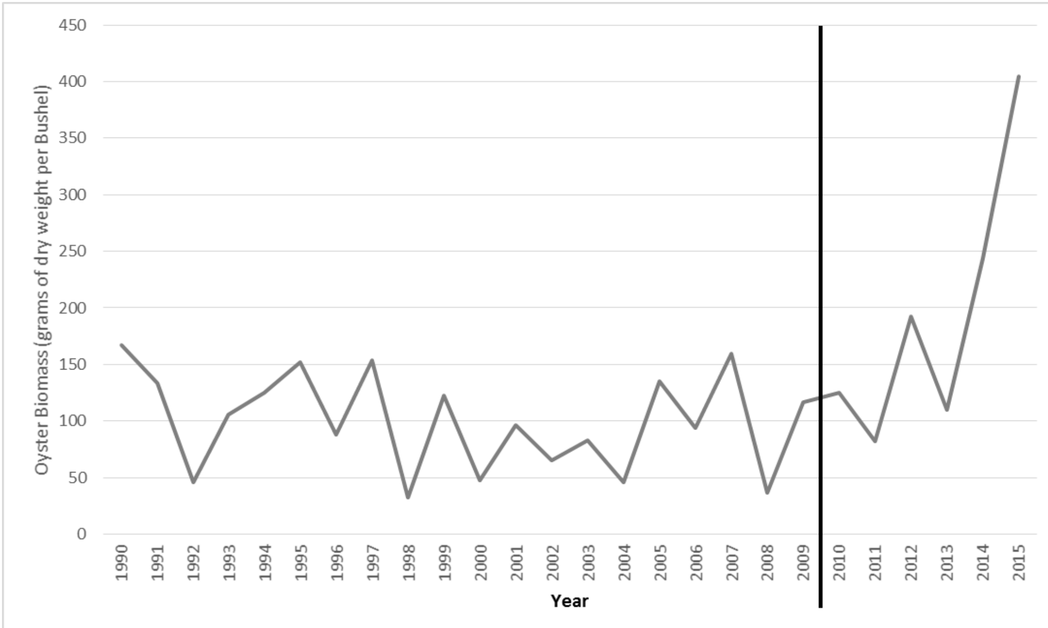


Figure A.27-5. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Nanticoke River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Wilson Shoal bar. Black line indicates the date the sanctuary was established.

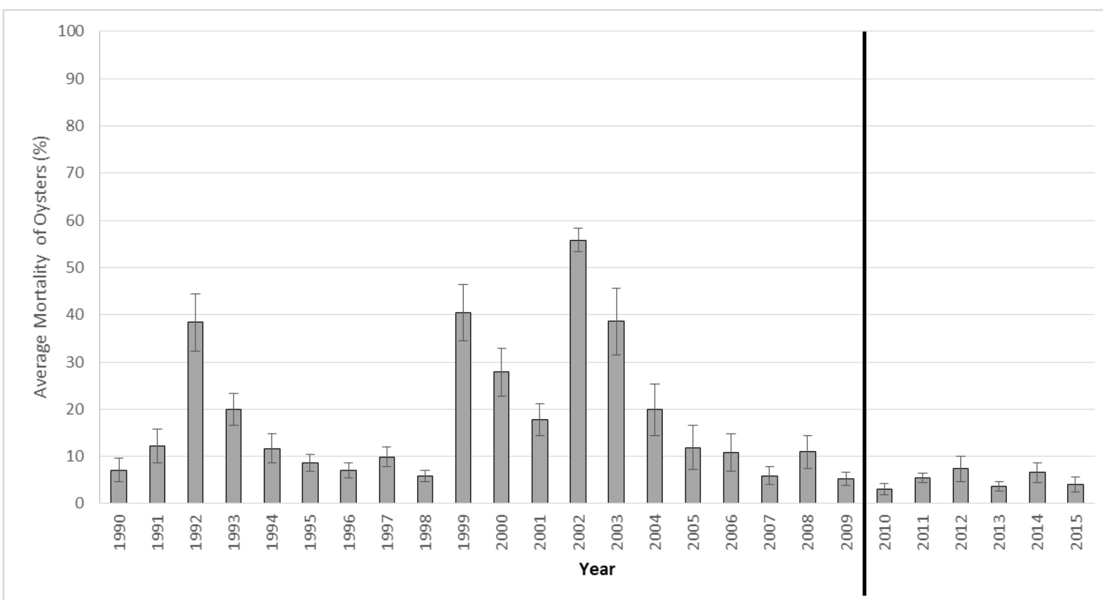


Figure A.27-6. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Nanticoke River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

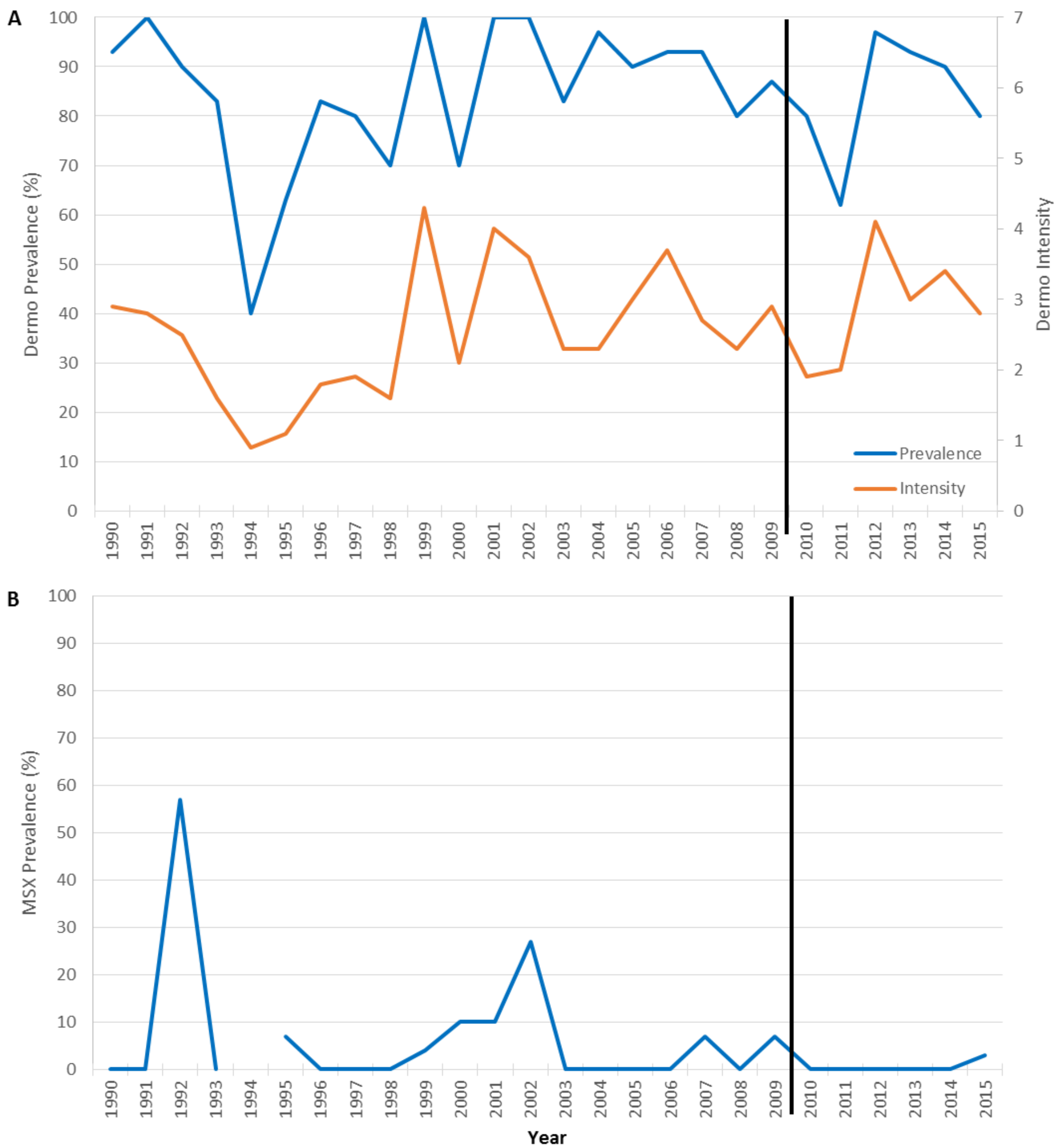


Figure A.27-7. Oyster disease prevalence and intensity from 1990 to 2015 in the Nanticoke River Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Wilson Shoal bar.

Harvest

The sanctuary encompasses 85% of the 19,661 acres in NOAA Code 062. There is one bar, Middleground, within NOAA Code 062 which is partially outside the sanctuary boundary and open to harvest. Harvest reported by seafood dealers prior to the establishment of the sanctuary peaked in the 1997-1998 season at 23,747 bushels (Figure A.27-8). The average seasonal harvest from 1990 to 2009 was 5,405 bushels. In 2009-2010 watermen reported a harvest of 4,009 bushels.

After the 2009-2010 season, 85% of the NOAA Code area was a sanctuary where harvest is prohibited. Catch increased after 2010 despite the reduction in area open to harvest. Catch reported by watermen peaked during the 2012-2013 season. Harvest reported on seafood dealer buy tickets peaked during the 2014-2015 season with the second highest catch since 1990.

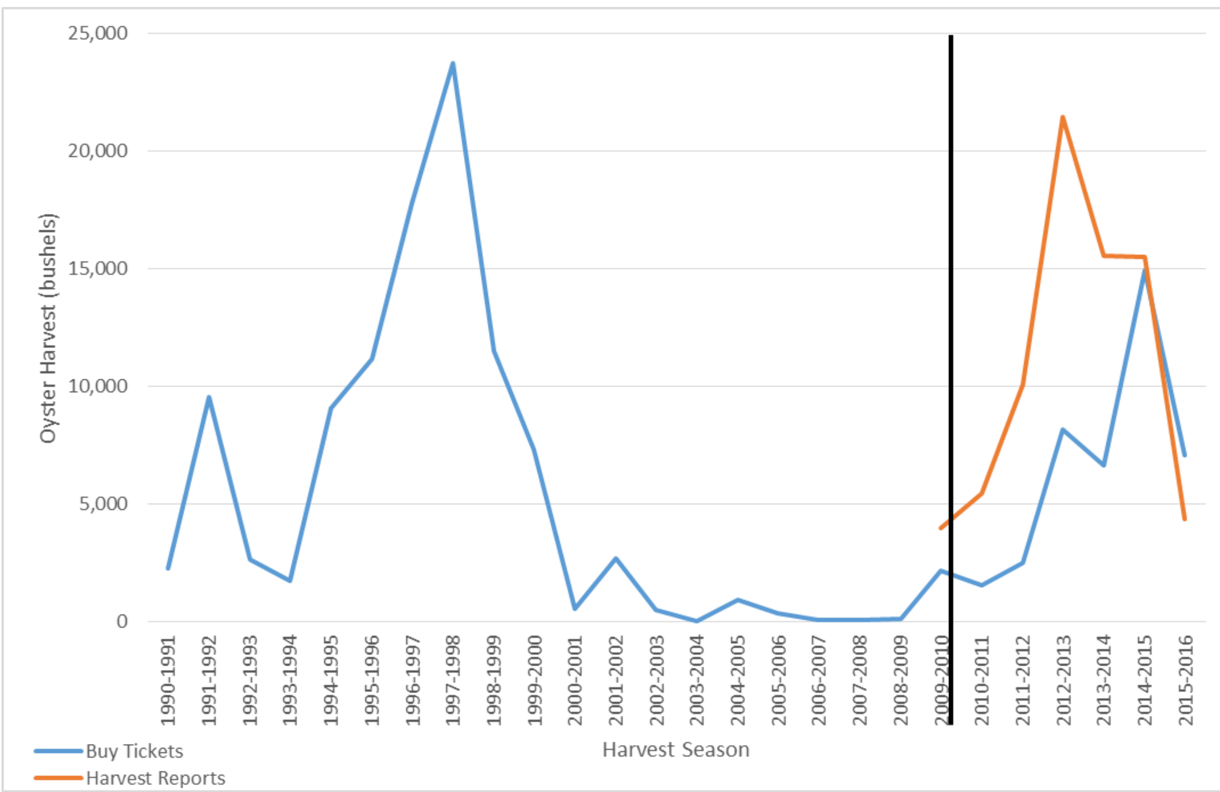


Figure A.27-8. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 062 (Nanticoke River). In 2010, 85% of NOAA Code became an oyster sanctuary (denoted by the black line) where harvest is prohibited.

Environmental Conditions and Ecosystem Services

Maryland's Eyes on the Bay Program monitors monthly water quality at station ET6.2 (38.34133, -75.88834) in this area (Figure A.27-9). Salinity, water temperature and secchi depth minimum and maximum ranges have remained similar over the 25 year period. Variability of total nitrogen, chlorophyll a, and total suspended solids have decreased in more recent years. Salinity has often been low for reproduction since 1990.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

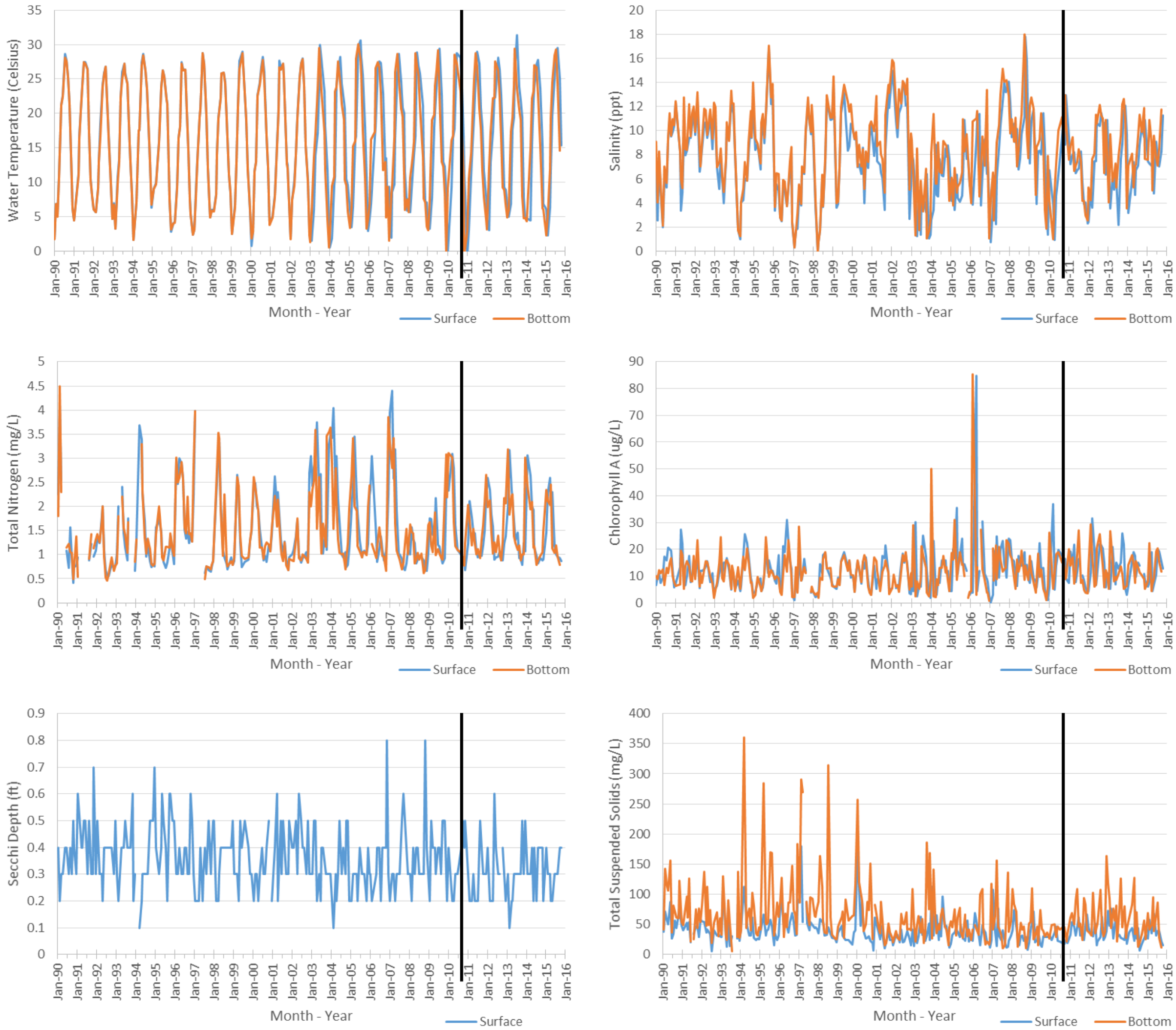


Figure A.27-9. Water quality data collected at Station ET6.2 in Nanticoke River. Black line denotes the date the sanctuary was established.

Section A.28: Neal Addition Sanctuary

The Neal Addition Sanctuary is located in the middle Patuxent River, a low salinity (less than 12 ppt) region (Figure A.28-1). The sanctuary was created in 2001 as an Army Corps of Engineers project examining three-dimension habitat. It encompasses seven acres all of which is one historic oyster bar (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments).

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.28-2). Of the 6.7 acres surveyed within the sanctuary, 4.4 acres (65%) were classified as oyster reef habitat. No bottom surveys using side scan sonar have been conducted since the Bay Bottom Survey.

Restoration and Replenishment Activities

In 1999, 2.89 acres were planted with 24,408 bushels of dredged shell during a temporary closure for an Army Corps project. In 2008, a restoration planting of 10.23 million hatchery spat-on-shell was placed on 4.99 acres.

Oyster Population Characteristics

The Fall Survey has taken one sample in this area since 2000. No samples were collected prior to 2000. Since only one sample was taken prior to the establishment of the sanctuary, it is difficult to compare population characteristics before and after sanctuary establishment (Table A.28-1). The average number of live oysters per bushel (market, small, and spat) from 2000 to 2015 ranged from 16 to 464 per bushel (Figure A.28-3). The average number of small-sized oysters per bushel ranged from 2 to 410 per bushel and average number of market-sized oysters per bushel ranged from 4 to 102 per bushel.

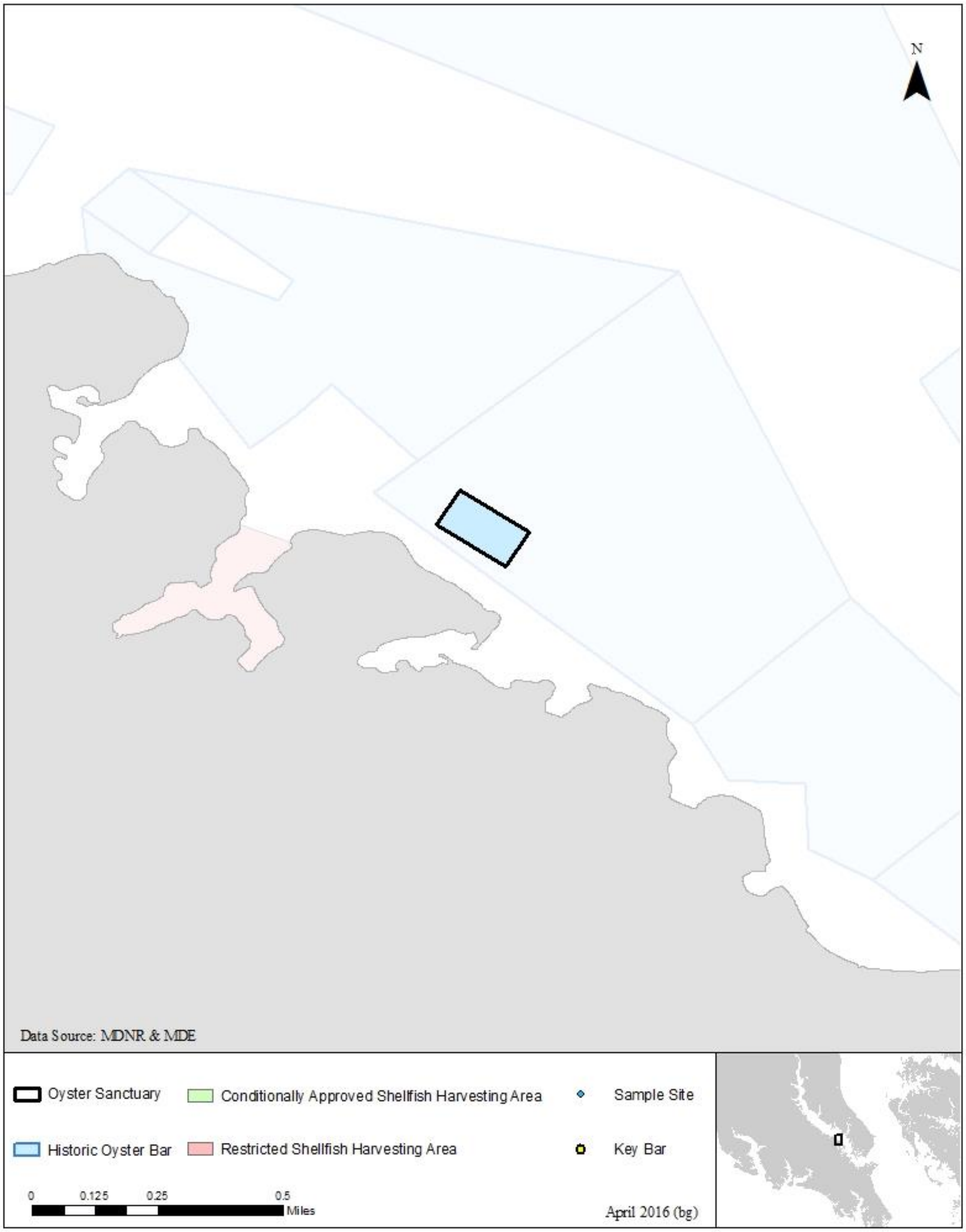


Figure A.28 -1. Neal Addition Sanctuary.

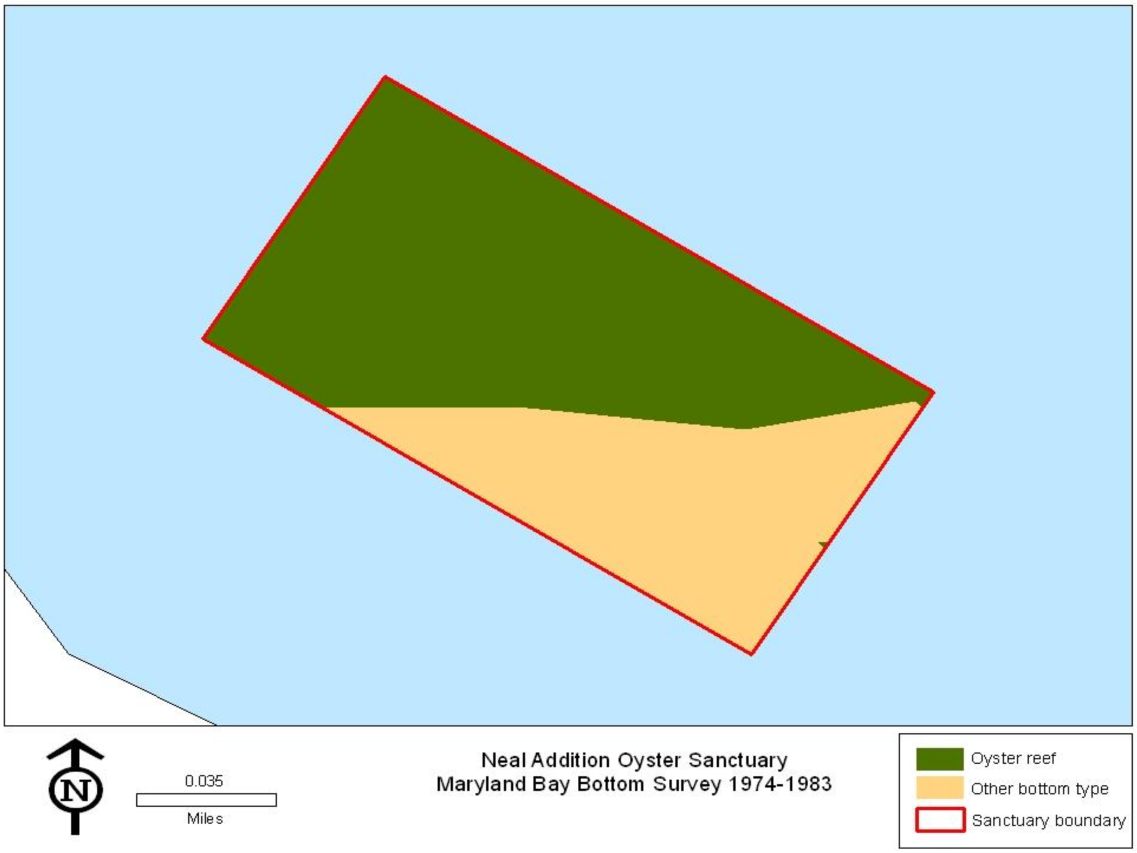


Figure A.28 -2. Neal Addition Sanctuary bottom types. Data from Maryland Bay Bottom Survey of 1974-1983. Tan and green colored areas depict areas examined during the surveys.

Table A.28-1. Oyster population characteristics based on the Fall Survey before and after the establishment of the Neal Addition Sanctuary in 2001. ND = No Data. Values are given as mean ± standard error.		
	1990-2000	**2001-2015**
Number of Years Sampled / Number of Samples	1 / 1	15 / 15
Number of Live Oysters per Bushel	464	126 ± 21
Number of Live Small-Sized Oysters per Bushel	410	65 ± 19
Number of Live Market-Sized Oysters per Bushel	54	55 ± 8
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	0	22.9 ± 6.1

No patent tong population surveys have been conducted by the Department since 1990.

Oyster Size Structure

The Fall Survey has not measured oyster shell heights in this area since 1990.

Biomass

The Fall Survey has not calculated biomass in this area since 1990.

Recruitment (Spatfall)

Based on the Fall Survey spat data, average spatfall ranged from 0 to 30 spat per bushel, with the largest spatset occurring in 2002 (Figure A.28-3). Spatset has occurred annually since the establishment of the sanctuary with the exception of 2004 and 2011.

Mortality

Based on Fall Survey box counts, the average mortality ranged from 0% to 94%, with the highest mortality occurring in 2002 (Table A.28-1; Figure A.28-4). Since 2011, average mortality has been relatively low.

Disease

Oysters collected by the Fall Survey in this area have not been analyzed for disease since 1990.

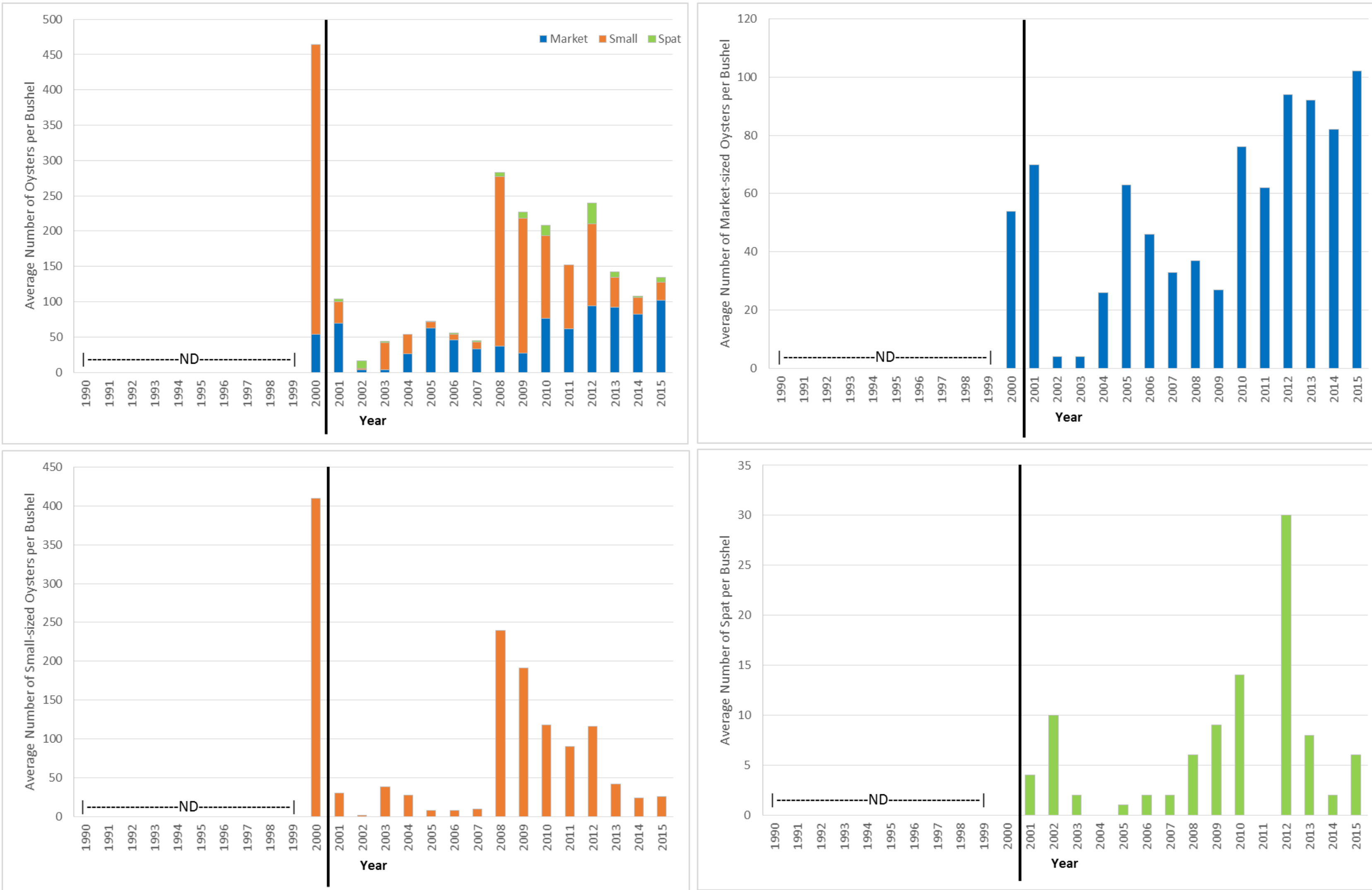


Figure A.28-3. Average number of live oysters per bushel of material by size class in the Manokin River Sanctuary. The black line denotes the year the sanctuary was established. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data

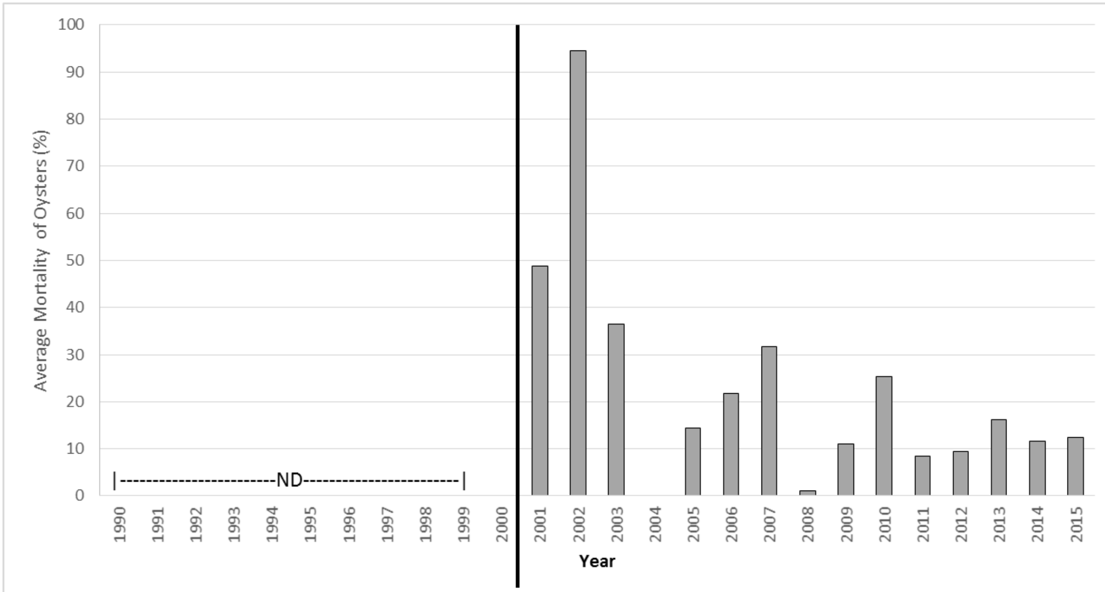


Figure A.23-4. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Neal Addition Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. ND = No Data

Harvest

The sanctuary encompasses less than 1% of the 4,573 acres in NOAA Code 268. Because harvest from NOAA Code 268 is likely to have come from areas outside the sanctuary, seafood dealer reports for this NOAA Code cannot be used to assess harvest in this area. Oyster harvester reports were not collected prior to the establishment of the sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or examining oyster ecosystem services in this area.

Section A.29: Oxford Lab Sanctuary

The Oxford Lab Sanctuary is located in the Tred Avon River, a low salinity (less than 11 ppt) region (Figure A.29-1). The sanctuary was created in 1961 and encompasses 36 acres of which 3 (7%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There is one historic oyster bar within the sanctuary. This was Maryland's first oyster sanctuary and was created to support the Cooperative Oxford Research Laboratory's oyster research needs.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.29-2). Of the 27.1 acres surveyed, 24.8 (91%) were classified as oyster reef habitat. In 2009, NOAA Chesapeake Bay Office surveyed a portion of the sanctuary using sonar. Of the 12.4 acres surveyed, 1.4 acres (11%) were classified as oyster reef habitat. Greater coverage of the area during the Bay Bottom Survey as compared to NOAA's sonar work in Oxford Lab Sanctuary precludes comparison of the two surveys.

Restoration and Replenishment Activities

In 2003, approximately 31,000 bushels of dredge shell were planted on 4.81 acres for restoration purposes.

Marylanders Grow Oysters, a public outreach program, has planted oysters since 2008 at one site in the Oxford Lab Sanctuary.

Oyster Population Characteristics

The Fall Survey has not sampled within this area since 1990, nor has the Department conducted any patent tong surveys.

Paynter et al. (2011) found a maximum density of 11.8 oysters m^{-2} on a hatchery planting eight to nine years after placement.[67]

Oyster Size Structure

Paynter et al. (2011) found an average shell height of 99.2 mm on a hatchery planting eight to nine years after placement.[68]

[67] Paynter, K.T. 2011. 2008 Sanctuary Assessment. Report to the U.S. Army Corps of Engineers, Baltimore District. 67 pp. http://www.nab.usace.army.mil/Portals/63/docs/Environmental/Oysters/2008SanctuaryAssessment.pdf

Disease

Paynter et al. (2011) found a dermo prevalence of 93% on an eight to nine year old hatchery planting in 2008.[69]

Harvest

The sanctuary encompasses less than 1% of the 6,869 acres in NOAA Code 637. Because harvest from NOAA Code 637 is likely to have come from areas outside the sanctuary, seafood dealer reports cannot be used to assess harvest in this area. Oyster harvester reports were not collected prior to the establishment of the sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) and oyster ecosystem services in this area.

[68] Paynter, K.T. 2011. 2008 Sanctuary Assessment. Report to the U.S. Army Corps of Engineers, Baltimore District. 67 pp. http://www.nab.usace.army.mil/Portals/63/docs/Environmental/Oysters/2008SanctuaryAssessment.pdf

[69] IBID

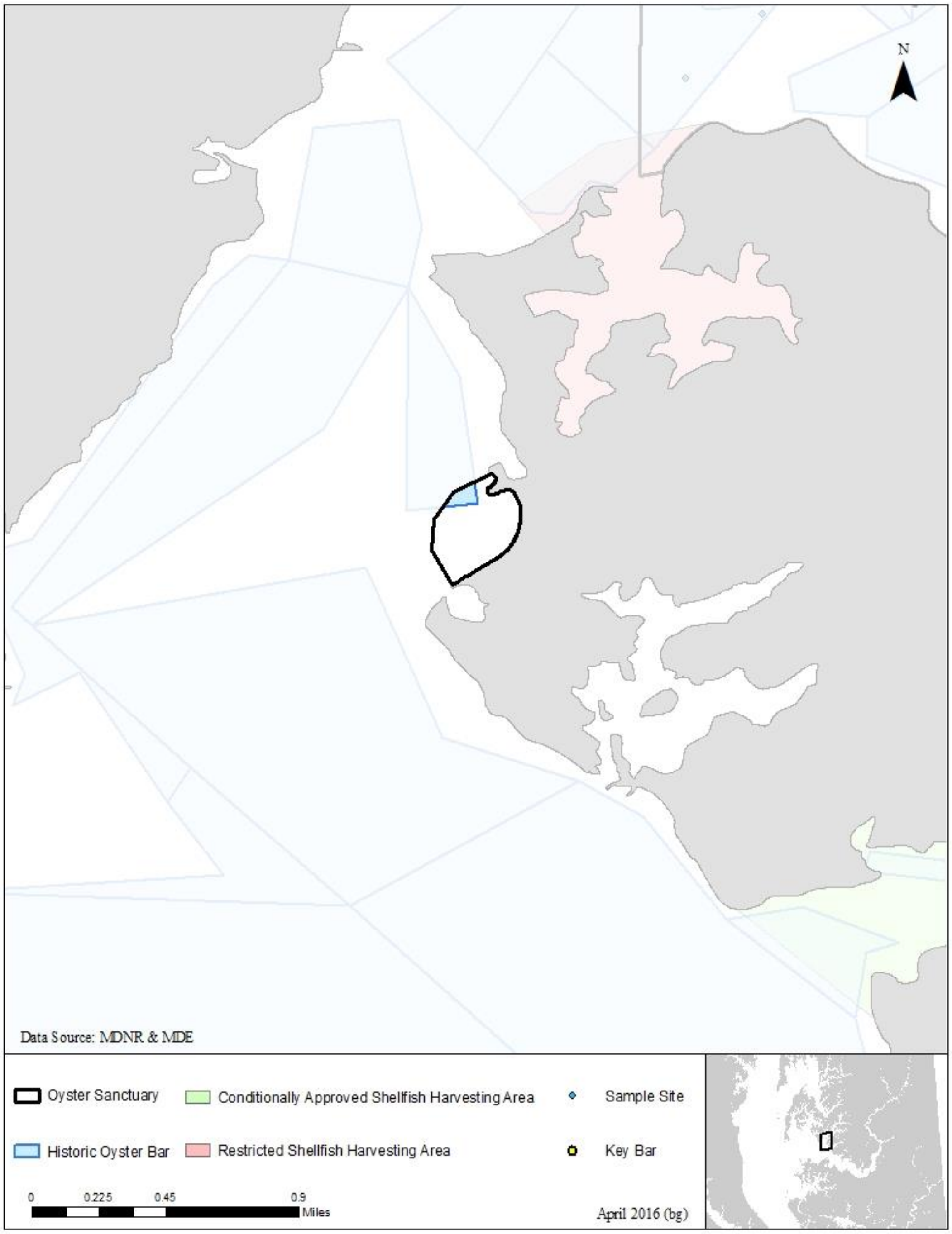


Figure A.29 -1. Oxford Lab Sanctuary.

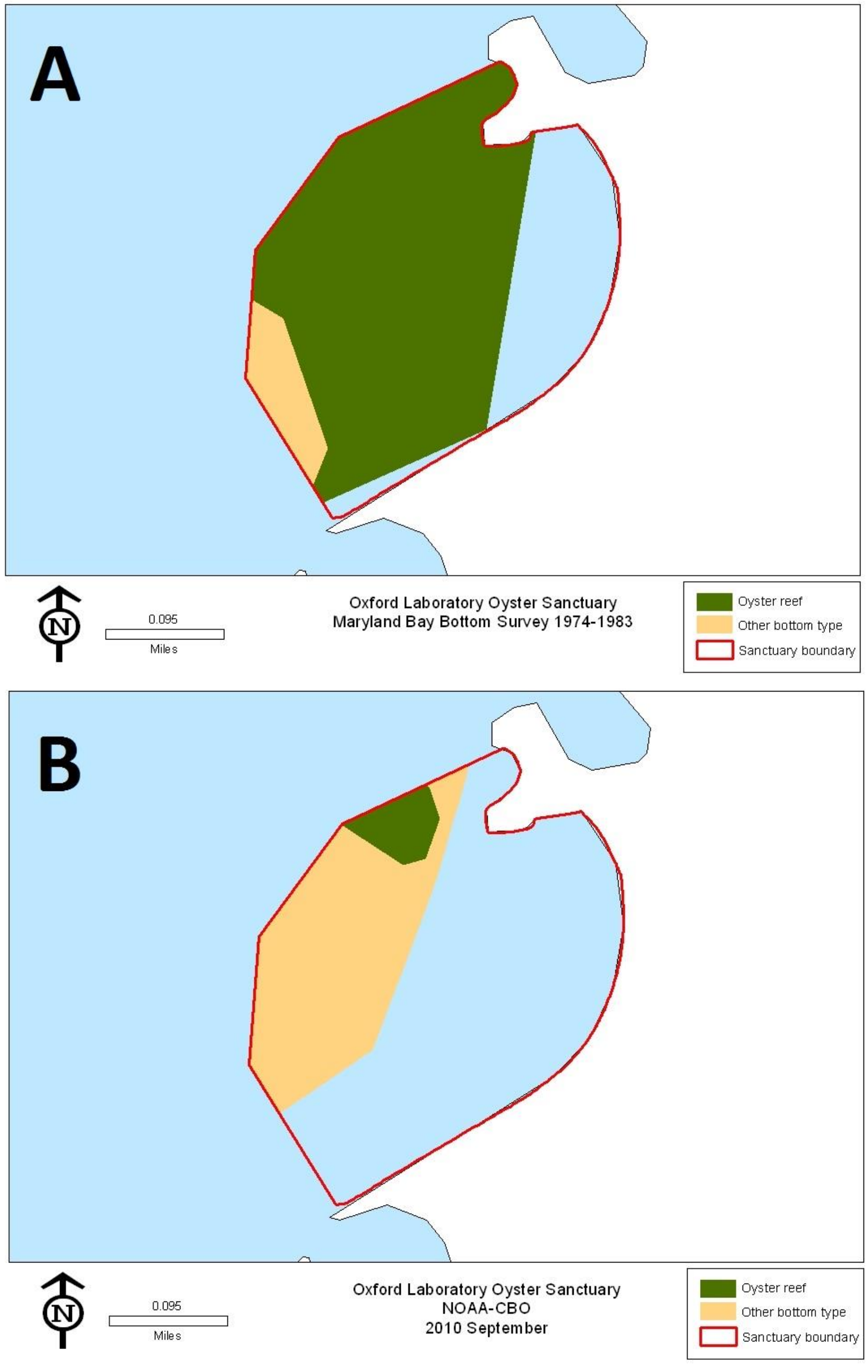


Figure A.29 -2. Oxford Lab Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from NOAA Chesapeake Bay Office in 2010. Tan and green colored areas depict areas examined during the surveys.

Section A.30: Piney Point Sanctuary

The Piney Point Sanctuary is located in St. George Creek, a low salinity (less than 12 ppt) tributary of the lower Potomac River (Figure A.30-1). The sanctuary was created in 1986 to support the Piney Point Aquaculture Center's logistical and research needs and encompasses 13 acres in which there is no historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). The sanctuary is located in a conditionally restricted shellfish harvest area as classified by Maryland Department of the Environment due to the potential for contamination by fecal coliform and other bacteria.

Bottom Habitat Characteristics

This area has not been surveyed for bottom types during either the Maryland Bay Bottom Survey (1974 to 1983) or during more recent side scan sonar surveys.

Restoration and Replenishment Activities

No replenishment or restoration efforts have taken place in the area since 1990.

Oyster Population Characteristics

The Fall Survey has not taken any samples within this area, nor has a patent tong survey been conducted by the Department since 1990.

Harvest

No oyster harvest has been recorded from this area prior to it becoming a sanctuary in 1986. The sanctuary is encompassed by NOAA Code 177 (total of 78,000 acres).

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental condition (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

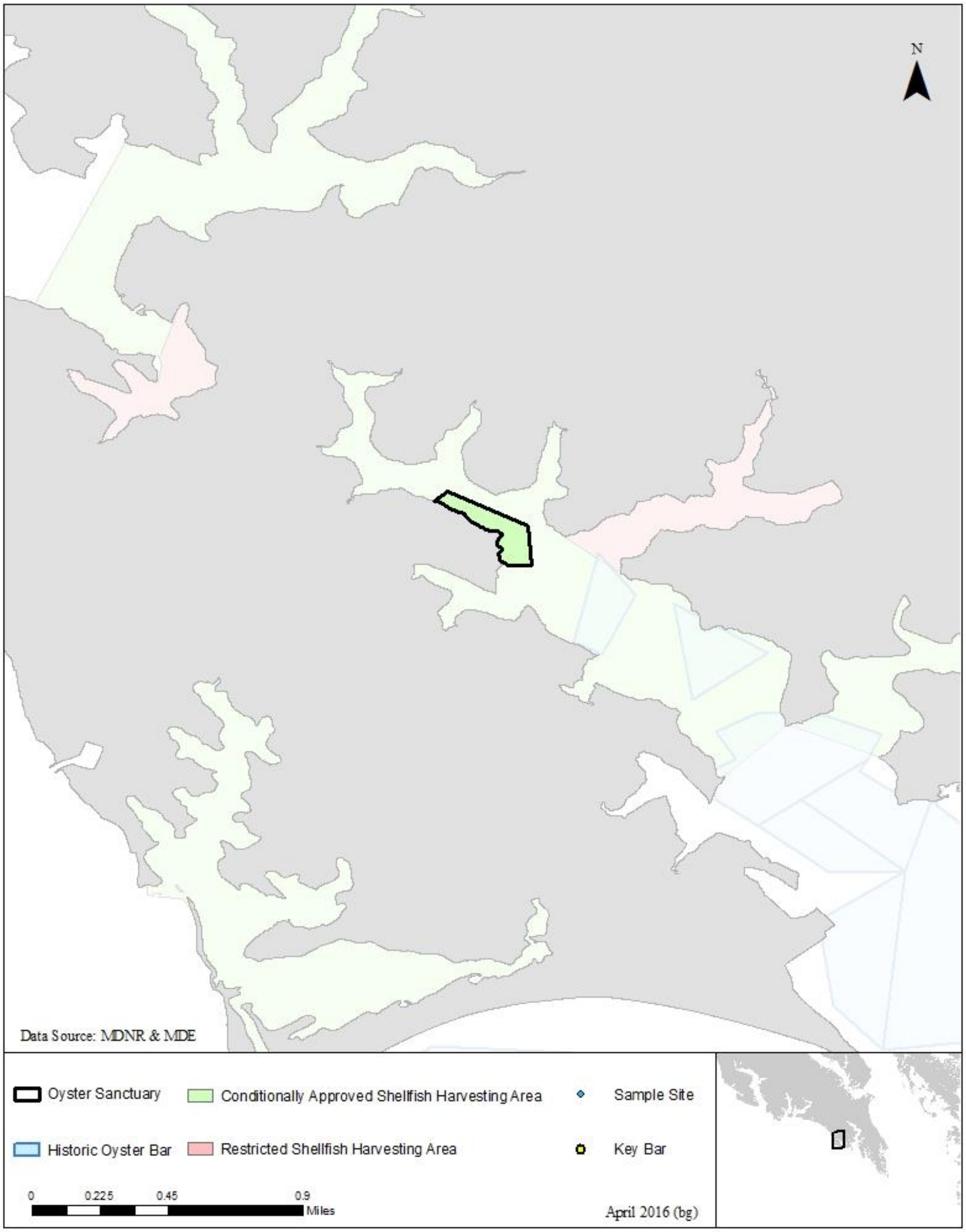


Figure A.30-1. Piney Point Sanctuary.

Section A.31: Plum Point Sanctuary

The Plum Point Sanctuary is located in the middle-western portion of Maryland's Chesapeake Bay along the Calvert County shore in a medium salinity (12 to 14 ppt) region (Figure A.31-1). The sanctuary was created in 1999 and encompasses 6,209 acres of which 4,405 (71%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). Six historic oyster bars are within the sanctuary[70]. The sanctuary was one of four sanctuaries created in 1999 when legislation was passed opening up new areas to power dredging of oysters.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.31-2). Of the 5,847 acres surveyed within the sanctuary, 1,532 acres (26%) were classified as oyster reef habitat. No recent bottom side scan sonar surveys have been conducted.

Restoration and Replenishment Activities

No restoration or replenishment activities have taken place in this area since 1990.

Oyster Population Characteristics

No Fall Survey or patent tong samples have been taken in this area since 1990 by the Department.

Harvest

The sanctuary encompasses 3% of the 186,830 acres in NOAA Code 027. Given that harvest from NOAA Code 027 is likely to have come from areas other than the sanctuary, seafood dealer reports cannot be used to assess harvest in this area. Oyster harvester reports were not collected prior to the establishment of the sanctuary.

Environmental Conditions and Ecosystem Services

[70] See chart 17 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

Maryland's Eyes on the Bay Program monitors monthly water quality at station CB4.2W (38.64354, -76.50217) in this area (Figure A.31-3). Water quality was favorable for oysters except for periodic low salinity events.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

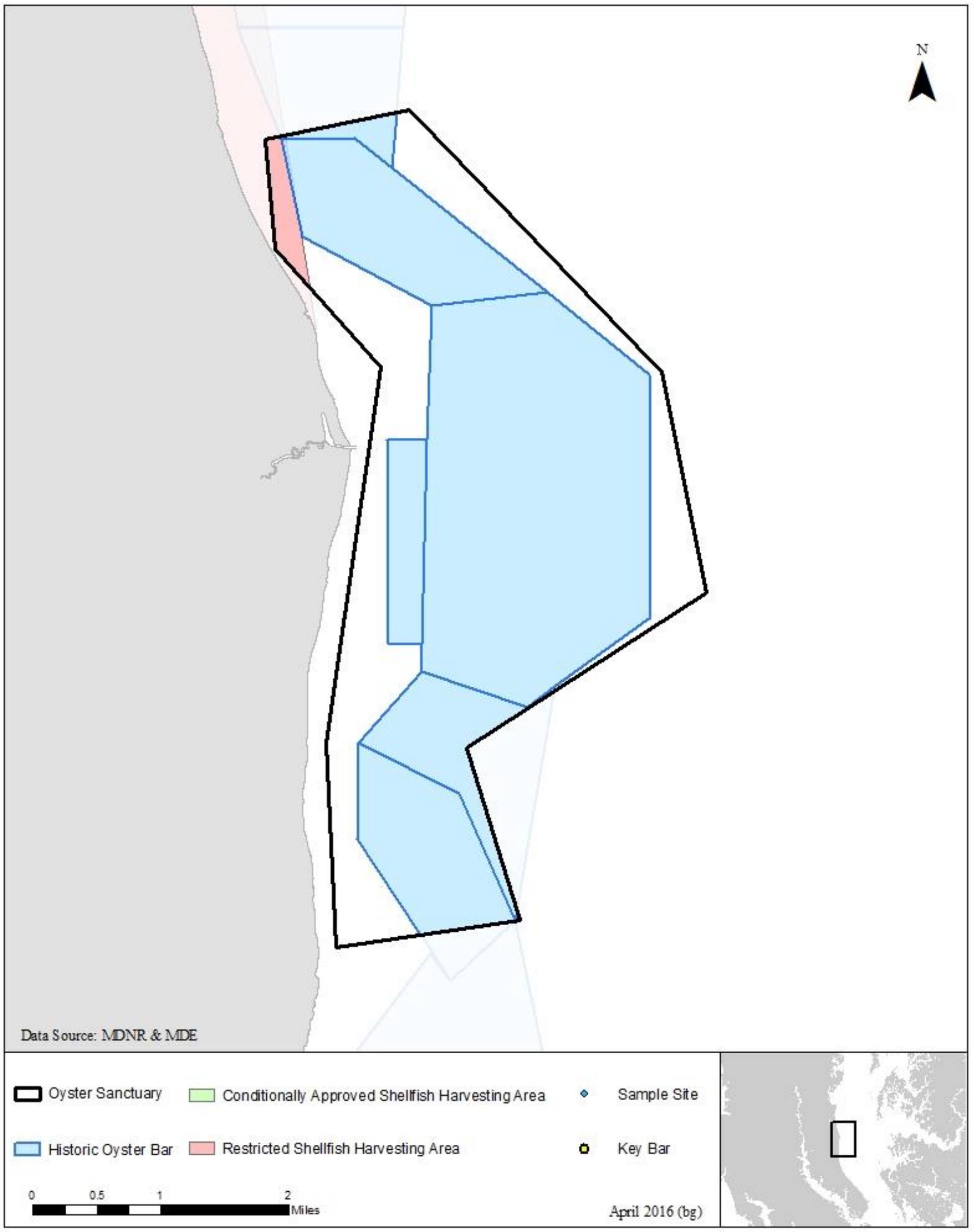


Figure A.31 -1. Plum Point Sanctuary.

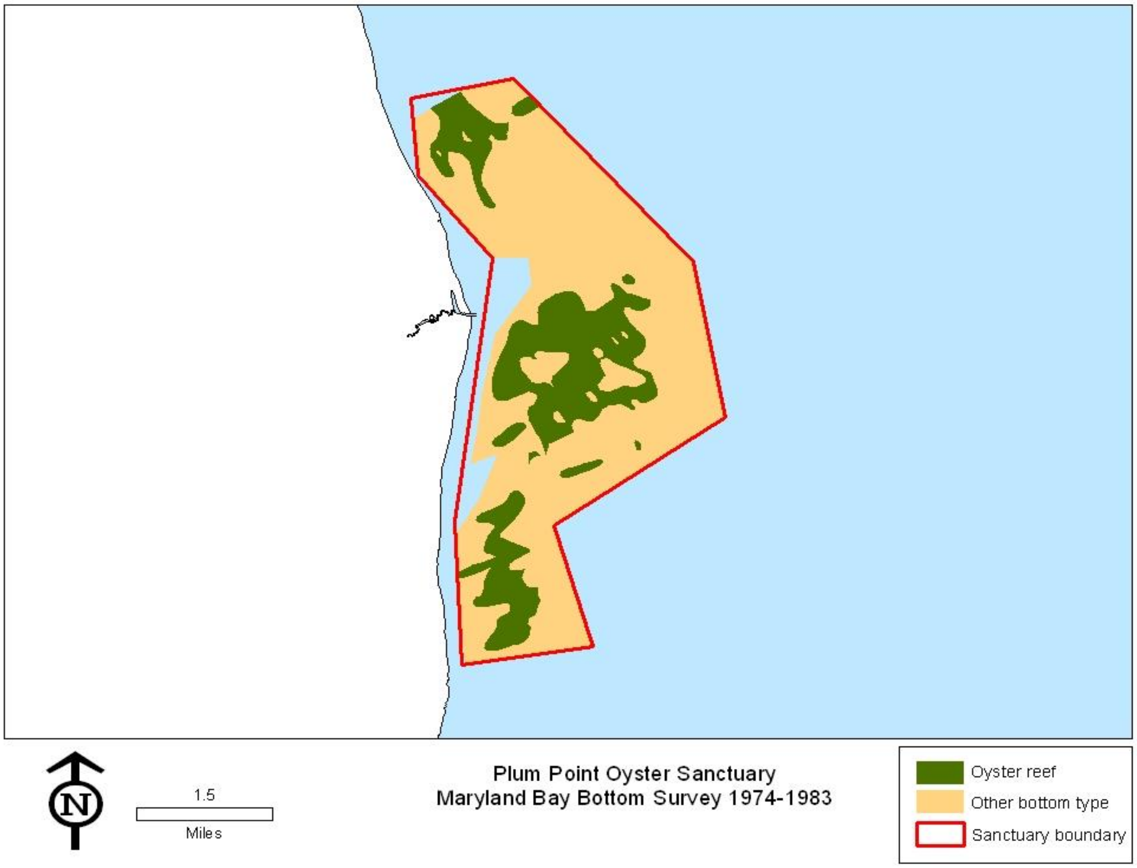


Figure A.31 -2. Plum Point Sanctuary bottom types. Data from Maryland Bay Bottom Survey of 1974-1983. Tan and green colored areas depict areas examined during the surveys.

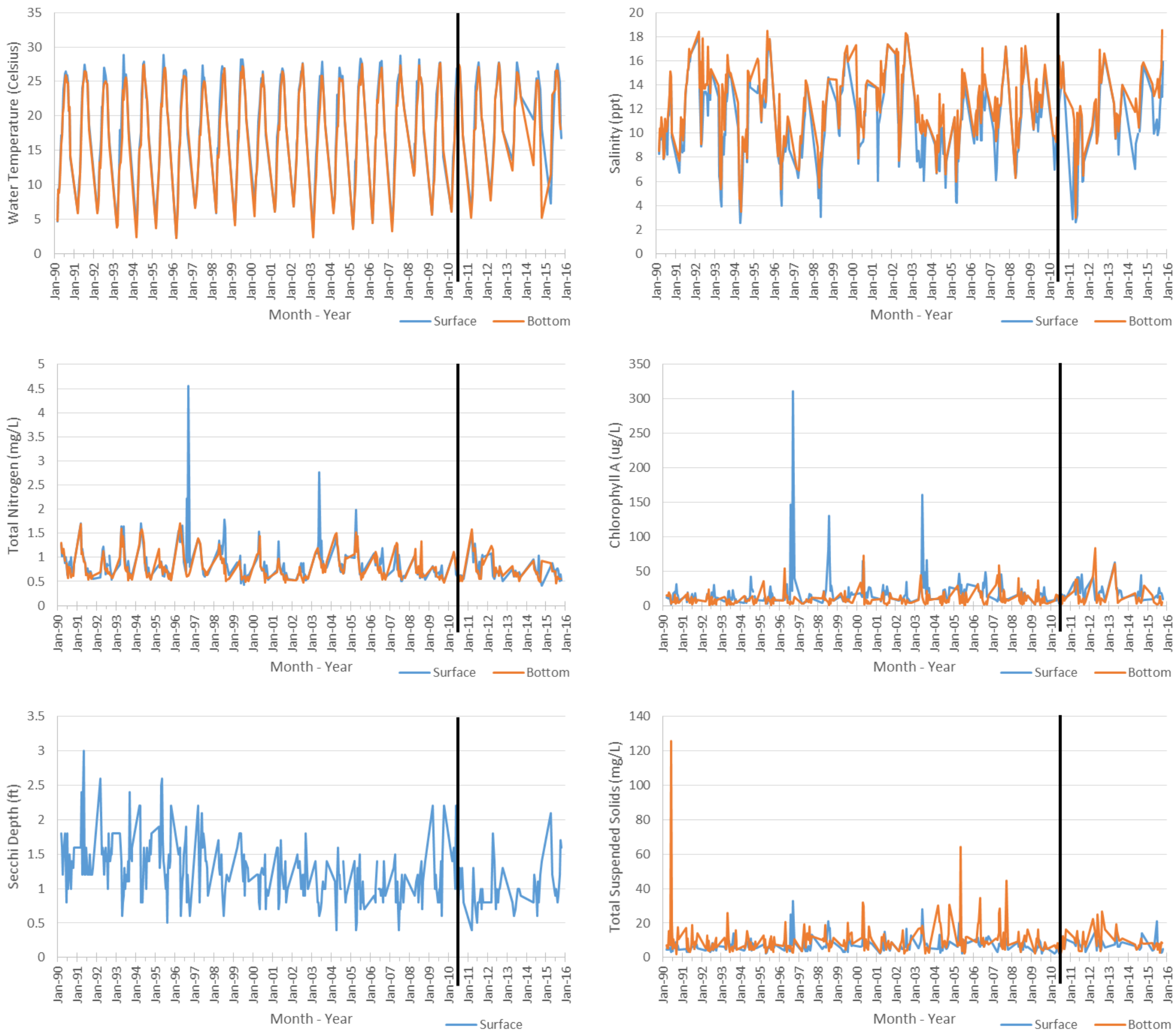


Figure A.31-3. Water quality data collected at Station CB4.2W in middle western shore of Chesapeake Bay. Black line denotes the date the sanctuary was established.

Section A.32: Point Lookout Sanctuary

The Point Lookout Sanctuary is located in the lower western portion of Maryland's Chesapeake Bay at the mouth of the Potomac River, a medium salinity (12 to 14 ppt) region (Figure A.32-1). The original sanctuary (104 acres) was created in 1999 as mitigation for a new power dredge area in St. Mary's County. The sanctuary was expanded to 399 acres in 2010, of which 396 acres (99%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 2 historic oyster bars within the sanctuary[71].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.32-2). Of the 503 acres surveyed within the sanctuary, 155 acres (31%) were classified as oyster reef habitat. No recent side scan sonar bottom surveys have been conducted.

Restoration and Replenishment Activities

Only restoration activities have occurred in this area since 1990. Wild seed and dredged shell were planted on the original sanctuary area created in 1999. In 2003, 26 reef balls were placed in the sanctuary (Table A.32-1).

Table A.32-1. Replenishment and restoration planting activities occurring since 1990 in the area that is now established as Point Lookout Sanctuary. S = planting occurring after the area was established as a sanctuary. ND = No Data.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1999 (S)	Wild Seed	113.93	ND	-
2001 (S)	Dredged Shell	10.43	489.17	-
2003 (S)	-	0.76	26 Reef Balls	

[71] See chart 40 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

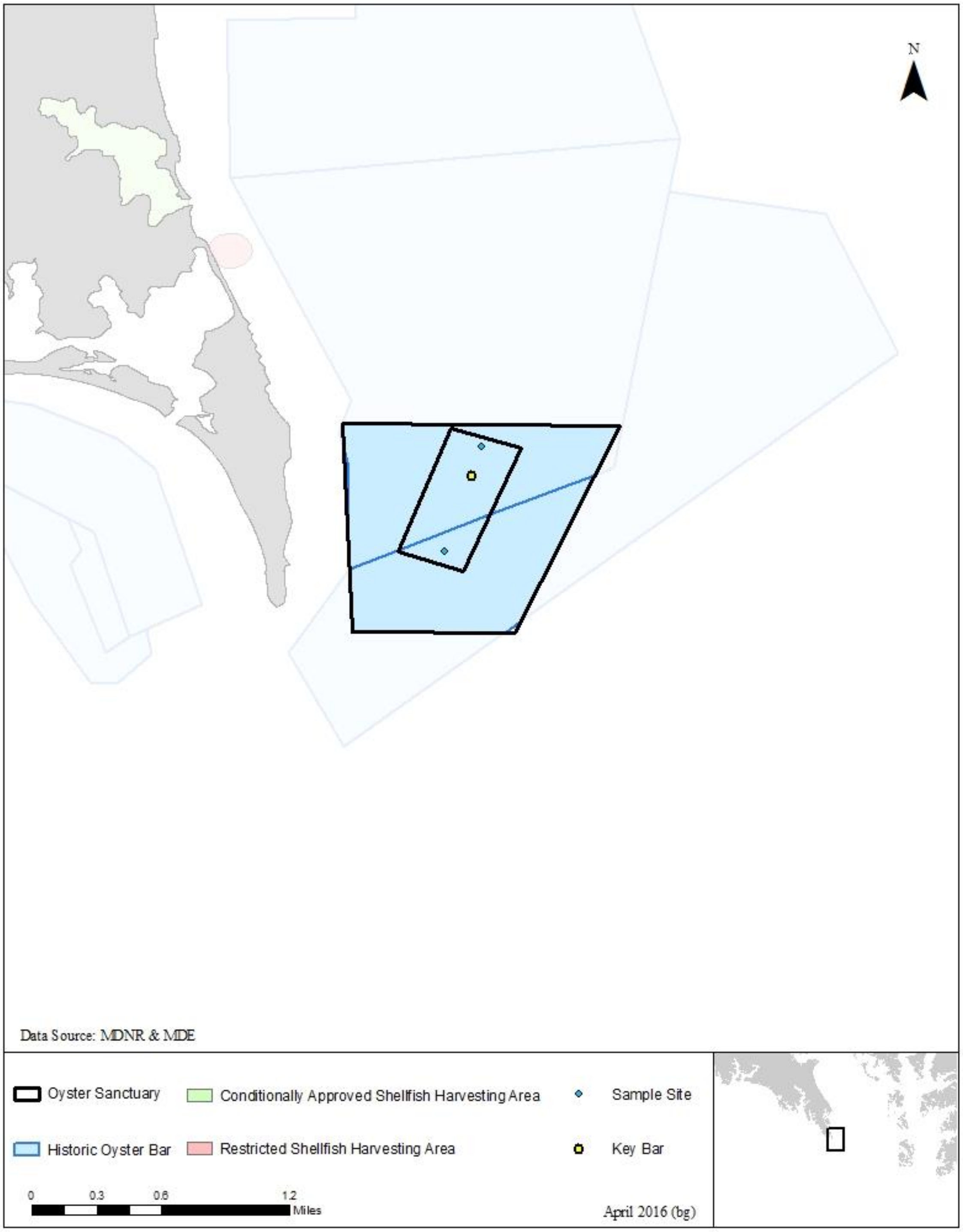


Figure A.32 -1. Point Lookout Sanctuary. The smaller black outline within the sanctuary represents the original footprint of the sanctuary in 1999.

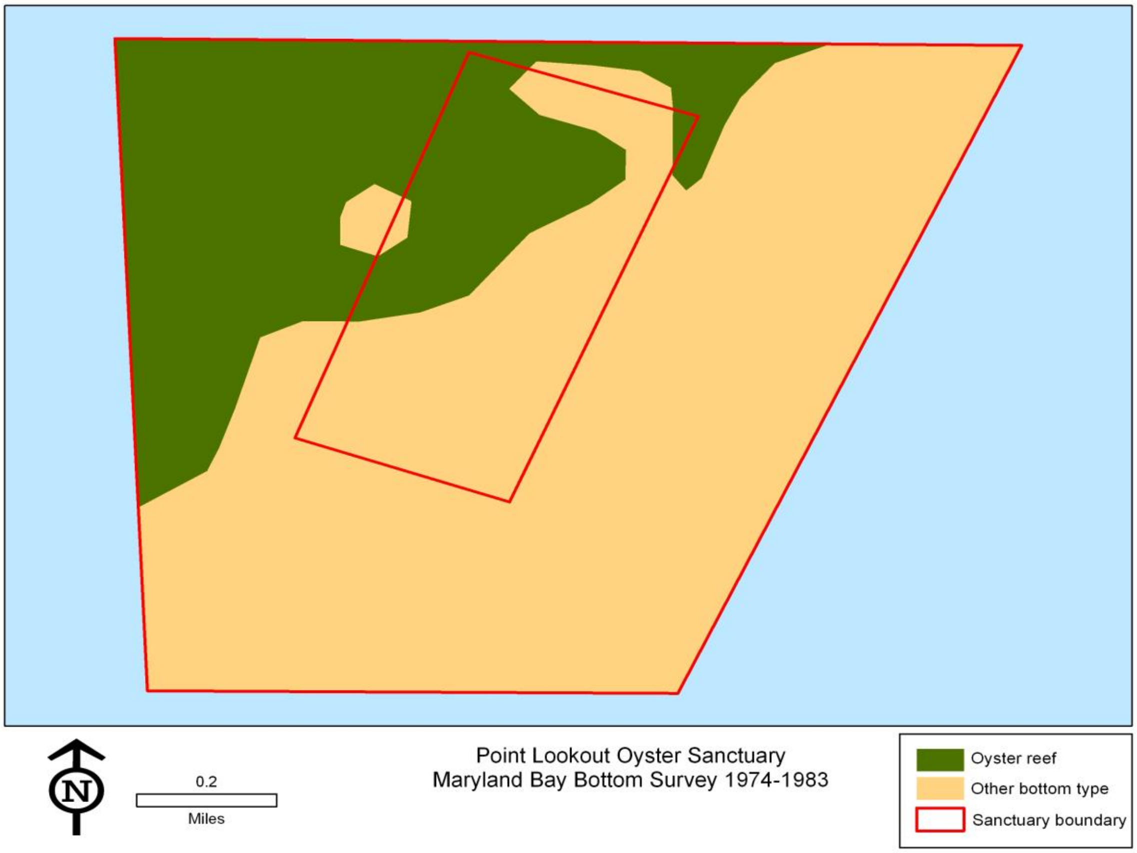


Figure A.32 -2. Point Lookout Sanctuary bottom types, Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled one oyster bar annually in this area since 2000 and in some years took 2 samples on the same bar. No samples were collected from 1990 to 1999. The average number of live oysters per bushel (market, small, and spat) was similar before and after sanctuary expansion (Table A.32-2; Figure A.32-3). A large spatfall in 2001 lead to an increase in small-sized oysters in 2002 and 2003 and market-sized oysters in 2004 and 2005. While the average number of small-sized oysters per bushel decreased after sanctuary establishment, the average number of market-sized oysters per bushel remained the same.

Table A.32-2. Oyster population characteristics based on the Fall Survey before and after the expansion of the Point Lookout Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.		
	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	10 / 14	6 / 8
Number of Live Oysters per Bushel	198 ± 27	159 ± 39
Number of Live Small-Sized Oysters per Bushel	85 ± 29	37 ± 7
Number of Live Market-Sized Oysters per Bushel	81 ± 21	75 ± 11
Live Oyster Biomass (g Dry Weight per Bushel)	ND	107 ± 14.7
Mortality (%)	18.7 ± 5.2	19.3 ± 2.7

A patent tong population survey was conducted in 2014 (Figures A.32-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 1.82 ± 0.53 oysters m^{-2} (mean ± standard error, n= 160), with the highest densities found on plantings in the old St. Mary's sanctuary area. Densities of small-sized oysters and market-sized oysters were similar (0.85 ± 0.26 and 0.89 ± 0.28 oysters m^{-2}, respectively). Eighty-one percent of the samples collected had no live oysters or boxes. Live oyster density increased with the volume of shell (Figure A.32.5).

Oyster Size Structure

Oysters collected by the Fall Survey in this area on Point Lookout bar have been measured since 2010 (Figure A.32-6). Oysters were also measured during the 2014 patent tong population survey (Figure A.32-7). Spat, small oysters, and market sized oysters are all represented in the size distribution.

Biomass

Biomass of oysters has been calculated from Fall Survey samples since 2010 when the sanctuary was expanded (Table A.32.2; Figure A.32-8). Biomass ranged from 58 to 166 grams of dry weight per bushel material, with a sharp increase from 2013-2015.

Recruitment (Spatfall)

Based on Fall Survey samples from 2000 to 2015, spatfall ranged from 0 to 198 spat per bushel (Figure A.32-3). The highest spatsets occurred in 2001 and 2015. With the exception of 2004, spatfall occurred annually. A total of 13 spat were collected during the 2014 patent tong survey yielding a density of 0.08 ± 0.03.

Mortality

Based on Fall Survey box counts, the average mortality before and after sanctuary expansion was similar (Table A.23-2; Figure A.23-9). Mortality ranged from 0% to 59% with the greatest mortality seen in 2000..

Disease

Oysters collected from Point Lookout bar during the 2005-2015 Fall Survey were analyzed for disease (Figure A.32-10). During this period, dermo prevalence ranged from 72% to 100% with intensities from 2.5 to 4.6. In only two years (2011 and 2015) was prevalence less than 80%. MSX prevalence ranged from 0% to 10% with an extended period of in which MSX was present, although at low prevalence from 2007-2010.

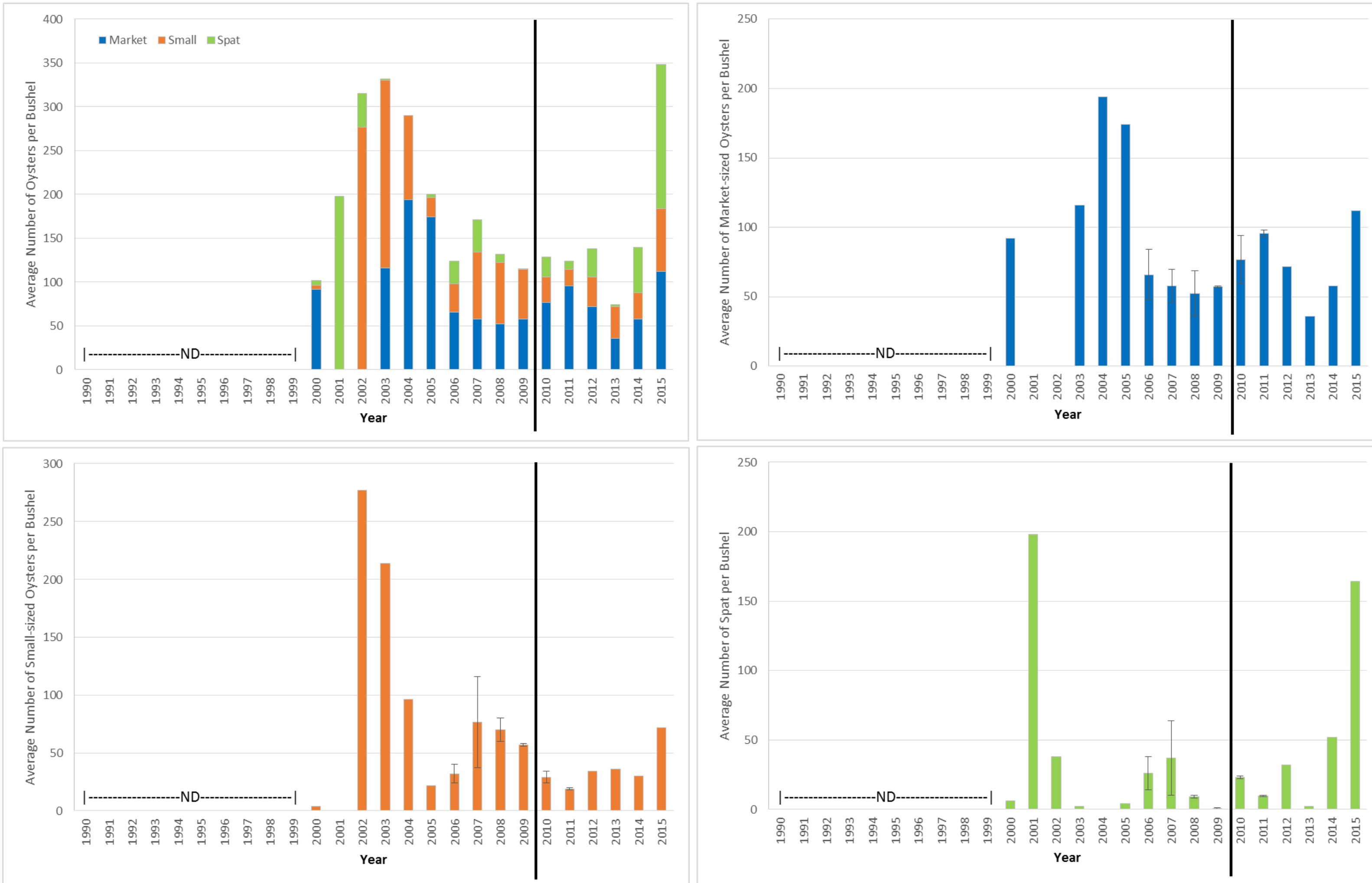


Figure A.32-3. Average number of live oysters per bushel of material by size class in the Point Lookout Sanctuary. The black line denotes the year the sanctuary was expanded. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data.

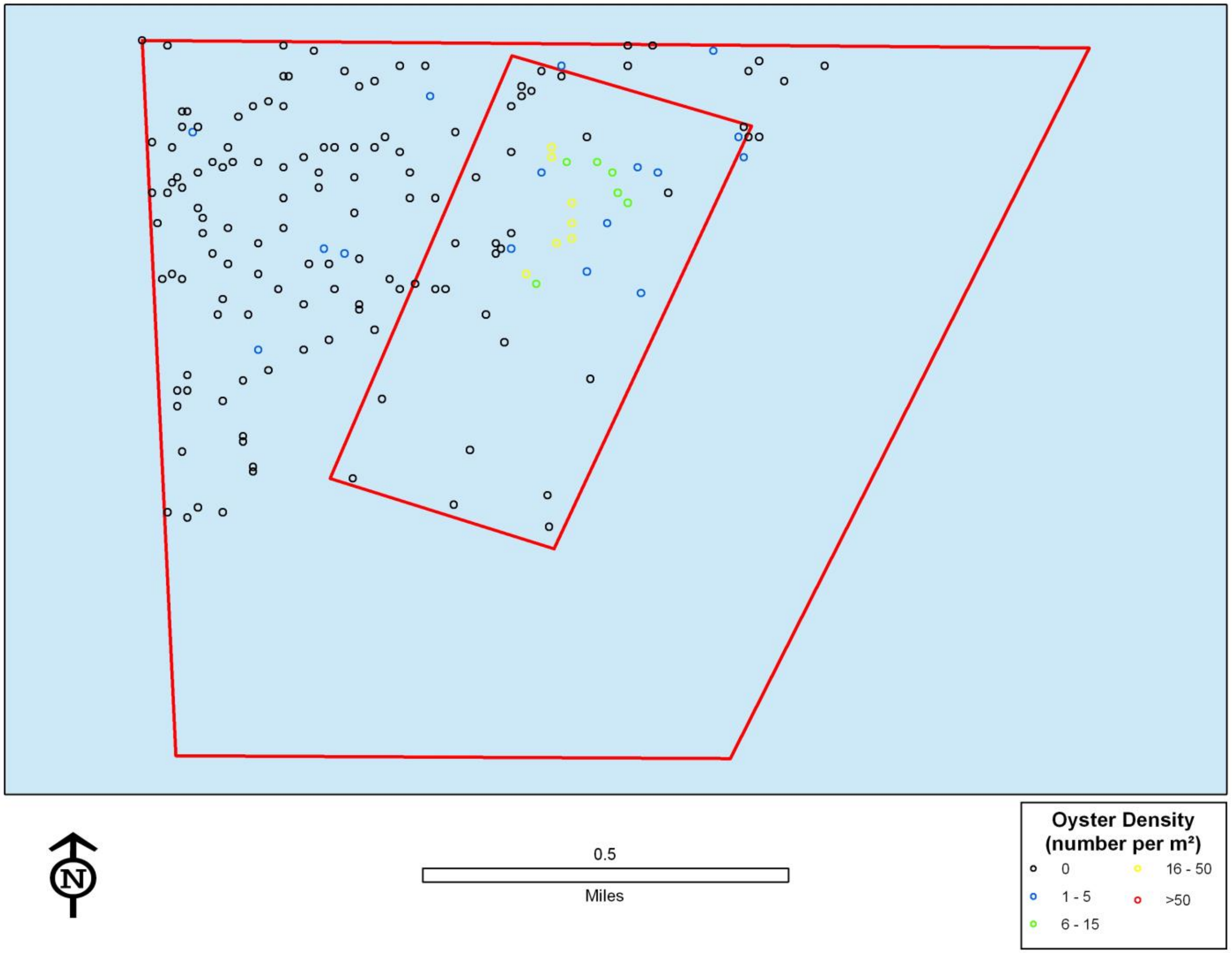


Figure A.32-4. Map of 2014 oyster density in the Point Lookout Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

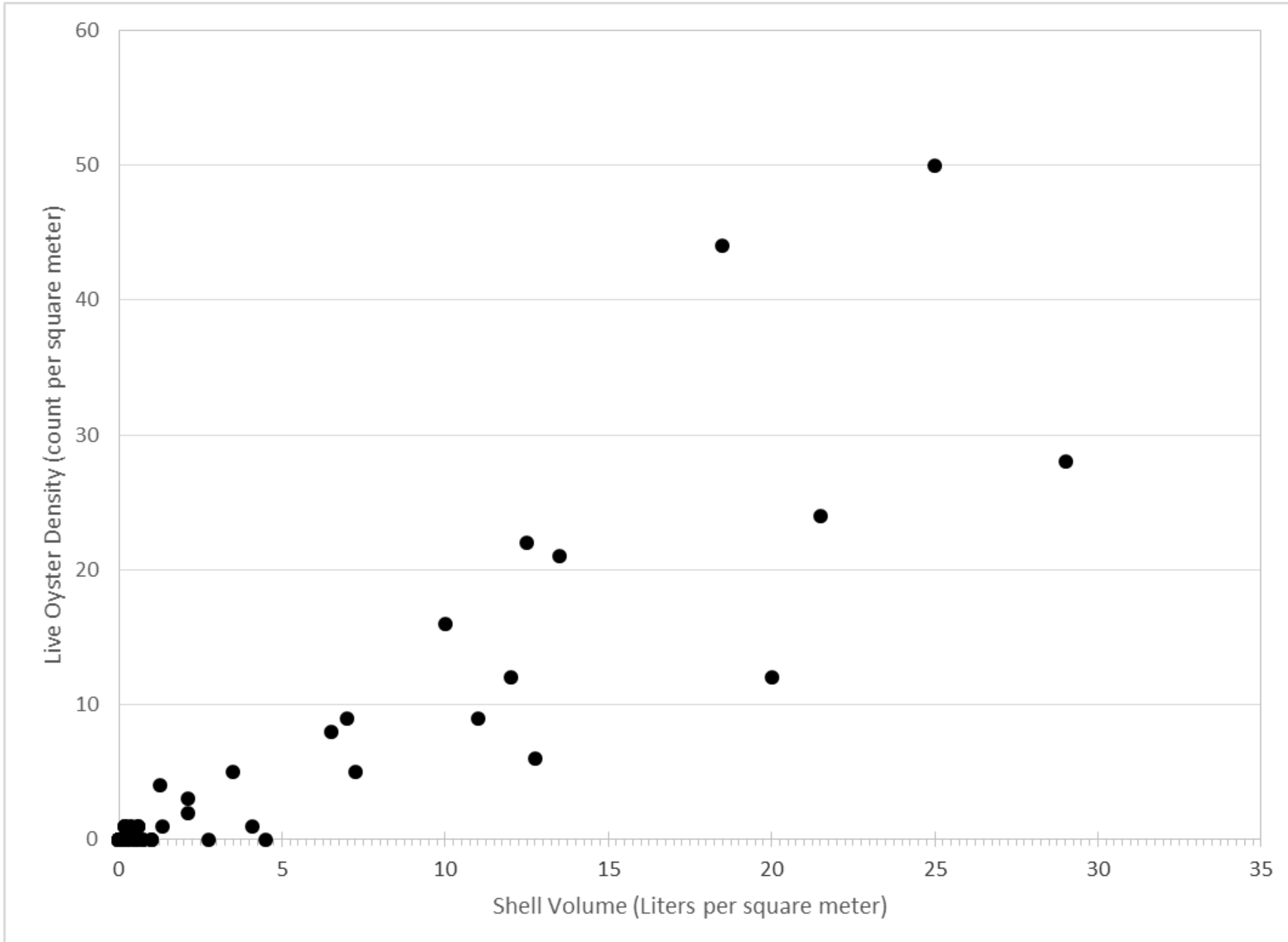


Figure A.32-5. 2014 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Point Lookout Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

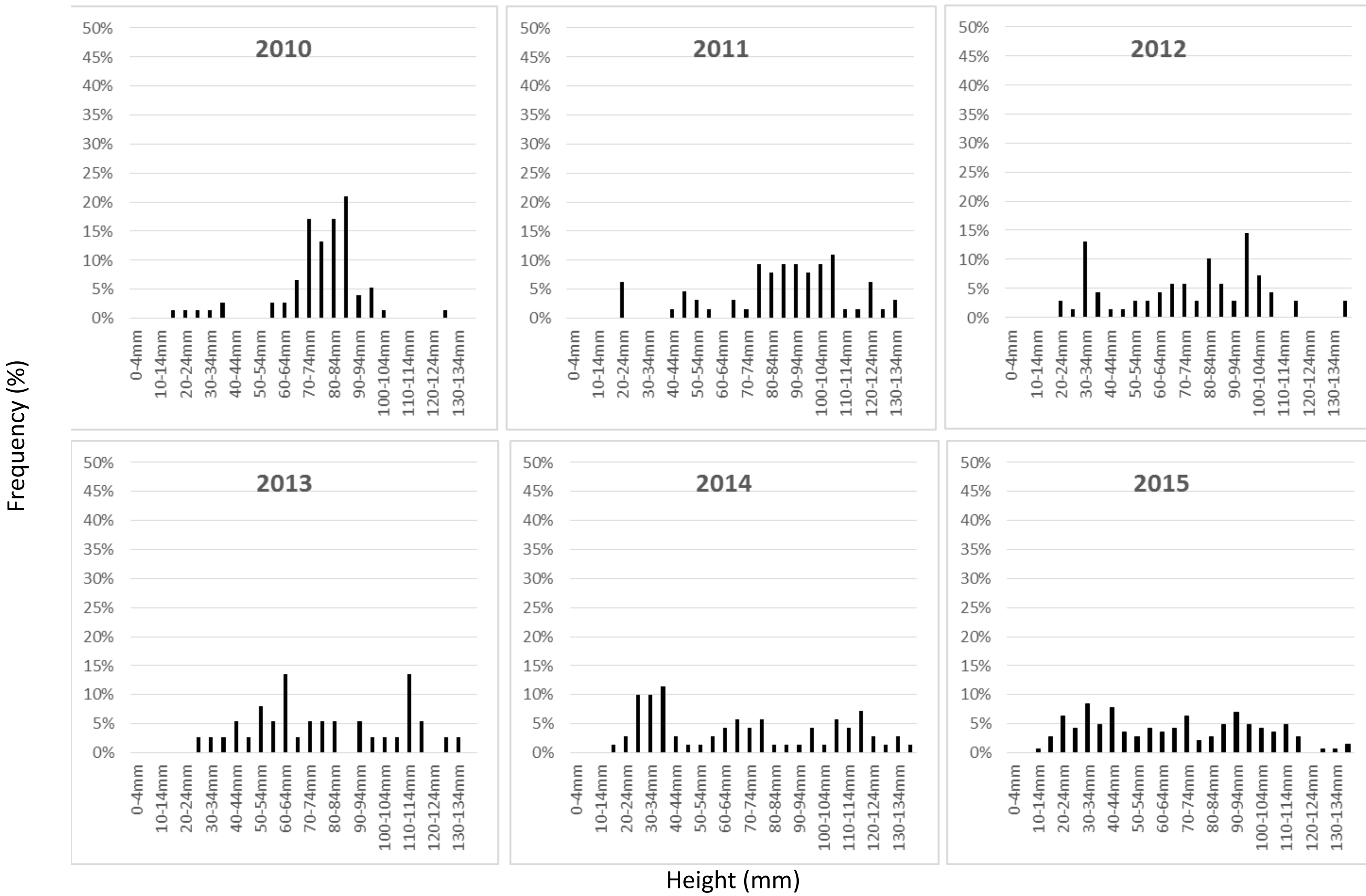


Figure A.32-6. Shell height frequencies of live oysters per bushel of material from 2010 to 2015 in the Point Lookout Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Point Lookout bar. Shell heights were not measured prior to 2010.

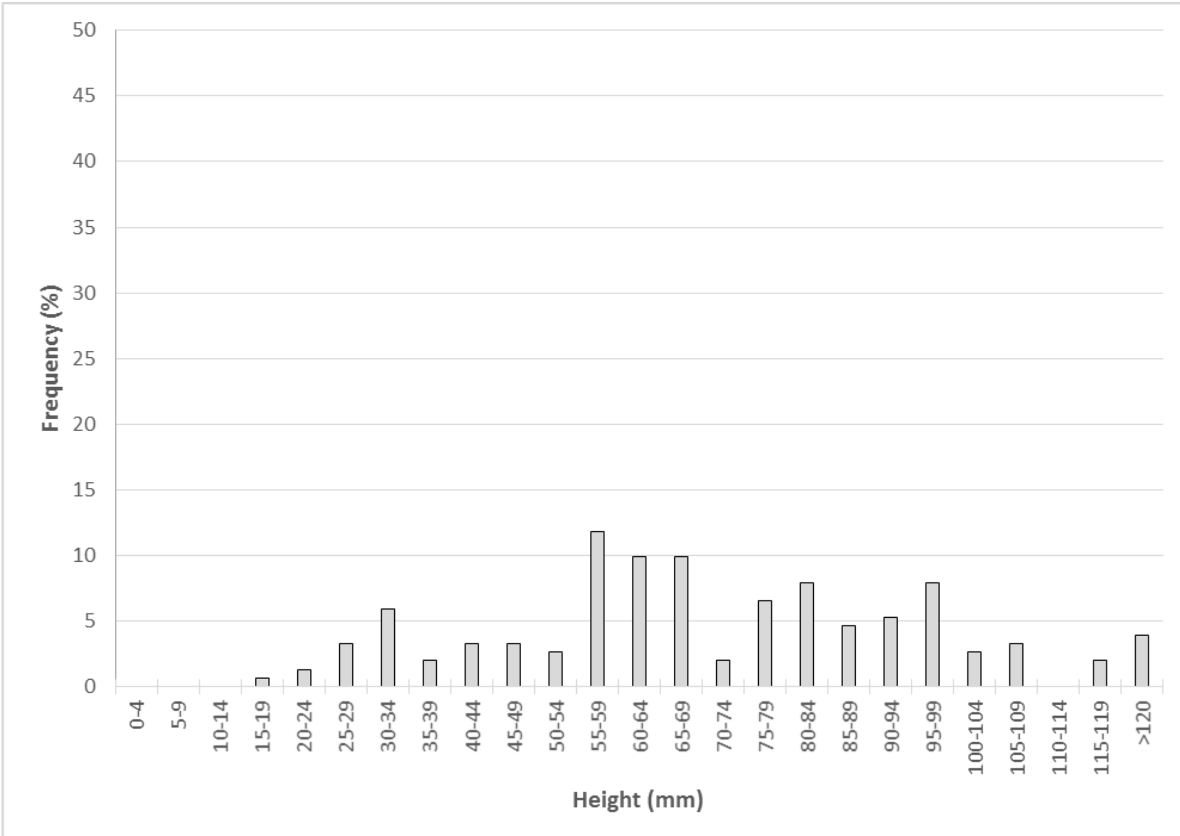


Figure A.32-7. Shell height frequencies of live oysters in the Point Lookout Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

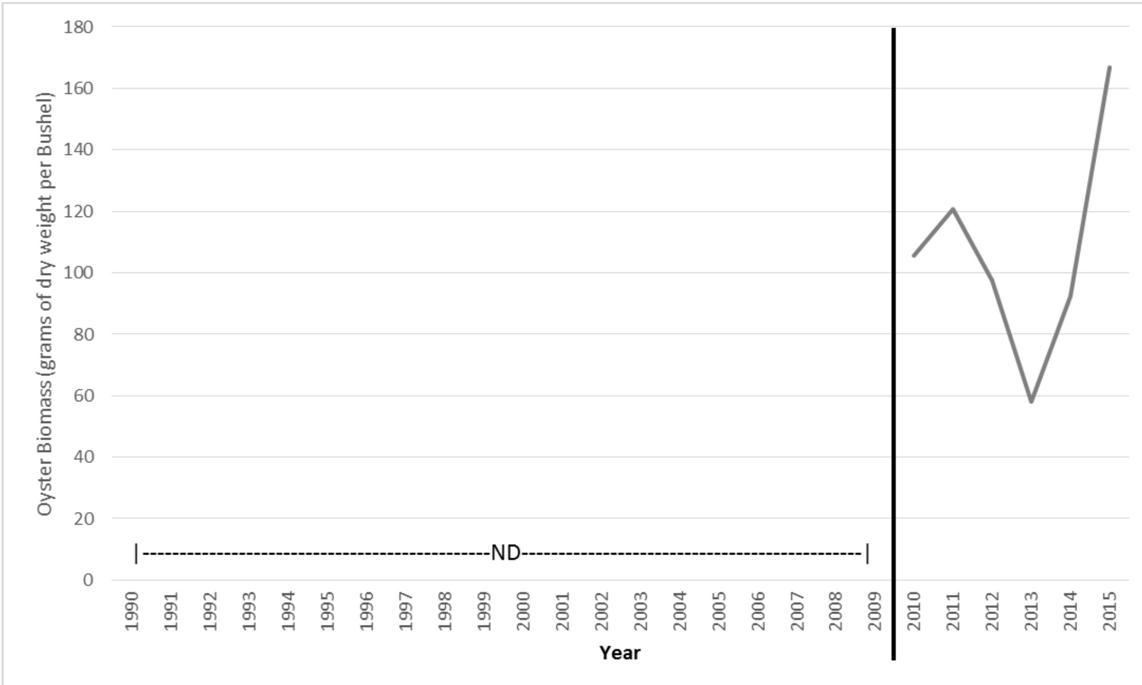


Figure A.32-8. Oyster biomass (grams of dry weight per bushel of material) from 2010 to 2015 in the Point Lookout Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Point Lookout bar. Black line indicates the date the sanctuary was expanded. ND = No Data.

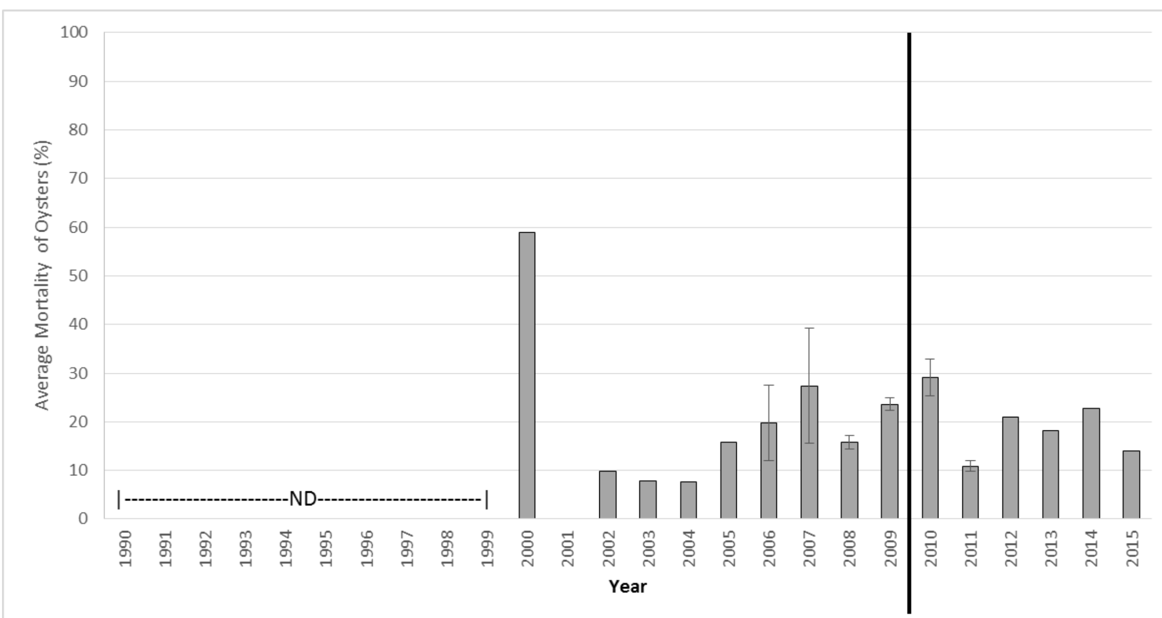


Figure A.32-9. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Point Lookout Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was expanded. Error bars represent ± 1 standard error. ND = No Data.

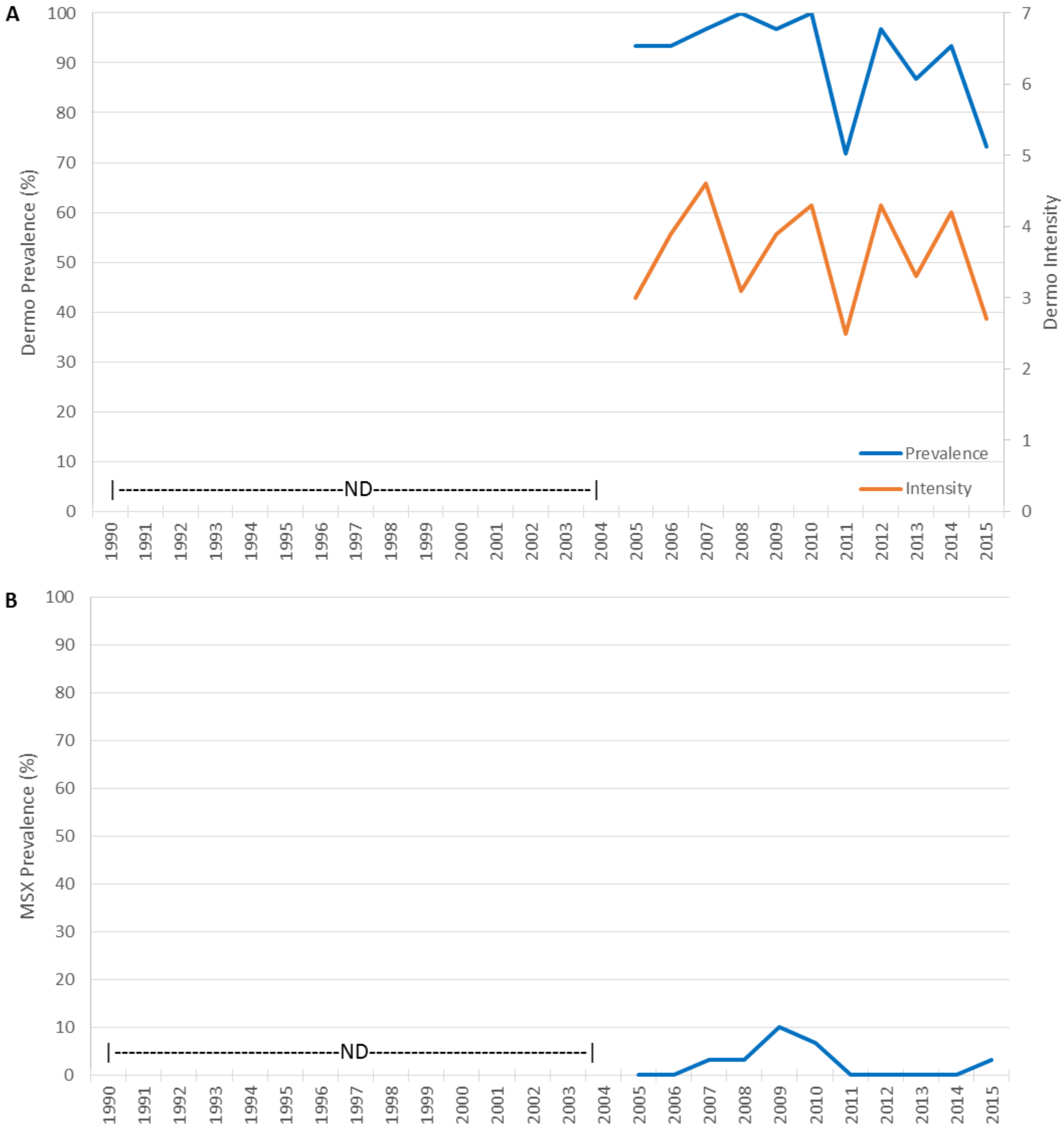


Figure A.32-10. Oyster disease prevalence and intensity from 2005 to 2015 in the Point Lookout Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Point Lookout bar. ND = No Data.

Harvest

The sanctuary encompasses less than 1% of the 105,377 acres in NOAA Code 229. Because harvest from NOAA Code 229 is likely to have come from areas other than the sanctuary, seafood dealer reports cannot be used to assess harvest in this area. Commercial watermen reported no harvest from bars located in this area prior to sanctuary establishment.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.33: Poplar Island Sanctuary

The Poplar Island Sanctuary is located in the central portion of Maryland's Chesapeake Bay, a low salinity (less than 12 ppt) region (Figure A.16-1). The sanctuary was created in 2003 and encompasses seven acres all of which is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). The sanctuary is located in the southwest corner of the historic Poplar Island bar and was created to restore the oyster population and enhance the ecology in that area.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.33-2). Of the 7.1 acres surveyed within the sanctuary, 1.2 acres (17%) were classified as oyster reef habitat. No recent bottom surveys using side scan sonar have been conducted.

Restoration and Replenishment Activities

There was a restoration planting in 2003 when 1,870 cubic yards of dredged shell was planted on 5.28 acres to enhance the oyster population. No replenishment planting activities have occurred from 1990 to 2003.

Oyster Population Characteristics

The Fall Survey taken one sample in this area once since 1990, in 2004. Six small-sized live oysters were found per bushel. Mortality was 0%.

No recent patent tong population surveys have been conducted by the Department on the sanctuary.

Harvest

The sanctuary encompasses less than 1% of the 186,830 acres in NOAA Code 027. Because harvest from NOAA Code 027 is likely to have come from areas other than the sanctuary, seafood dealer reports for the NOAA Code cannot be used to assess harvest in this area. Commercial watermen reported no harvest from this area prior to sanctuary establishment.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

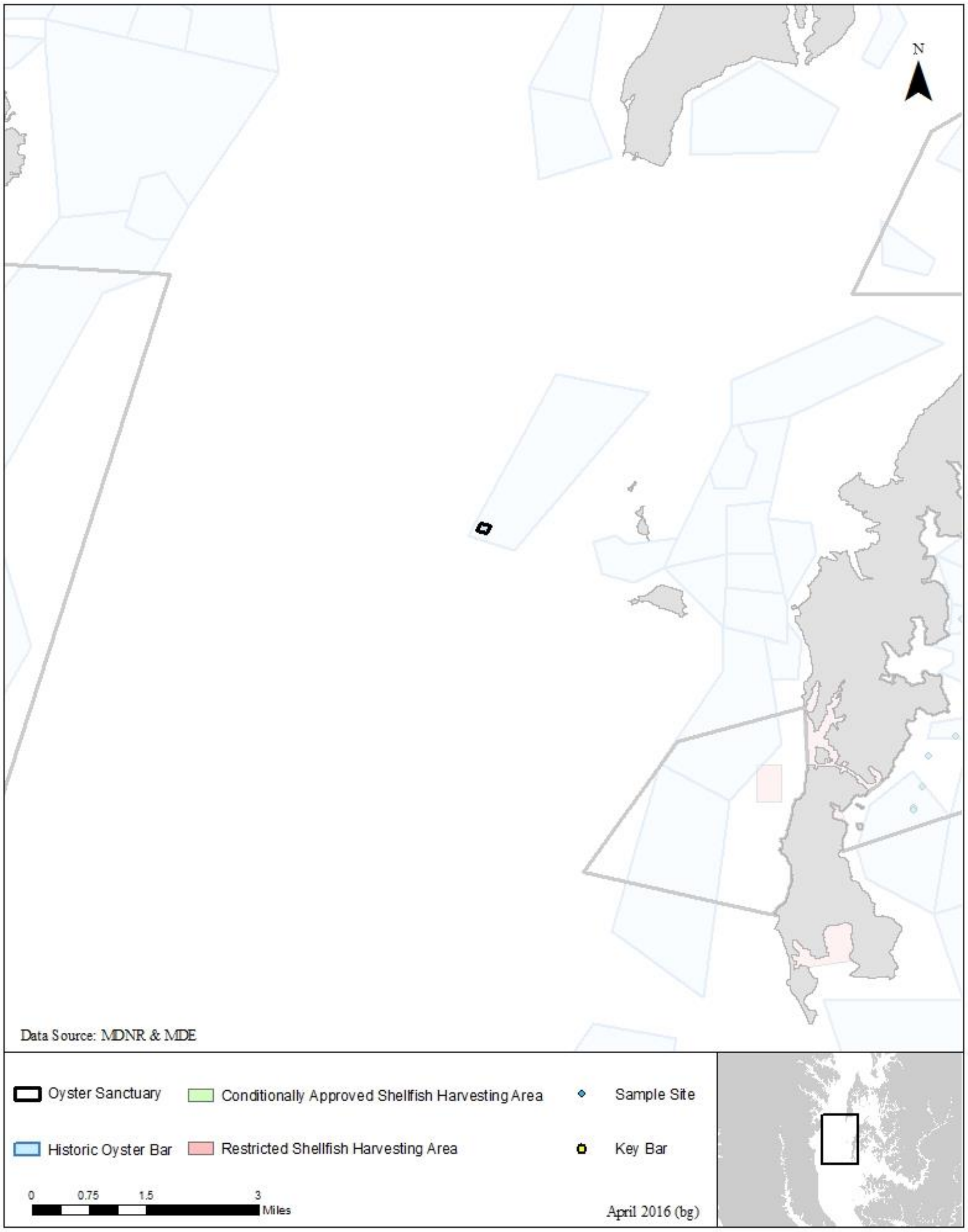


Figure A.33 -1. Poplar Island Sanctuary.

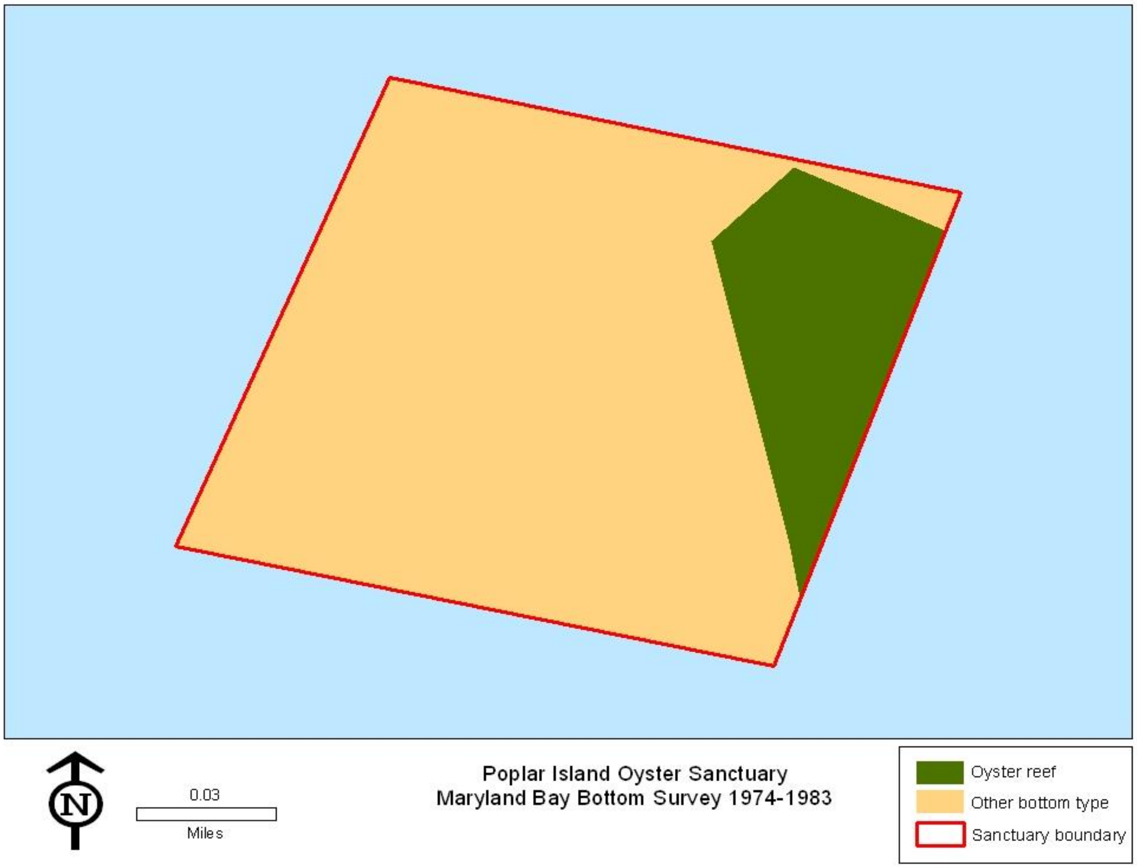


Figure A.33 -2. Poplar Island Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict areas examined during the surveys.

Section A.34: Prospect Bay Sanctuary

The Prospect Bay Sanctuary is located in Eastern Bay, a low salinity (less than 12 ppt) region (Figure A.34-1). The sanctuary was created in 2010 and encompasses 1,478 acres of which 1,061 (72%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 3 historic oyster bars within the sanctuary[72].

Bottom Habitat Characteristics

The area that is now the sanctuary was examined during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.11-2A). Of the 933 acres surveyed within the sanctuary, 483 (52%) were classified as oyster reef habitat. In 2012 NOAA Chesapeake Bay Office conducted a side scan sonar survey of the area. Of the 978 acres surveyed in 2012, 72 acres (7%) were classified as oyster reef habitat, indicating a substantial loss of oyster habitat since the Bay Bottom Survey.

Restoration and Replenishment Activities

This area has received both replenishment and restoration efforts since 1990. Prior to the area becoming a sanctuary, 67,553 bushels of shell were planted to enhance the wild fishery. After sanctuary establishment, hatchery spat-on-shell was planted for restoration purposes (Table A.34-1).

Table A.34-1. Replenishment and restoration planting activities occurring since 1990 in the area that is now established as Prospect Bay Sanctuary. S = planting activity occurring after the area was established as a sanctuary in 2010.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Dredged Shell	6.81	51.35	-
1990	Fresh Shell	6.94	16.20	-
2011 (S)	Hatchery Spat-on-Shell	8.48	-	21.33

[72] See chart 11 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

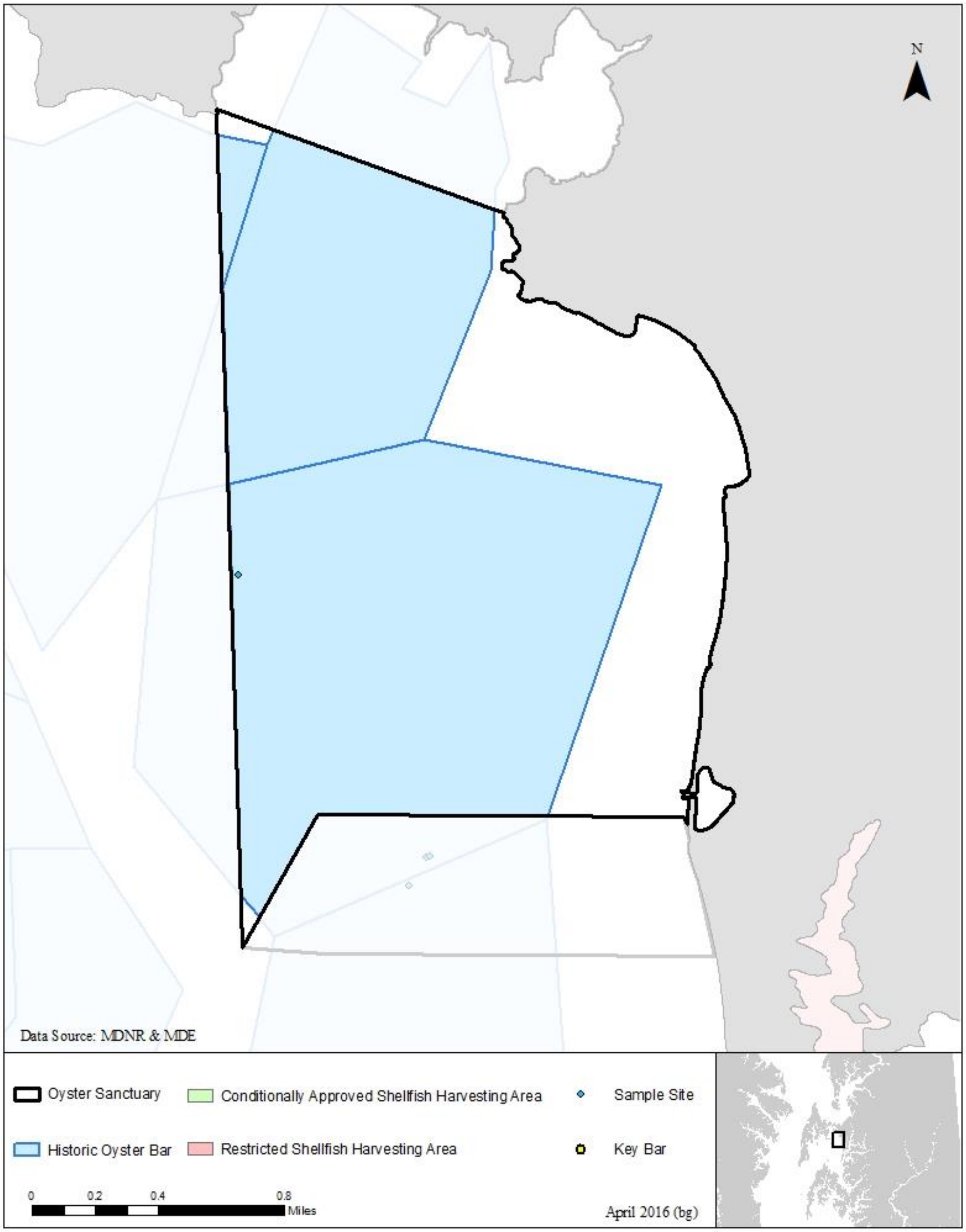


Figure A.34 -1. Prospect Bay Sanctuary.

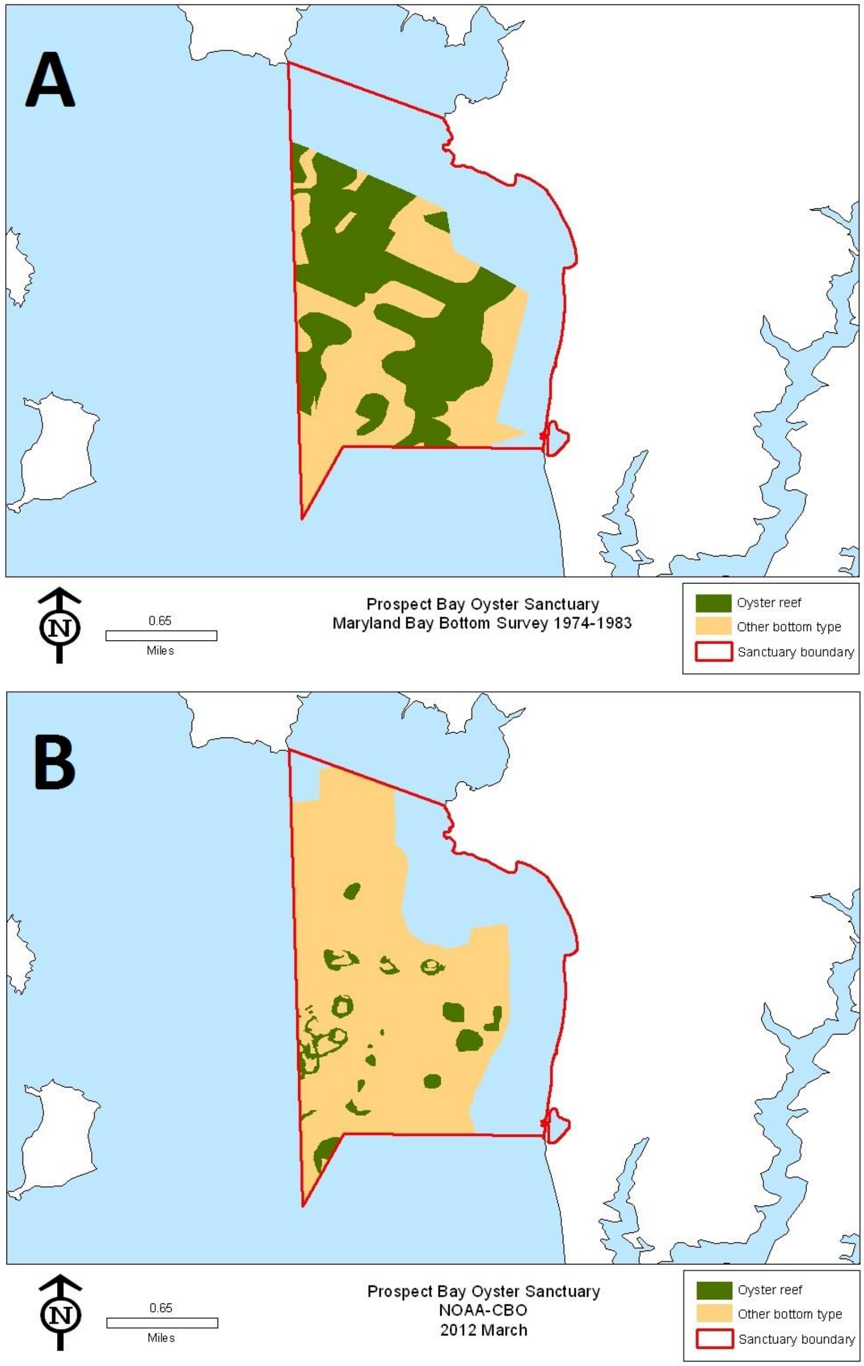


Figure A.34 -2. Prospect Bay Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from NOAA Chesapeake Bay Office in 2012. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey sampled one oyster bar in the area of the sanctuary from 1990 to 1993 (Table A.34-2); the area was not sampled after it became a sanctuary. From 1990 to 1993, the average number of live oysters per bushel was 51 ± 12 with the majority of the oysters being small-sized.

Table A.34-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Prospect Bay Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	4 / 6	0 / 0
Number of Live Oysters per Bushel	51 ± 12	ND
Number of Live Small-Sized Oysters per Bushel	32 ± 8	ND
Number of Live Market-Sized Oysters per Bushel	6 ± 4	ND
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	13.0 ± 5.6	ND

A patent tong population survey was conducted in 2013 (Figures A.34-3). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 0.68 ± 0.15 oysters m^{-2} (mean ± standard error, n = 104). The density of small-sized oysters was higher than the density of market-sized oysters (0.27 ± 0.07 and 0.10 ± 0.04 oysters m^{-2}, respectively). . The percentage of samples having no oysters was 74%. Oyster density increased with volume of shell (Figure A.34.4).

Oyster Size Structure

Shell heights were not measured during the Fall Survey. Shell heights were measured during the patent tong population survey (Figure A.34-5). The population was dominated by spat and small-sized oysters, with a few very large oysters.

Biomass

Biomass of oysters collected during the Fall Survey was not calculated.

Recruitment (Spatfall)

From 1990-1993 spatfall ranged from 0 to 36 spat per bushel with an average of 12.5 ± 4.1. A total of 33 spat were collected during the patent tong survey, yielding a density of 0.32 ± 0.08 m^{-2}.

Mortality

From 1990-2003 mortality ranged from 0 to 26% with an average of 13.0% ± 5.6%.

Disease

Oysters collected during the Fall Survey were not analyzed for disease.

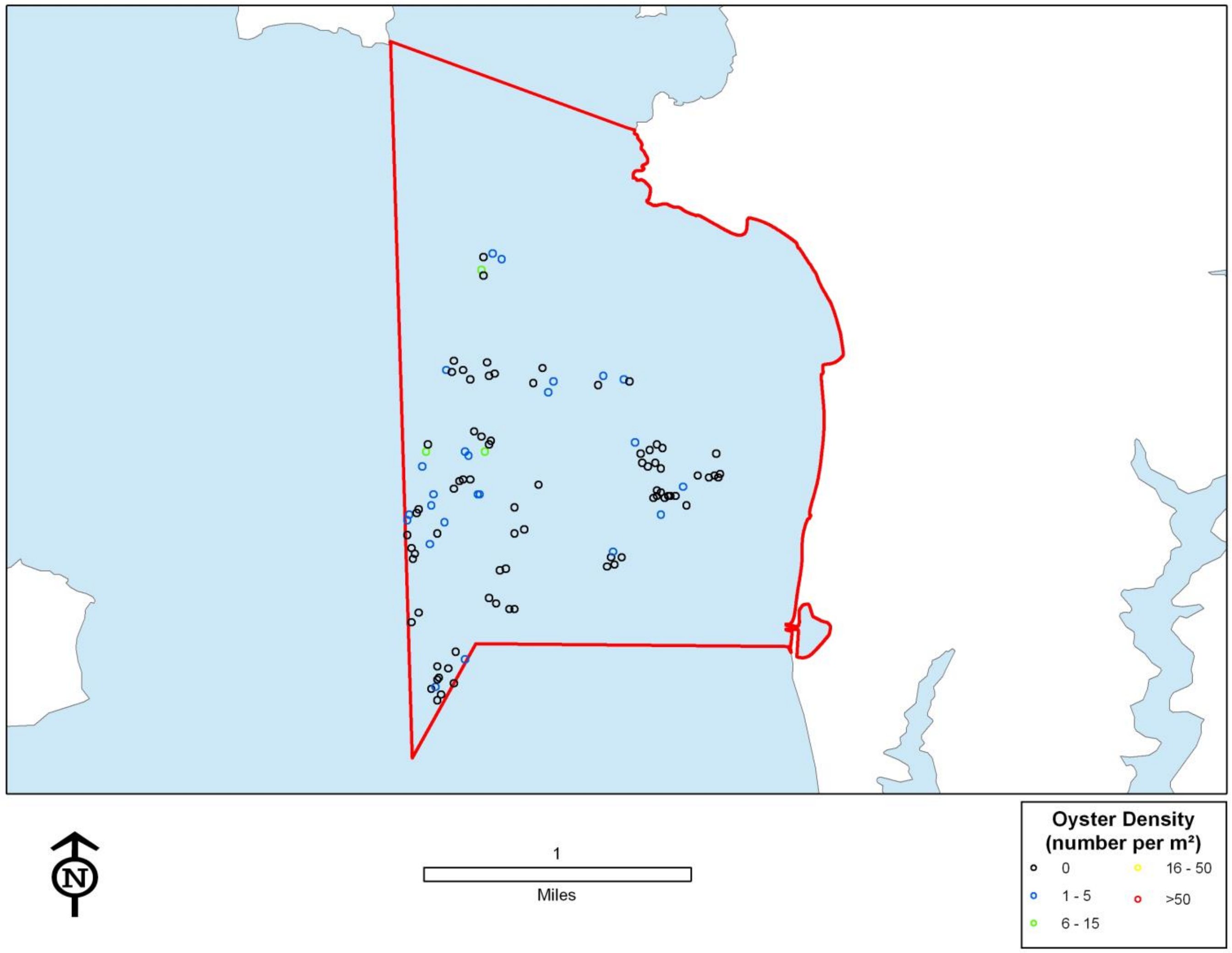


Figure A.34-3. Map of 2013 oyster density in the Prospect Bay Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

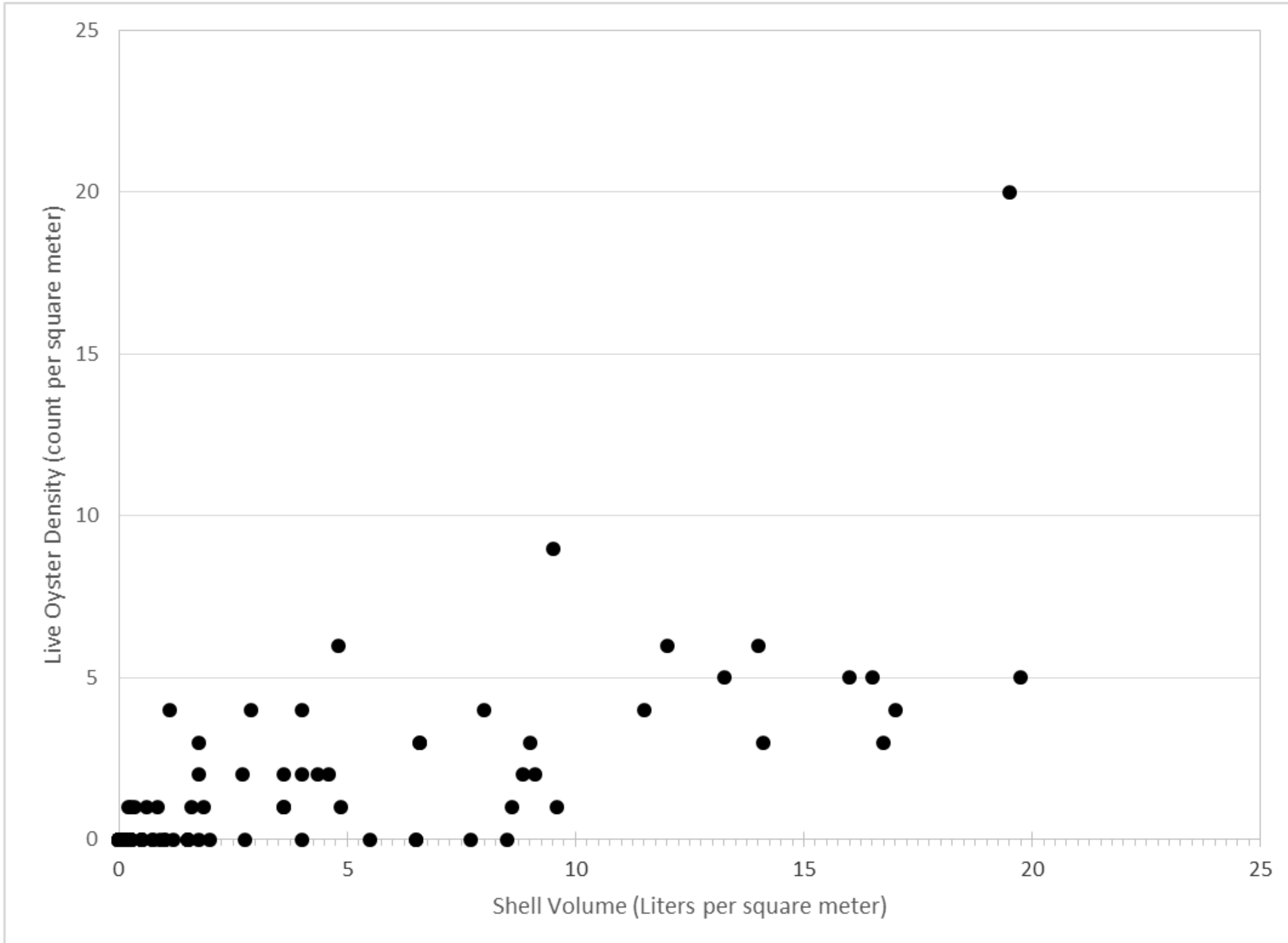


Figure A.34-4. 2013 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Prospect Bay Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

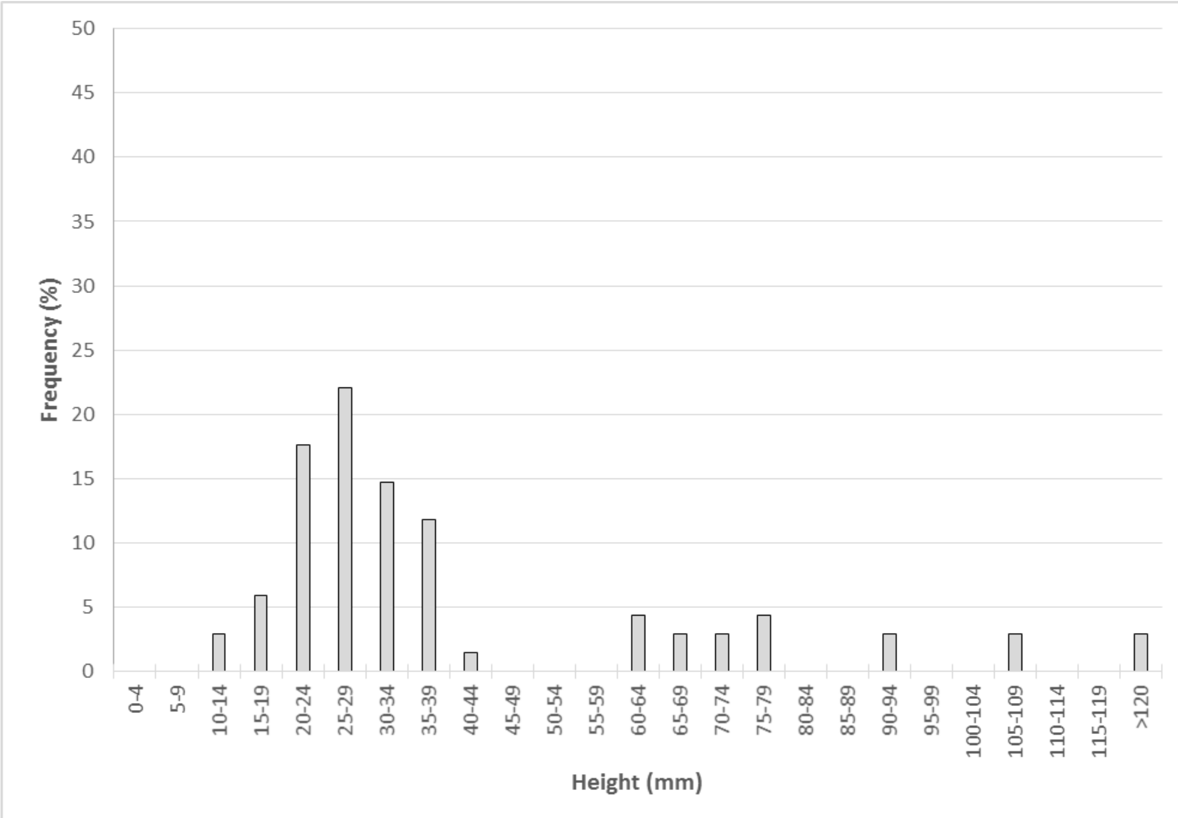


Figure A.34-5. Shell height frequencies of live oysters in the Prospect Bay Sanctuary in 2013. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

Harvest

The sanctuary constitutes 4% of the 33,334 acres in NOAA Code 039. Because harvest is likely to have come from areas outside the sanctuary, seafood dealer reports for NOAA Code 039 cannot be used to assess harvest in this area. Commercial watermen reported no harvest on bars located in sanctuary prior to sanctuary creation.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.35: Prospect Bay Cabin Creek Sanctuary

The Prospect Bay Cabin Creek Sanctuary is located in Eastern Bay, a low salinity (less than 12 ppt) region (Figure A.35-1). The sanctuary was created in 2005 for restoration work by the Chesapeake Bay Environmental Center, which was designated by the state as a site for testing and developing comprehensive restoration techniques that might have bay-wide application for enhancing oyster stocks. The sanctuary encompasses 298 acres of which 128 (43%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There is one historic oyster bar (Cabin Creek bar) within the sanctuary.

Bottom Habitat Characteristics

Although the area that is now the sanctuary may have been surveyed during the Bay Bottom Survey (1974 to 1983), the chart covering this area has been lost[73]. There have not been any recent bottom surveys using side scan sonar in this area.

Restoration and Replenishment Activities

Chesapeake Bay Environmental Center has implemented several oyster restoration projects in the sanctuary (Table A.35-1). In addition to oyster restoration projects, 100 pyramid-shaped fish havens were placed in the sanctuary. Also, Marylanders Grow Oysters, a public outreach program, planted 6,000 oysters in 2010 at one site in the sanctuary.

[73] Smith, G.F., K.N. Greenhawk, D.G. Bruce, E.B. Roach, and S.J. Jordan. 2001. A digital presentation of the Maryland oyster habitat and associated bottom types in the Chesapeake Bay (1974–1983). Journal of Shellfish Research 20:192–206.

Table A.35-1. Restoration activities occurring since 1990 in the area that is now established as Prospect Bay Cabin Creek Sanctuary. S = planting occurring after the area was established as a sanctuary. ND = No Data.				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
2002	Concrete Rubble	0.5	-	-
2002	Hatchery Spat-on-Shell	ND	-	1
2005 (S)	Stone	5	-	-
2005-2006 (S)	Hatchery Spat-on-Shell	ND	-	1.5
2005 (S)	Reef Balls	3	132 Reef Balls	
2004-2005 (S)	Hatchery Spat-on-Shell	3	-	1
2005-2011 (S)	Hatchery Spat-on-Shell	ND	-	4.5
2007 (S)	Reef Balls	3	28 Reef Balls	
2008 (S)	Hatchery Spat-on-Shell	ND	-	0.5
2012 (S)	Hatchery Spat-on-Shell	1	-	1.5

Oyster Population Characteristics

The Fall Survey has not sampled within this area since 1990. A patent tong population survey has not been conducted by the Department since 1990.

Harvest

The sanctuary constitutes less than 1% of the 33,334 acres in NOAA Code 039. Because harvest from NOAA Code 039 is likely to have come from areas other than the sanctuary, seafood dealer reports from this NOAA Code area cannot be used to assess harvest in this area. Harvester reporting was implemented after the sanctuary was established, so these reports contain no information about harvest in this area.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Data Hub recorded monthly water quality at station XGG6667 (38.9428, -76.2216) in this area from 2005 to 2008 (Figure A.35-2). Surface water was analyzed for salinity, water temperature, secchi disk depth, total suspended solids, total nitrogen, and chlorophyll a. Water quality was suitable for oysters during this time period.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

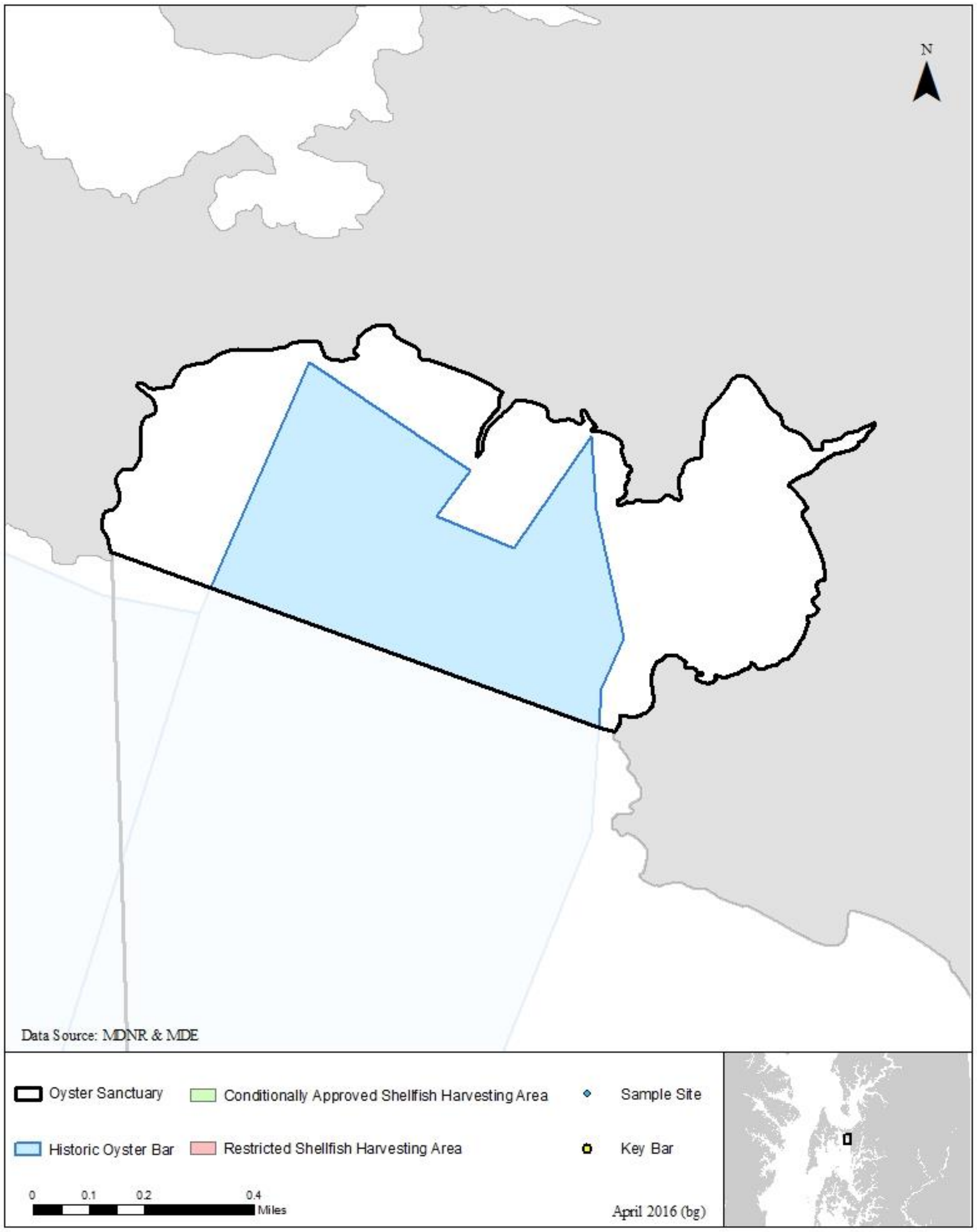


Figure A.35 -1. Prospect Bay Cabin Creek Sanctuary.

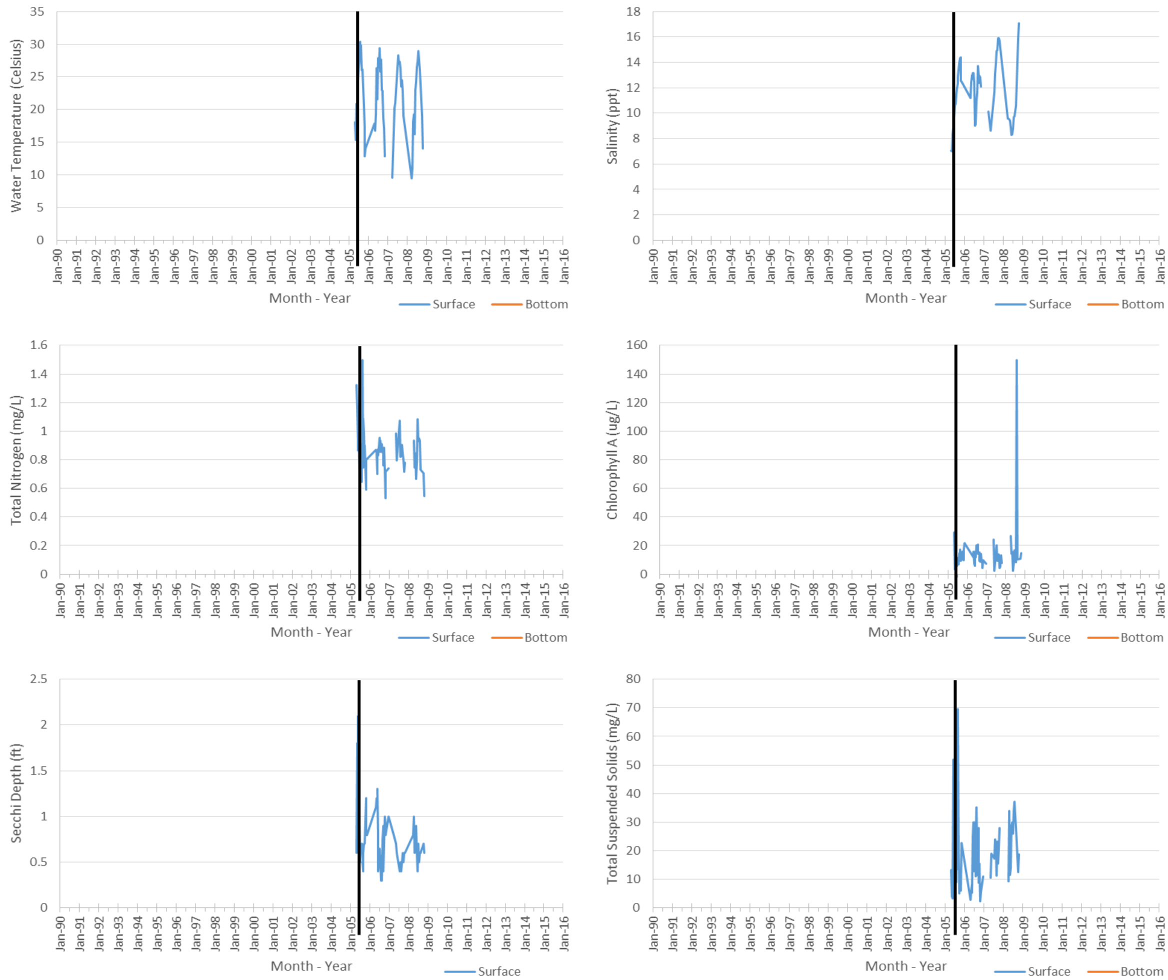


Figure A.35-2. Water quality data collected at Station XGG6667 within the area now established as Prospect Bay Cabin Creek Sanctuary from 2005 to 2008. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.

Section A.36: Ringgold Sanctuary

The Ringgold Sanctuary is located in the upper Chester River, a low salinity (less than 12 ppt) region (Figure A.36-1). The sanctuary was created in 2001 and encompasses 120 acres of which 63 (52%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There is one historic oyster bar (Bay Bush Point bar) within the sanctuary. The sanctuary was created for a project by the U.S. Army Corps of Engineers designed to examine differences in oyster growth, mortality and disease prevalence between hatchery spat-on-shell and natural seed between bars constructed with a minimum of 150 cm relief above the bottom and "flat" bars, with no more than 15 cm relief above the bottom.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.36-2). Of the 44 acres that were, 31 acres (71%) were classified as oyster reef habitat. Between 2003 and 2007, NOAA Chesapeake Bay Office conducted a side scan sonar survey of the area Of the 54 acres surveyed, 32 acres (58%) were classified as oyster reef habitat, suggesting a slight loss of habitat since the Bay Bottom Survey

Restoration and Replenishment Activities

This area has received both replenishment and restoration efforts since 1990 (Table A.36-1). Replenishment activities consisted of dredged shell and wild seed planting. After the area was established as a sanctuary in 2001, one million hatchery spat-on-shell were planted.

Table A.36-1. Replenishment and restoration planting activities occurring since 1990 in the area is that now Ringgold Sanctuary. S = a planting activity occurring after the area was established as a sanctuary in 2001. ND = No Data.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1998	Dredged Shell	1.15	ND	-
1998	Dredged Shell	2.93	23.05	-
1998	Wild Seed	2.21	0.66	-
1998	Hatchery Spat-on-Shell	0.33		0.5
2003 (S)	Stone and Dredged Shell	17.5	156.59	-
2003 (S)	Hatchery Spat-on-Shell	0.99	-	1

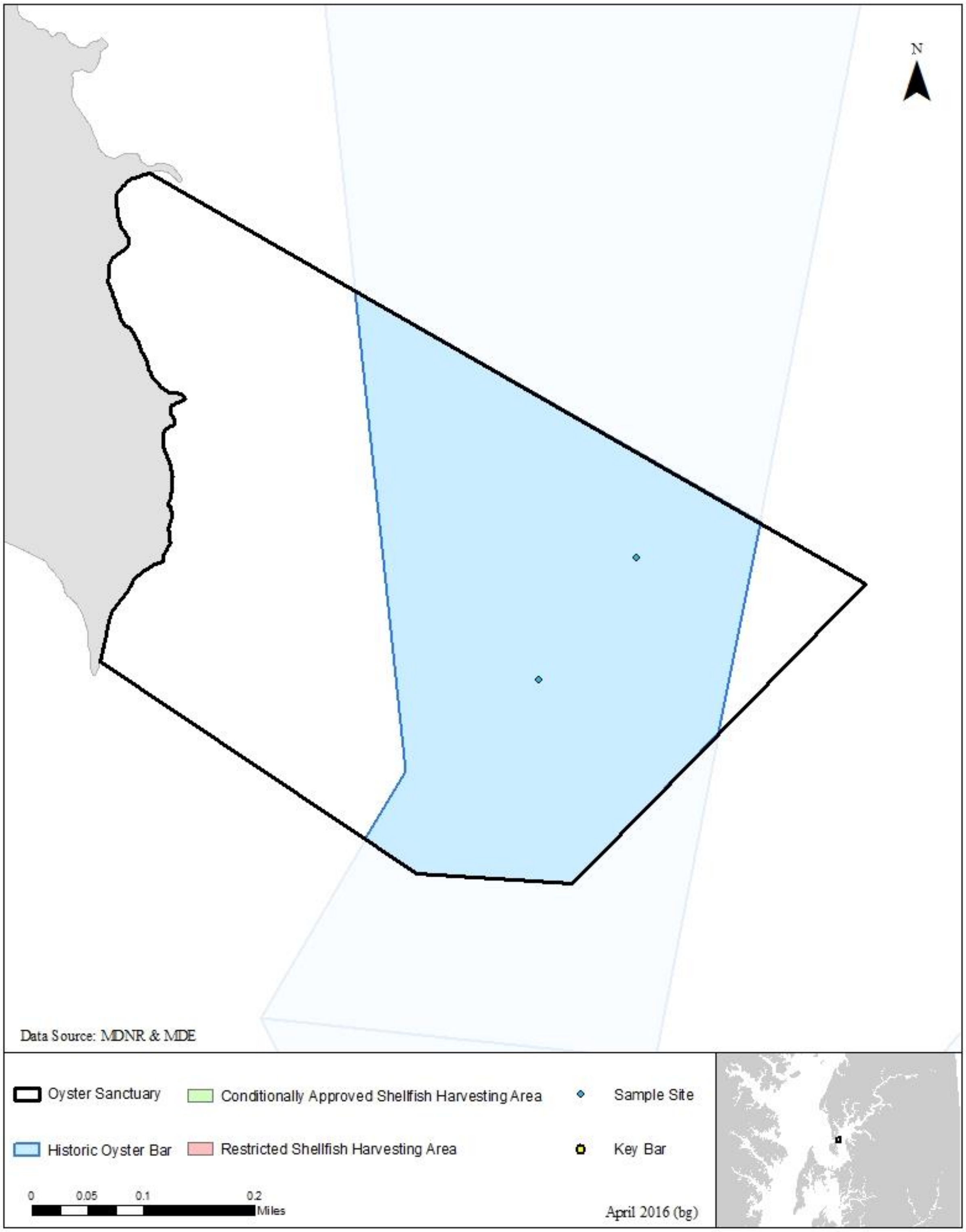


Figure A.36 -1. Ringgold Sanctuary.

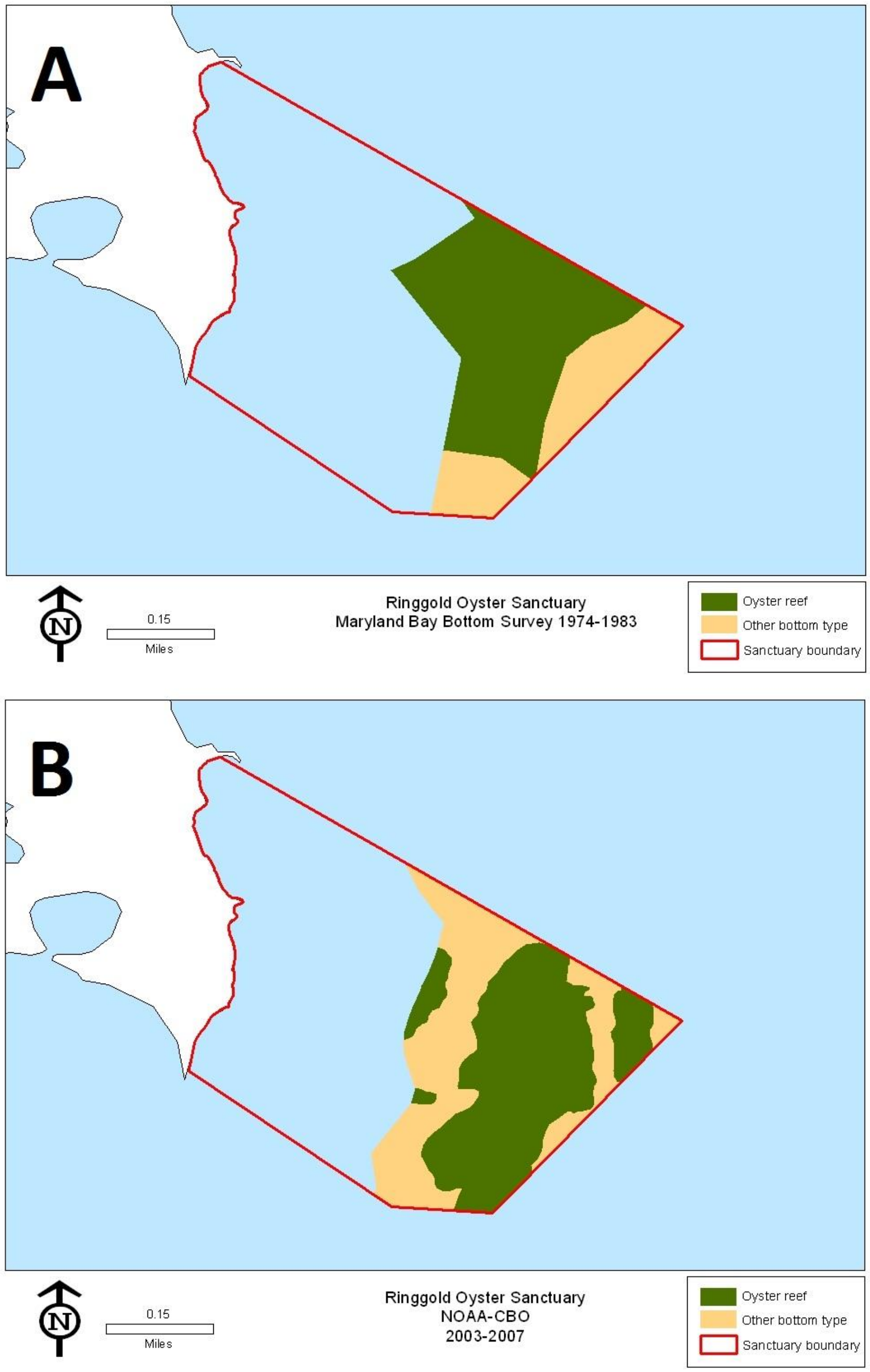


Figure A.36 -2. Ringgold Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B). Data from NOAA Chesapeake Bay Office from 2003-2007. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey sampled one oyster bar in the area of the sanctuary from 1992 to 2002. The area was only sampled twice after it became a sanctuary, thus pre and post comparisons are not practical. The average number of total live oysters per bushel (market, small, and spat) ranged from 4 to 94 with the greatest number of oysters found in 2000 (Table A.36-2; Figure A.36-3). The average number of small-sized oysters was less than the average number of market-sized oysters.

Table A.36-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Ringgold Sanctuary in 2001. ND = No Data. Values are given as mean ± standard error.

	1990-2000	**2001-2015**
Number of Years Sampled / Number of Samples	9 / 10	2 / 2
Number of Live Oysters per Bushel	33 ± 9	49 ± 15
Number of Live Small-Sized Oysters per Bushel	4 ± 2	1 ± 1
Number of Live Market-Sized Oysters per Bushel	28 ± 7	48 ± 14
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	26.9 ± 9	40.2 ± 18.3

There has not been a patent tong population survey in Ringgold Sanctuary since 1990.

Oyster Size Structure

The Fall Survey has not measured oyster shell heights in this area since 1990.

Biomass

The Fall Survey has not measured oyster biomass in this area since 1990.

Recruitment (Spatfall)

Based on the Fall Survey data, spat only were found in 1995 and 1997, 6 and 2 per bushel, respectively (Figure A.36-3).

Mortality

Based on Fall Survey box counts, average mortality fluctuated from 4% to 86% which (Figure A.36-4). The greatest mortality occurred in 1996. The second highest mortality (59%) occurred in 2002 and corresponded with high disease levels throughout the bay.

Disease

The Fall Survey has not measured oyster disease levels in this area since 1990.

Harvest

The sanctuary encompasses less than 1% of the 15,437 acres in NOAA Code 231. Because harvest from NOAA Code 231 is likely to have come from areas other than the sanctuary, seafood dealer reports from this NOAA Code cannot be used to assess harvest in this area. Harvester reporting was not implemented until after the establishment of sanctuary, therefore harvester reports for this area are not available.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

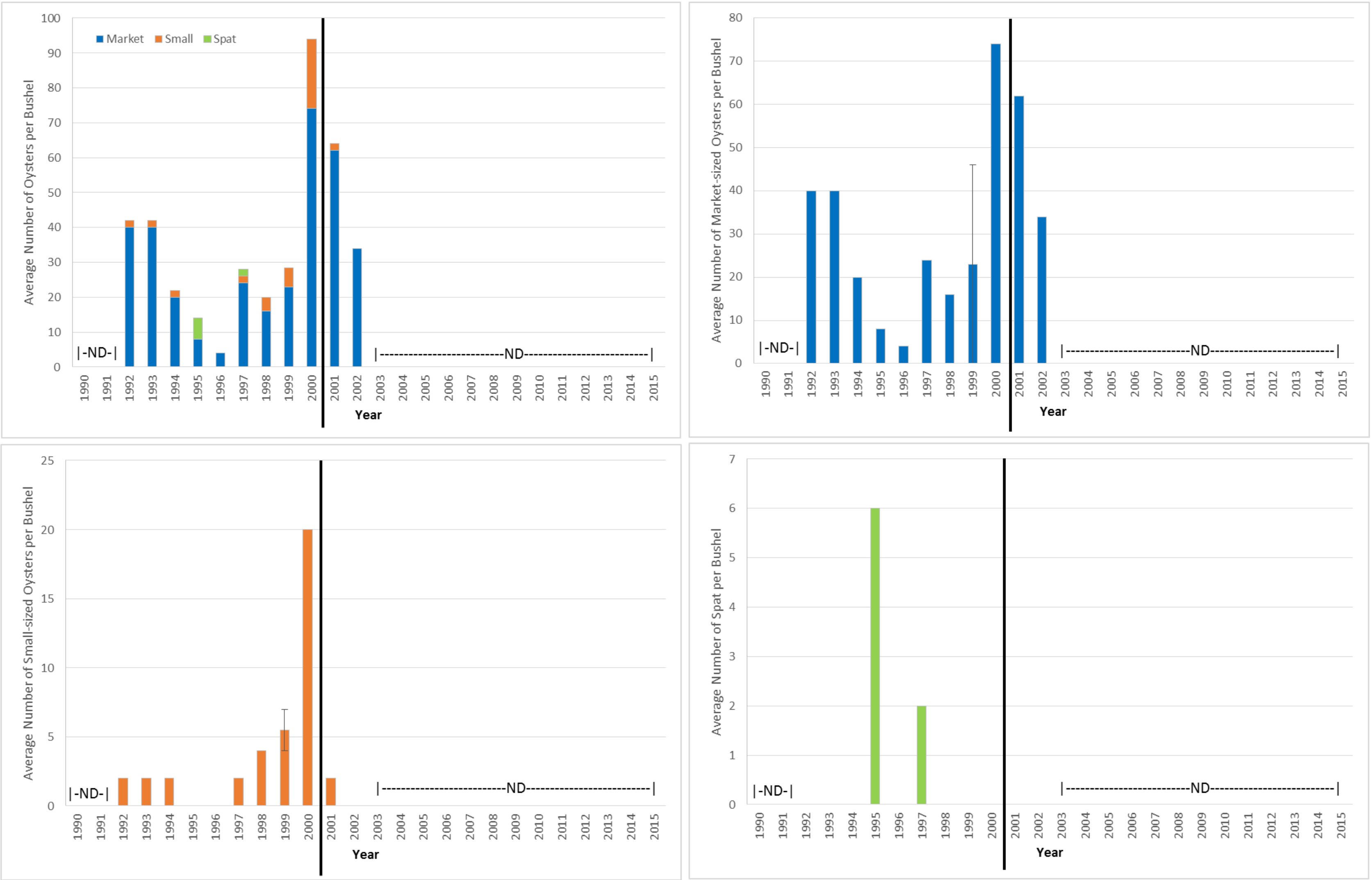


Figure A.36-3. Average number of live oysters per bushel of material by size class in the Ringgold Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

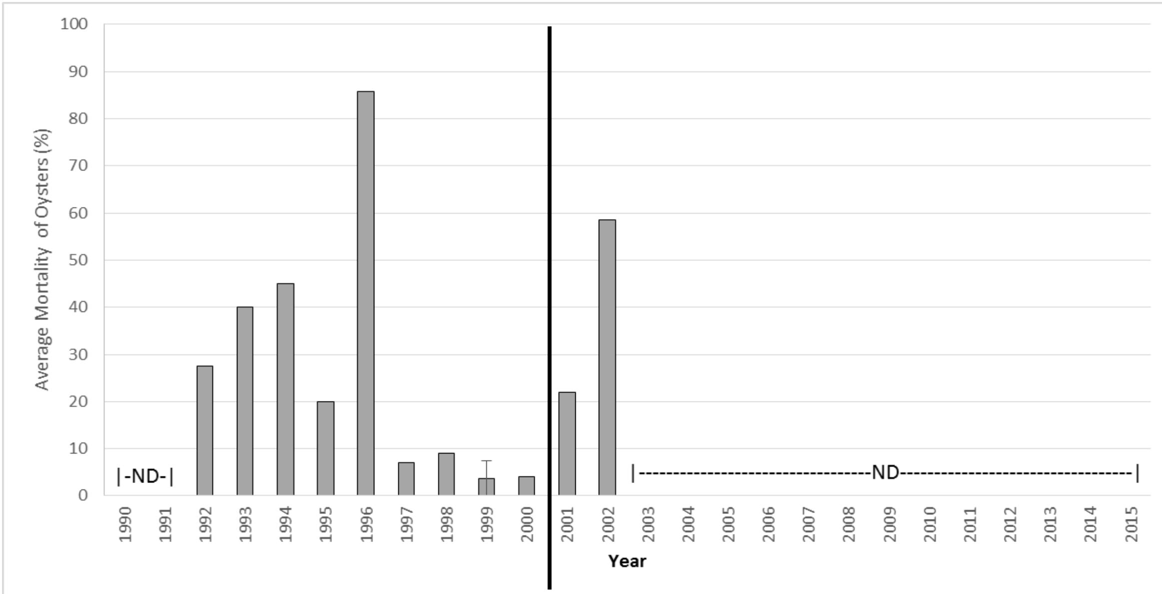


Figure A.36-4. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Ringgold Sanctuary in Maryland's portion of the Chesapeake Bay. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

Section A.37: Roaring Point Sanctuary

The Roaring Point Sanctuary is located at the mouth of the Nanticoke River, a medium salinity (12 to 14 ppt) region (Figure A.23-1). The sanctuary was created in 2004 and encompasses 10 acres of which none is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). Roaring Point Sanctuary was created from an old oyster lease for oyster restoration work by the Chesapeake Bay Foundation.

Bottom Habitat Characteristics

This area was not mapped by the Bay Bottom Survey, nor have any more recent surveys using side scan sonar been performed.

Restoration and Replenishment Activities

Both hatchery spat and fresh shell have been placed in this area (Table A.37-1). Participants in the Nanticoke River Marylanders Grow Oysters plant their oysters in sanctuary. Early plantings were plantings were poached and experienced predation by cownose rays. In 2016, growers tended 220 cages and planted approximately 66,000 oysters.

Table A.37-1. Replenishment and restoration planting activities occurring since 1990 in the area that is now established as Roaring Point Sanctuary. S = a planting activity occurring after the area was established as a sanctuary in 2004. ND = No Data.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
2001	Hatchery Spat-on-Shell	1	-	1.02
2001	Fresh Shell and Marl	-	82 tons	-
2005 (S)	Hatchery Spat-on-Shell	ND	-	1.7

Oyster Population Characteristics

The Fall Survey has not sampled the area of the sanctuary since 1990, nor has a patent tong population survey been conducted by the Department.

Harvest

The sanctuary encompasses less than 1% of the 19,661 acres in NOAA Code 062. There is no recorded oyster harvest from this area prior to it becoming a sanctuary in 2004.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

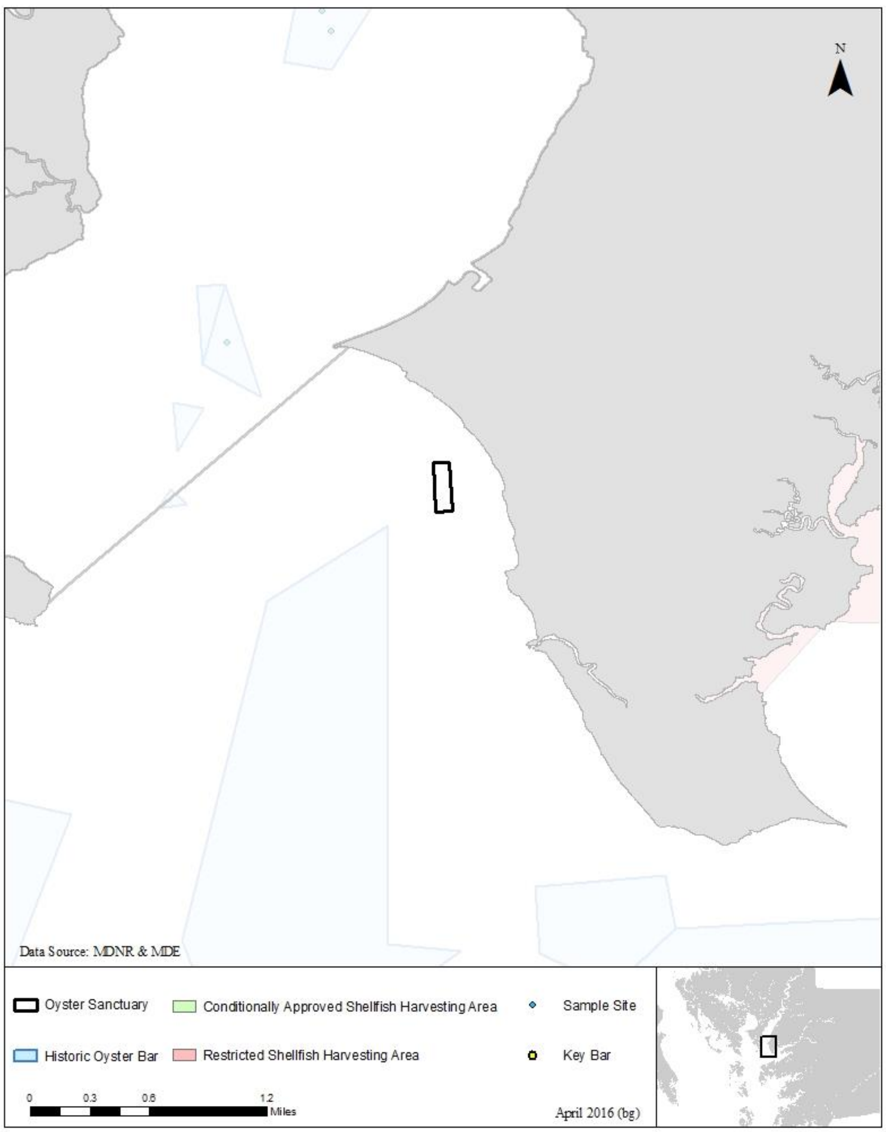


Figure A.37 -1. Roaring Point Sanctuary.

Section A.38: Sandy Hill Sanctuary

The Sandy Hill Sanctuary is located in middle Choptank River, a low salinity (less than 12 ppt) region of Maryland (Figure A.38-1). This sanctuary connects the Lower and Upper Choptank River sanctuaries on the southern shore of the river, creating a large contiguous sanctuary area. The sanctuary was created in 2009 and encompasses 1,947 acres of which 1,308 (67%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 11 historic oyster bars within the sanctuary[74]. This sanctuary was created based on recommendations from the Oyster Advisory Commission to establish larger oyster sanctuaries in a range of salinities.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.38-2). Of the 1,291 acres surveyed within the sanctuary, 394 acres (31%) were classified as oyster reef habitat. In 2010, NOAA Chesapeake Bay Office conducted a side scan sonar survey of the area. Of the 1,431 acres surveyed, 386 (27%) acres were classified as oyster reef habitat. While there has been no major loss of habitat, the location of the oyster bottom has shifted.

Restoration and Replenishment Activities

Since 1990 both replenishment and restoration activities have occurred in this area (Table A.38-1). Replenishment activities consisted of 91,215 bushels of shell and 46,430 bushels of wild seed planted. After the sanctuary was established in 2009, 93.89 million hatchery spat-on-shell were planted.

[74] See chart 21 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

Table A.38-1. Replenishment and restoration planting activities occurring since 1990 in the area that is now established as the Sandy Hill Sanctuary. S = a planting activity occurring after the area was established as a sanctuary in 2009.				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Dredged Shell	19.83	91.22	-
1990	Wild Seed	32.13	22.63	-
1999	Wild Seed	32.05	14.80	-
2000	Wild Seed	5.34	9.00	-
2009 (S)	Hatchery Spat-on-Shell	42.16	-	49.65
2010 (S)	Hatchery Spat-on-Shell	32.32	-	44.24

Oyster Population Characteristics

The Fall Survey has sampled one oyster bar in the area of the sanctuary since 1990; however, in 1990 two samples were collected on the same bar. The average number of live oysters per bushel (market, small, and spat) was similar before and after sanctuary creation (Table A.38-2; Figure A.38-3). There has been a trend toward increasing the number of oysters per bushel since 2003. The average number of small-sized oysters per bushel decreased after sanctuary establishment, whereas the average number of market-sized oysters increased during the same period.

Table A.38-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Sandy Hill Sanctuary in 2009. ND = No Data. Values are given as mean ± standard error.		
	1990-2008	**2009-2015**
Number of Years Sampled / Number of Samples	19 / 20	7 / 7
Number of Live Oysters per Bushel	73 ± 13	74 ± 13
Number of Live Small-Sized Oysters per Bushel	24 ± 8	12 ± 4
Number of Live Market-Sized Oysters per Bushel	34 ± 6	59 ± 15
Live Oyster Biomass (g Dry Weight per Bushel)	94 ± 13.8	158 ± 40.2
Mortality (%)	36.2 ± 5.8	6.6 ± 1.7

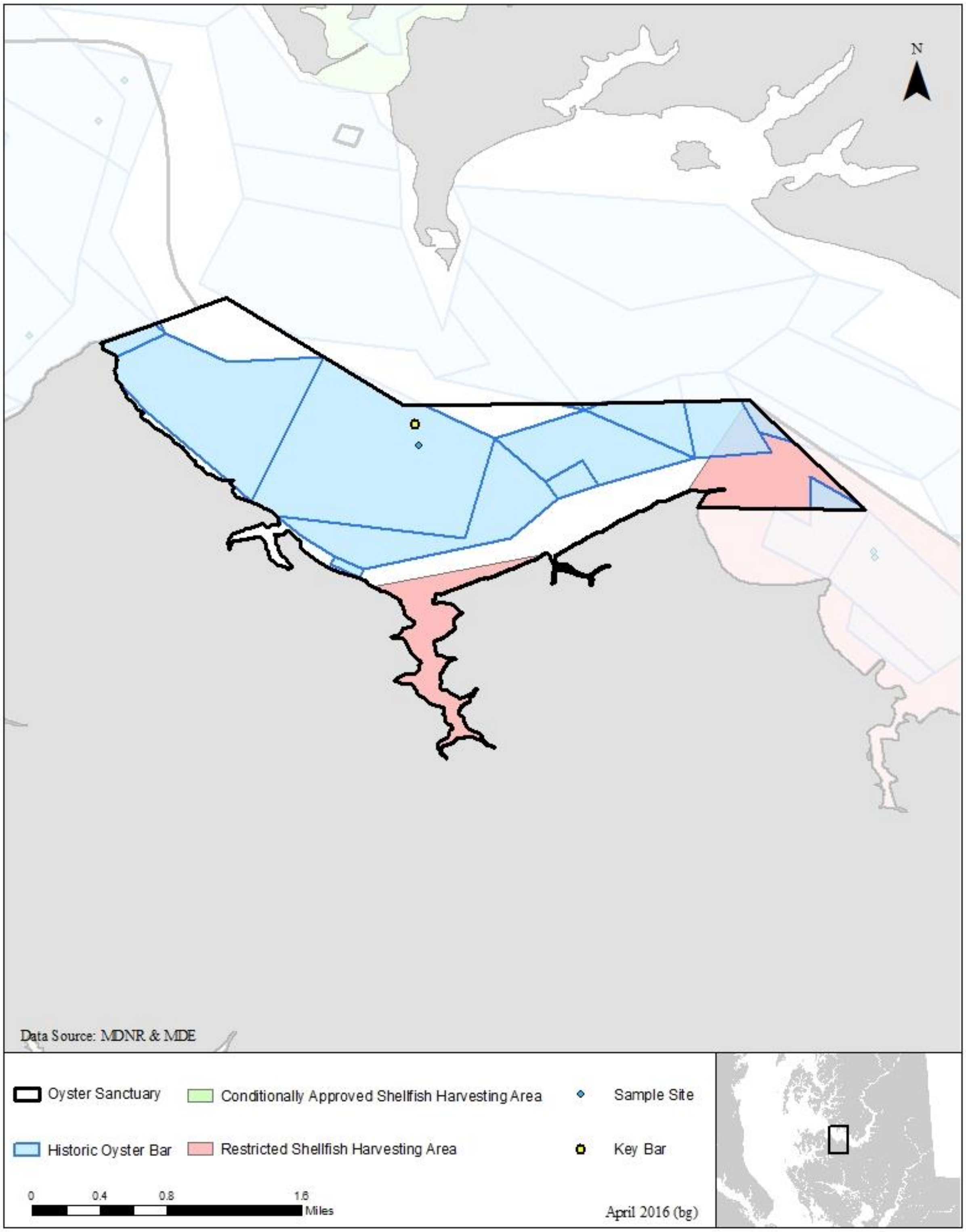
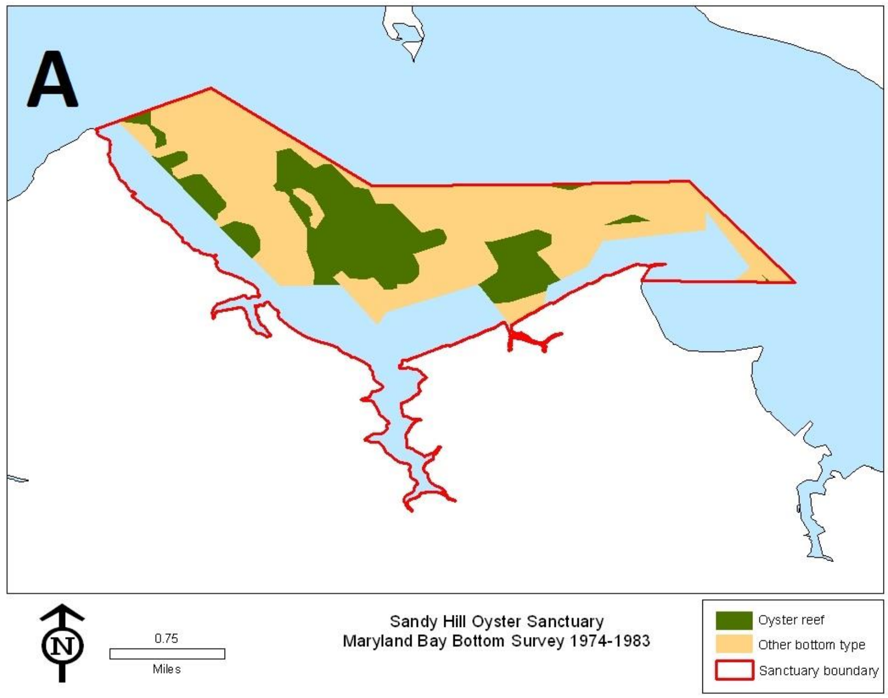


Figure A.38 -1. Sandy Hill Sanctuary.



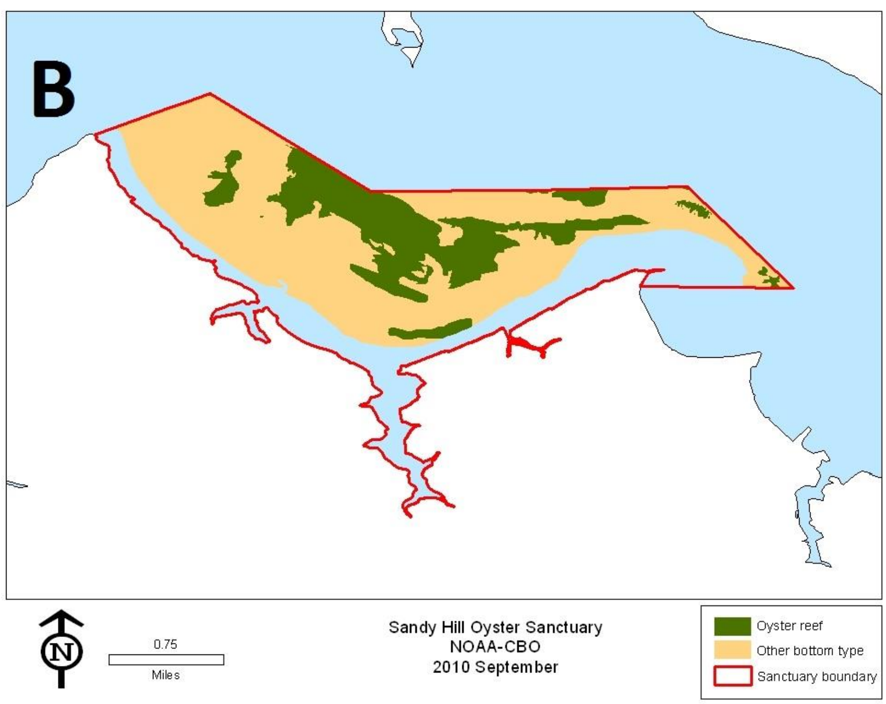


Figure A.38 -2. Sandy Hill Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from NOAA Chesapeake Bay Office from 2010. Tan and green colored areas depict areas examined during the surveys.

A patent tong population survey was conducted in 2015 (Figures A.38-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 2.29 ± 0.68 oysters m^{-2} (mean ± standard error, n= 96). The density of small-sized oysters was lower than the density of market-sized oysters (0.39 ± 0.15 and 1.86 ± 0.56 oysters m^{-2}, respectively). Fifty-eight percent of the samples collected had no live oysters or boxes. Live oyster density generally increased with volume of volume of shell (Figure A.38.5).

Paynter et al. (2013) found a density of 1.5 oysters m^{-2} on a hatchery planting three years after placement.[75]

Oyster Size Structure

Oysters collected by the Fall Survey from Sandy Hill bar have been measured since 1990 (Figure A.38-6). Oysters were also measured during the patent tong population survey (Figure A.38-7). There has been a notable increase in the number of very large oysters due to low mortality of the 2010 and 2012 year classes and the cessation of harvest. The size distribution of oysters from the 2012 patent tong survey agrees well with the 2012 Fall Survey size distribution.

Paynter et al. (2013) found an average shell height of 97.3 mm on a hatchery planting three years after placement.[76]

Biomass

Average biomass of oysters from Sandy Hill Bar collected by the Fall Survey was greater after sanctuary establishment than before (Table A.38-2; Figure A.38-8). Since 2009, biomass has increased steadily due to the increase in both number and size of oysters.

Paynter et al. (2013) found a biomass of 2.1 g m^{-2} on a hatchery planting three years after placement.[77]

Recruitment (Spatfall)

Based on the Fall Survey data, average spatfall ranged from 0 to 179 per bushel, but tended toward the low end of this range (Figure A.38-3). The longest consecutive spatfall occurred from 2006 to 2010 with an average of 4 spat per bushel. Based on the patent tong population survey, the density of spat in 2012 was 0.04 ± 0.03 m^{-2}.

[75] Paynter, K., H. Lane, and A. Michaelis. 2013. Paynter Lab Annual Monitoring and Research Summary 2012. Report to the Oyster Recovery Partnership. 110 pp.
http://www.life.umd.edu/biology/paynterlab/labpub/2012%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf
[76] IBID
[77] IBID

Mortality

Based on Fall Survey box counts, average mortality after sanctuary creation was lower than before sanctuary creation (Table A.38-2; Figure A.38-9). Mortality ranged from 0% to 88%, with the highest mortality occurring in 2003. A period of high mortality occurred from 2000 to 2004 which corresponds to the baywide disease epizootic. Since 2007, mortality has been relatively low.

Disease

From 1990 to 2015, dermo prevalence has ranged from 13% to 100% and was greater than 80% in 17 of the 26 years samples were collected (Figure A.03-10). Dermo intensity ranged from 0.2 to 5.7 during this time period, reaching lethal levels (greater than5) in 1990, 1991, and 2002. MSX prevalence ranged from 0% to 53% from 1990 to 2015 but was zero for 23 of the 26 years disease was sampled. There have only been two consecutive years (2001-2002) with non-zero MSX prevalence.

Paynter et al. (2013) found a dermo prevalence of 100% on a three-year-old hatchery planting in 2013.[78] This corresponds well with the high dermo intensity found in the 2012 Fall Survey sample.

[78] Paynter, K., H. Lane, and A. Michaelis. 2013. Paynter Lab Annual Monitoring and Research Summary 2012. Report to the Oyster Recovery Partnership. 110 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2012%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

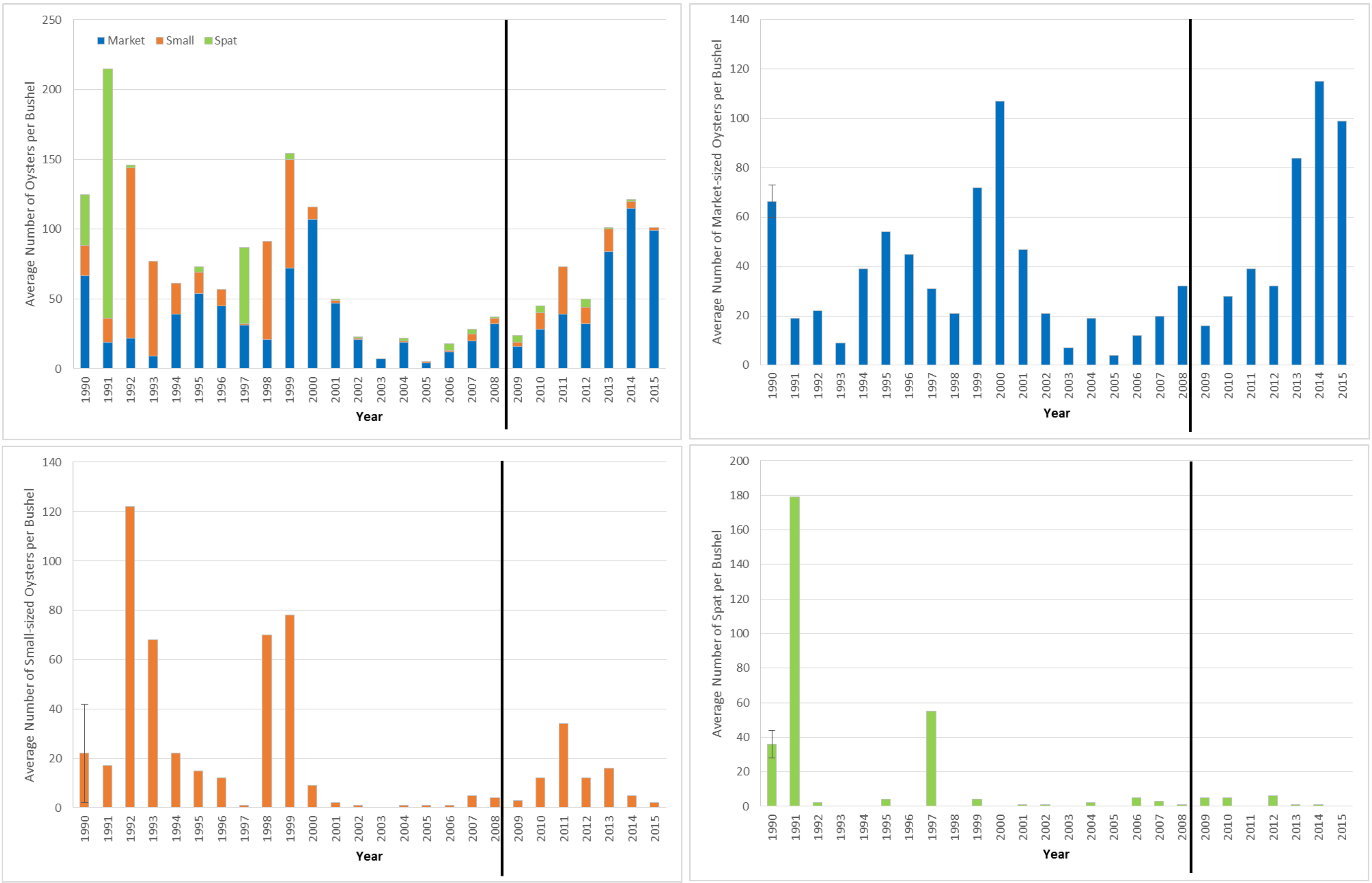


Figure A.38-3. Average number of live oysters per bushel of material by size class in the Sandy Hill Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

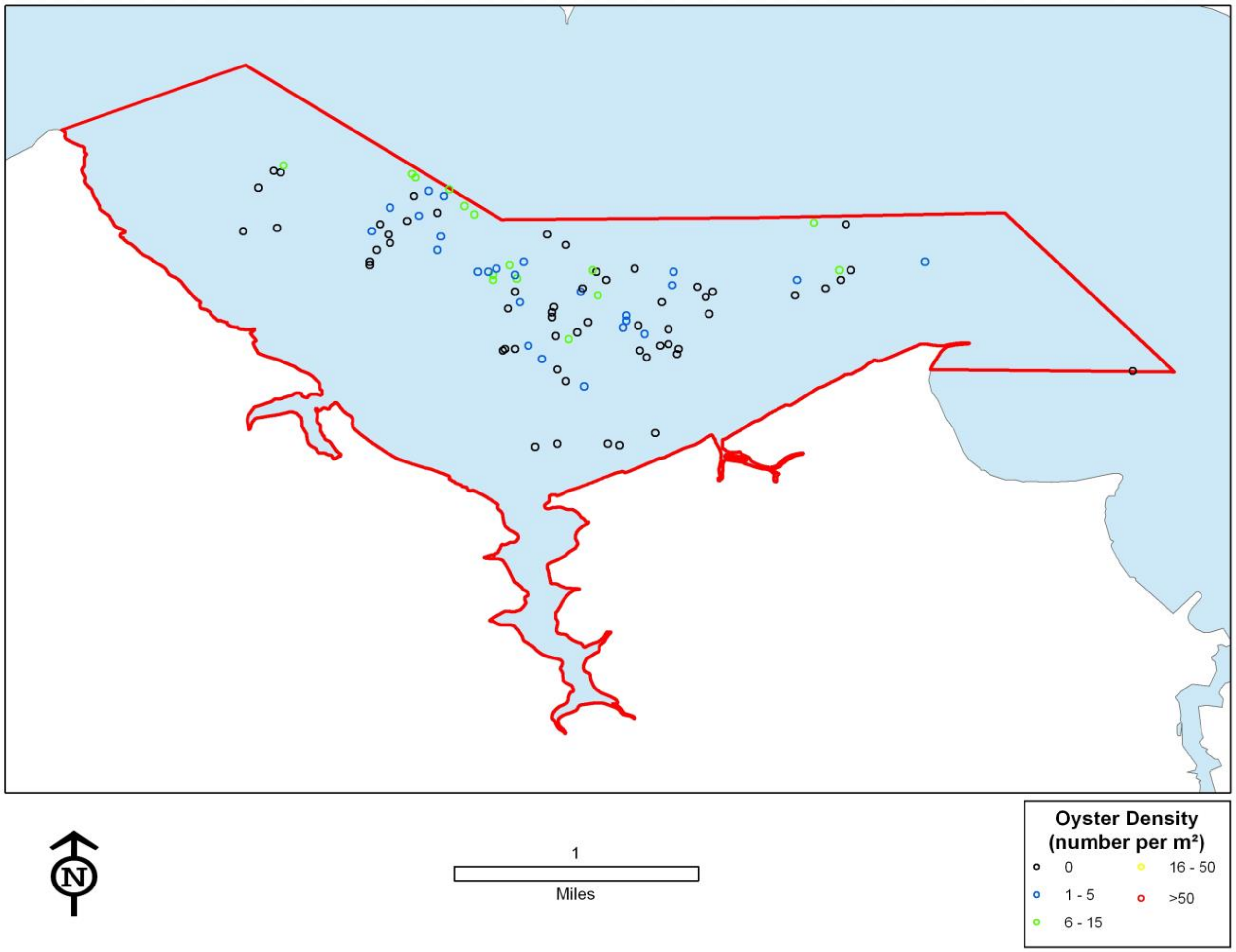


Figure A.38-4. Map of 2015 oyster density in the Sandy Hill Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

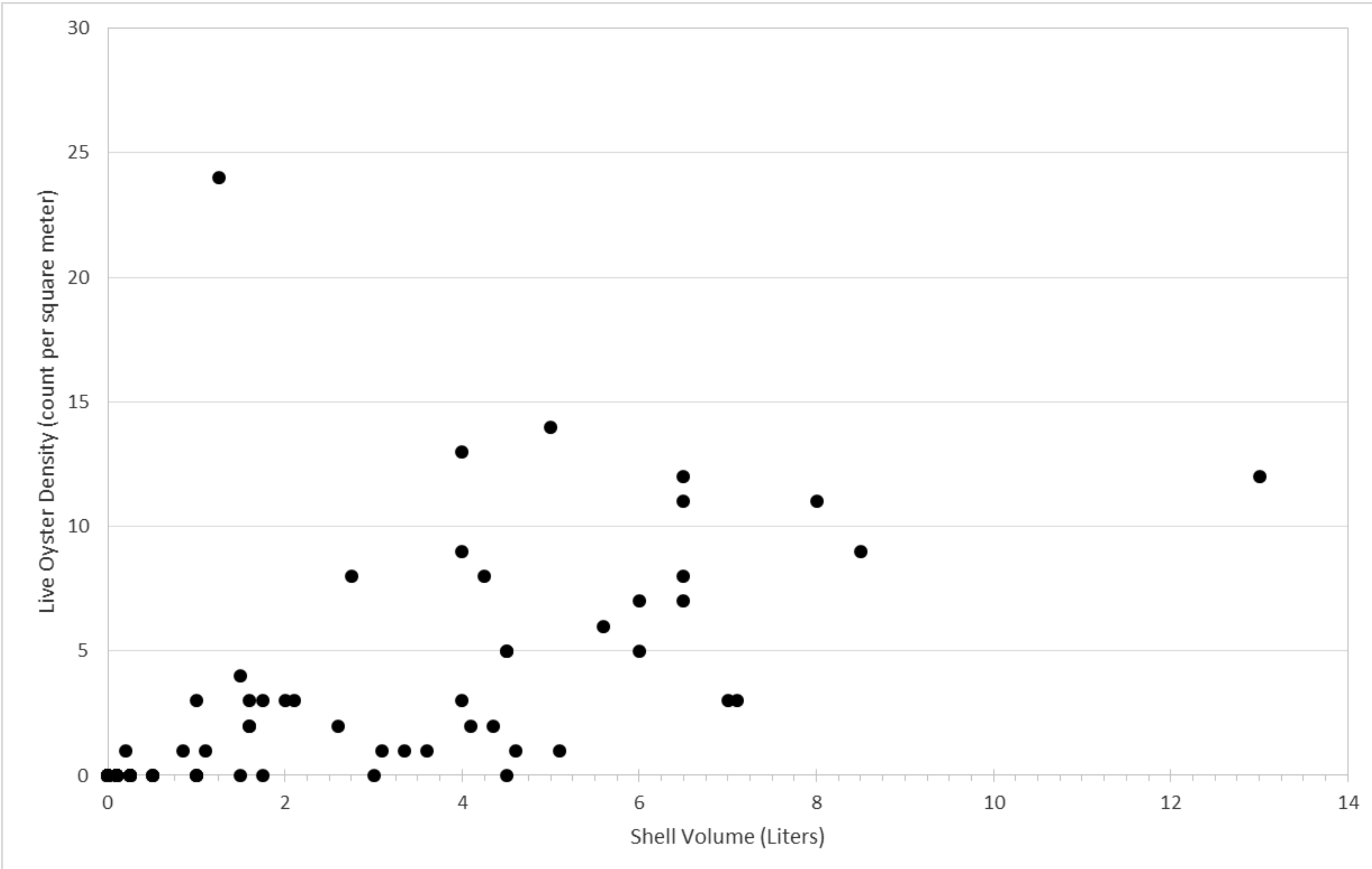


Figure A.38-5. 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Sandy Hill Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

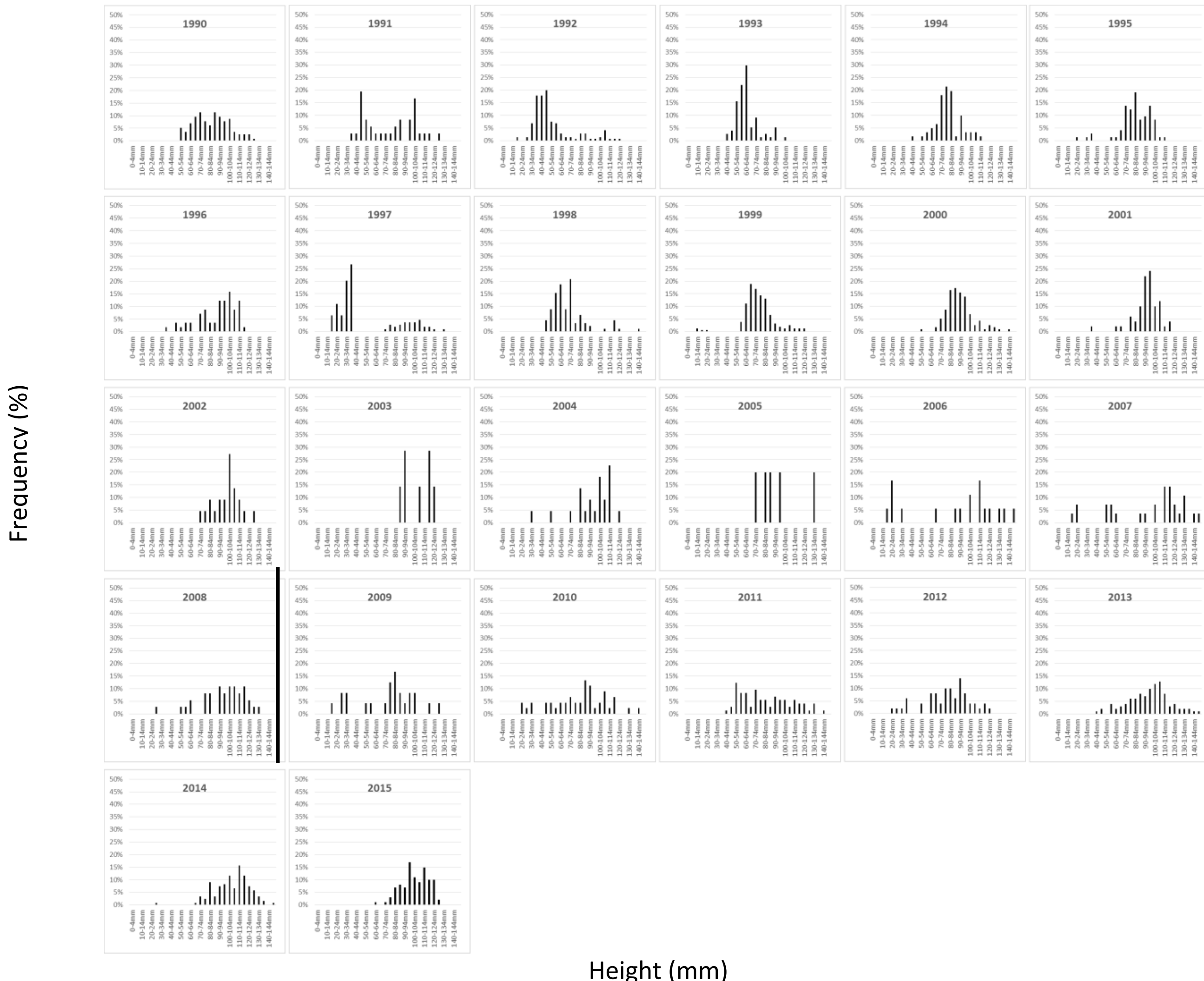


Figure A.38-6. Shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the Sandy Hill Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Sandy Hill bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

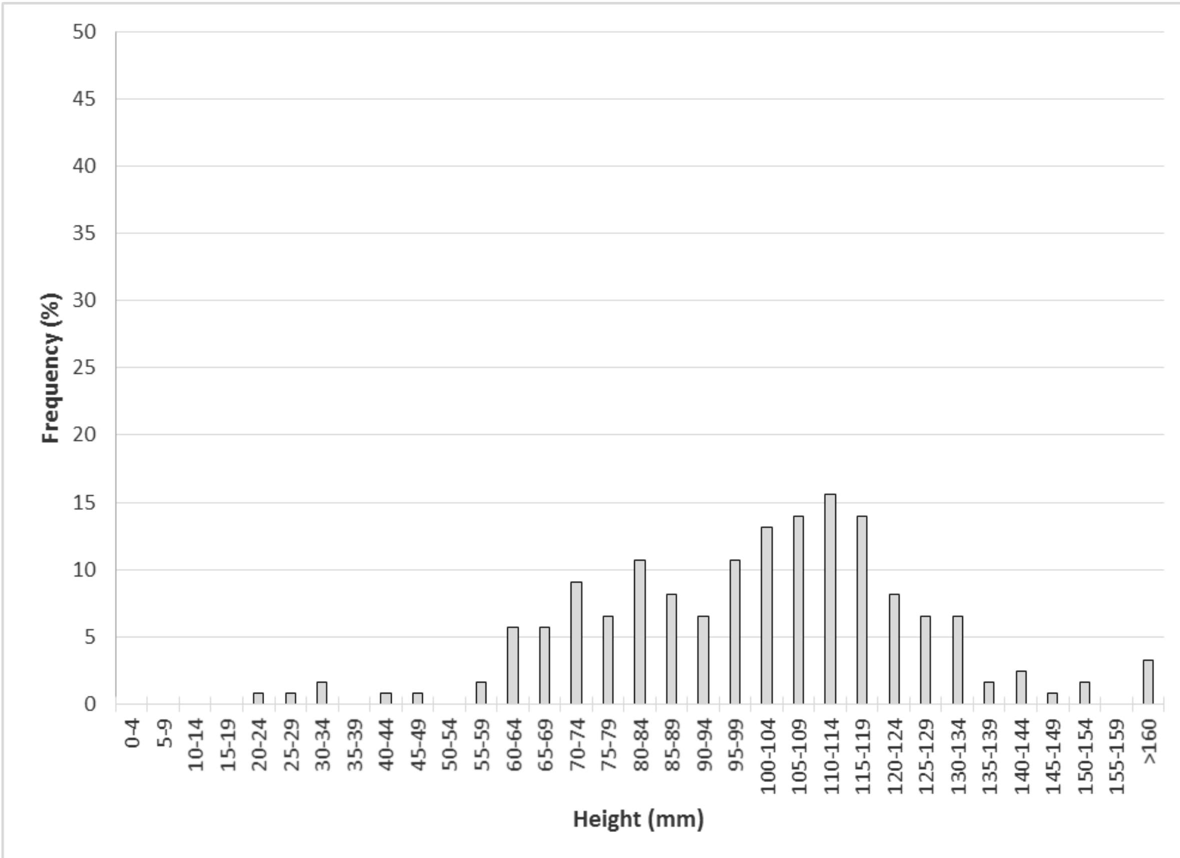


Figure A.38-7. Shell height frequencies of live oysters in the Sandy Hill Sanctuary in 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

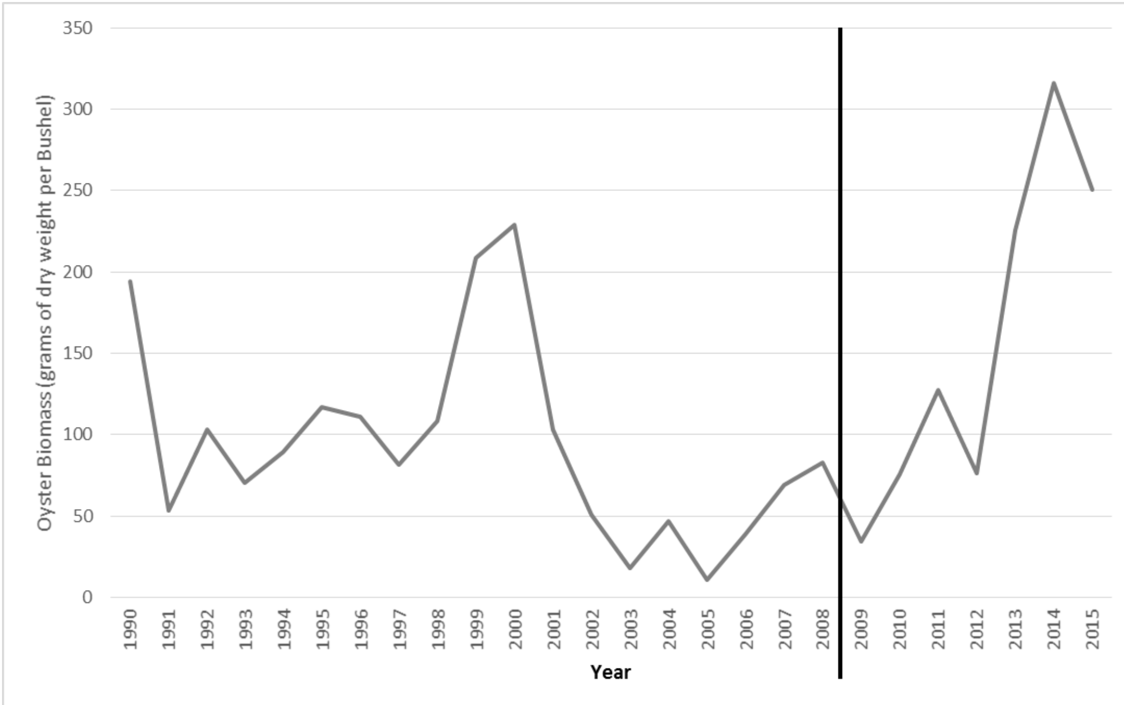


Figure A.38-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Sandy Hill Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Sandy Hill bar. Black line indicates the date the sanctuary was established.

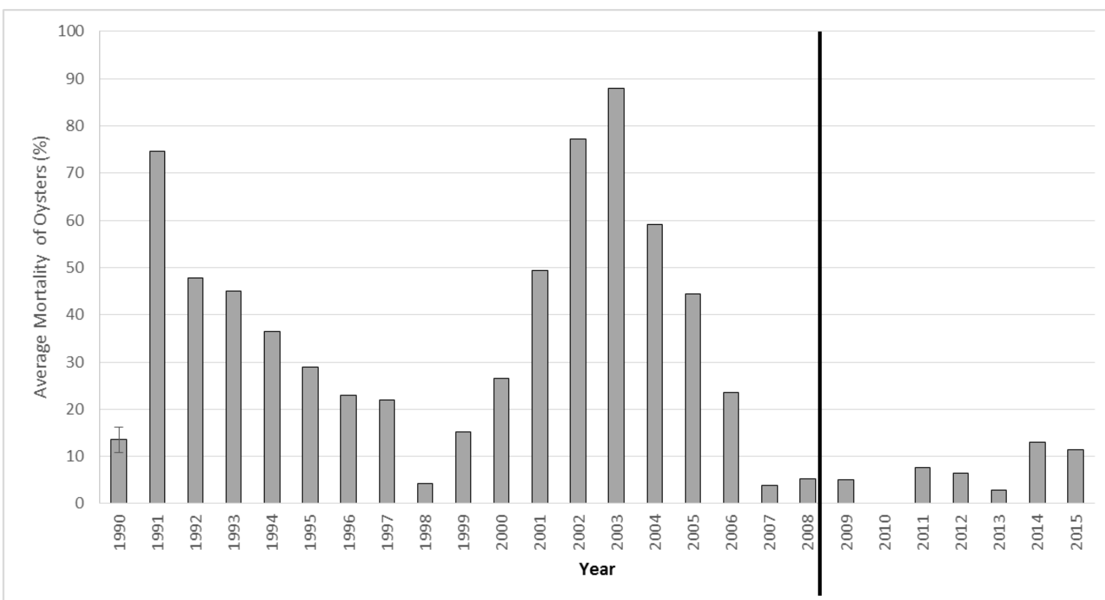


Figure A.38-9. Average annual mortality of market-sized and small-sized oysters from 1990 to 2015 in Sandy Hill Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

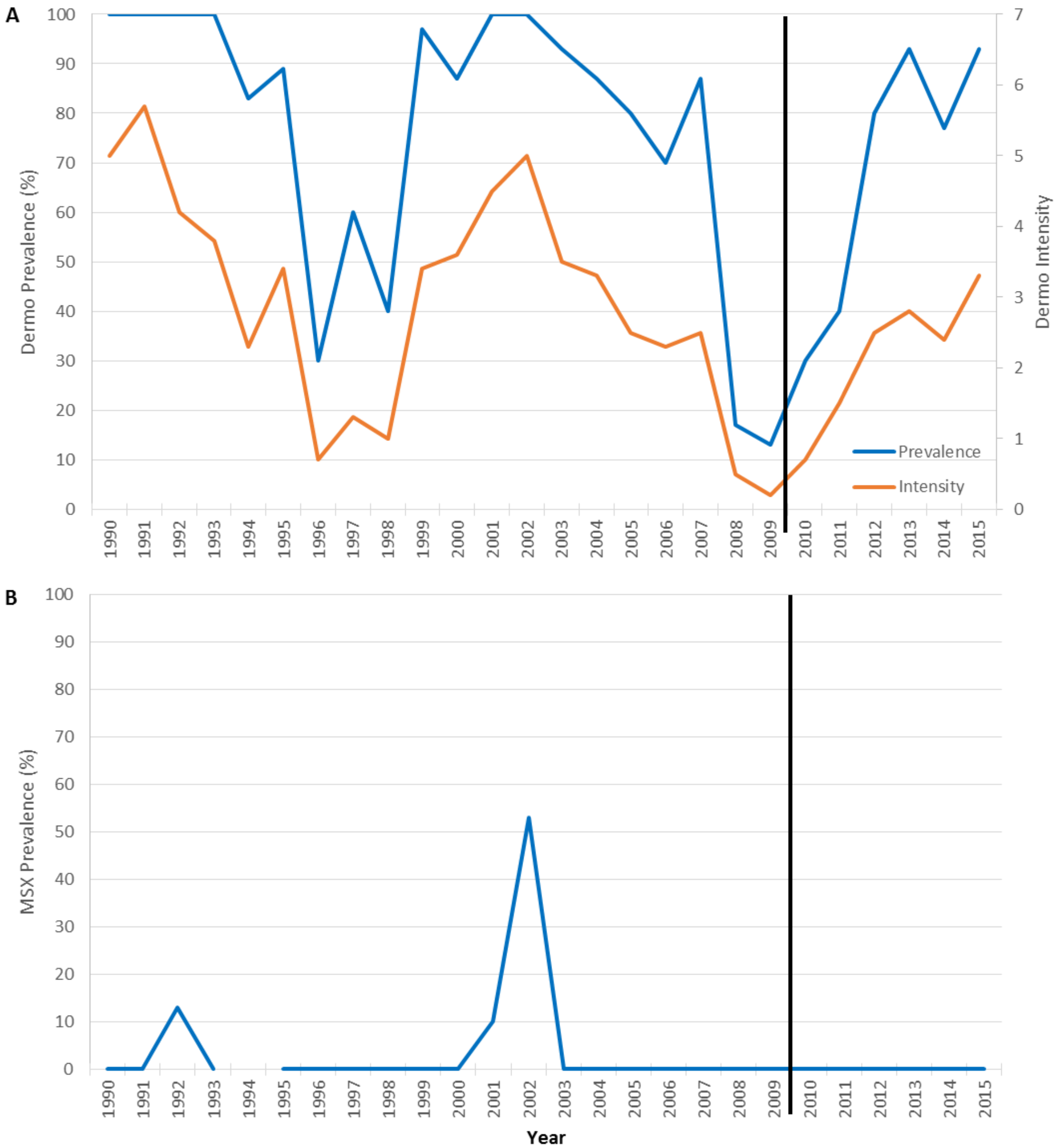


Figure A.38-10. Oyster disease prevalence and intensity from 1990 to 2015 in the Sandy Hill Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Sandy Hill bar.

Harvest

The sanctuary encompasses 16% of 11,934 acres in NOAA Code 237. Because harvest from NOAA Code 237 is likely to have come from areas other than the area that became the sanctuary, seafood dealer reports for NOAA Code 237 cannot be used to assess harvest in this area. Commercial watermen reported no harvest from bars located in the area prior to it becoming a sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.39: Severn River Sanctuary

The Severn River Sanctuary encompasses the entire Severn River, a tributary of the upper western Chesapeake Bay which is in a low salinity (less than 12 ppt) region (Figure A.39-1). In 1998, 6,719 acres were designated by Maryland Department of the Environment (MDE) as restricted from harvest due to potential contamination of shellfish by fecal coliform and other bacteria. This restricted area constituted most of the river and essentially made the area a sanctuary since no harvest was allowed. In 2010, the entire river (7,804 acres) was officially designated as a sanctuary. Within the sanctuary, 1,376 (18%) acres is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 27 historic oyster bars within the sanctuary[79].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.39-2). Of the 4,700 acres surveyed within the sanctuary, 1,030 acres (22%) were classified as oyster reef habitat. In 2009, Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 3,609 acres surveyed 919 acres (25%) were classified as oyster reef habitat, suggesting habitat stability in the Severn River.

Restoration and Replenishment Activities

This area has received both replenishment and restoration efforts since 1990 (Table A.39-1). Prior to the creation of the sanctuary, wild seed, fresh shell, and dredged shell were planted to enhance the public fishery. After the sanctuary was established, hatchery spat-on-shell, wild seed, and dredged shell were planted to restore the oyster population. In 2009, the U.S. Army Corps of Engineers constructed reefs out of a variety of alternative substrates to examine their potential for oyster restoration. Marylanders Grow Oysters, a public outreach program, raises oysters in cages and plants them on one of the Corps of Engineers reefs. In 2016, growers tended 1,550 cages and planted approximately 465,000 oysters.

[79] See chart 9 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

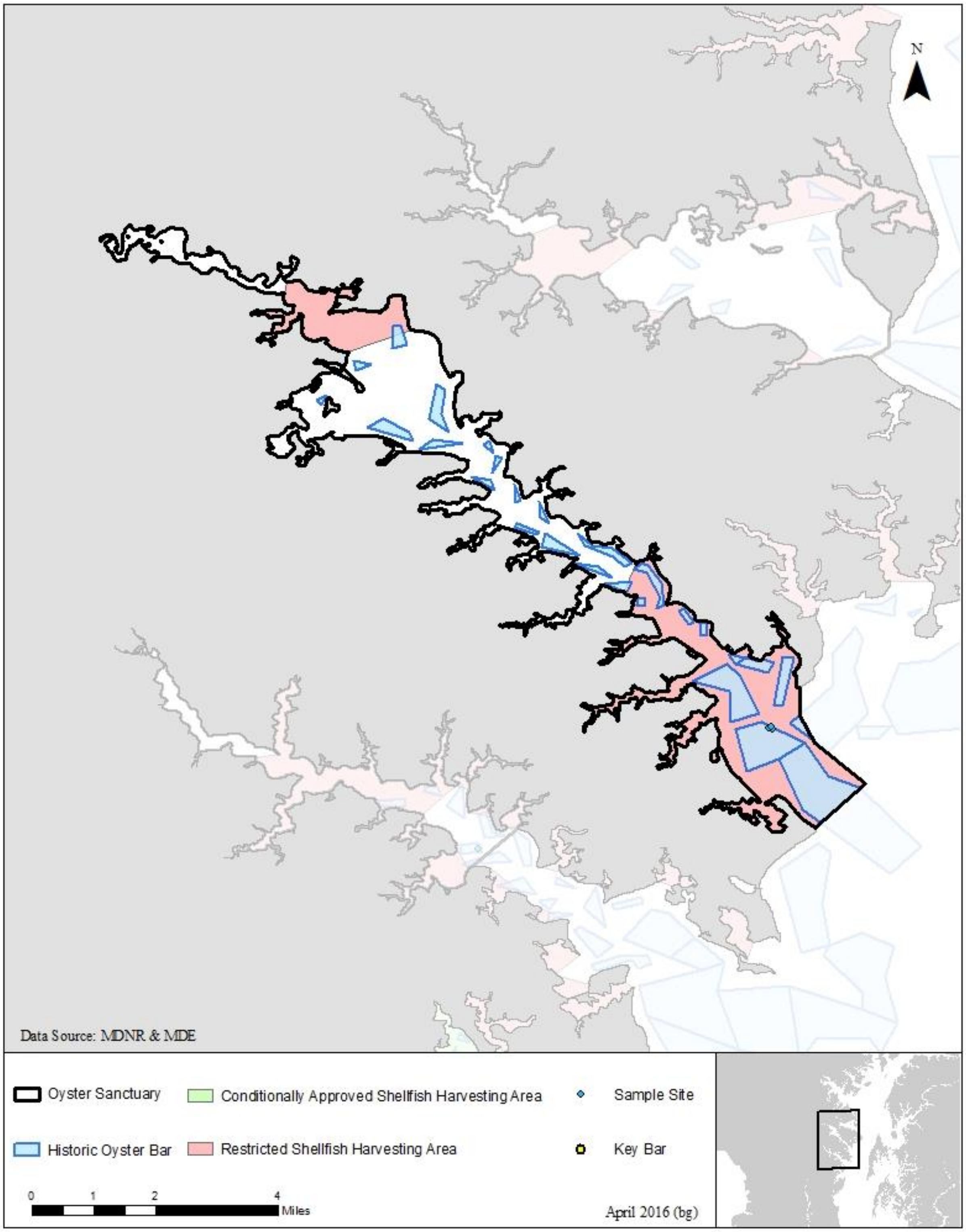


Figure A.39-1. Severn River Sanctuary.

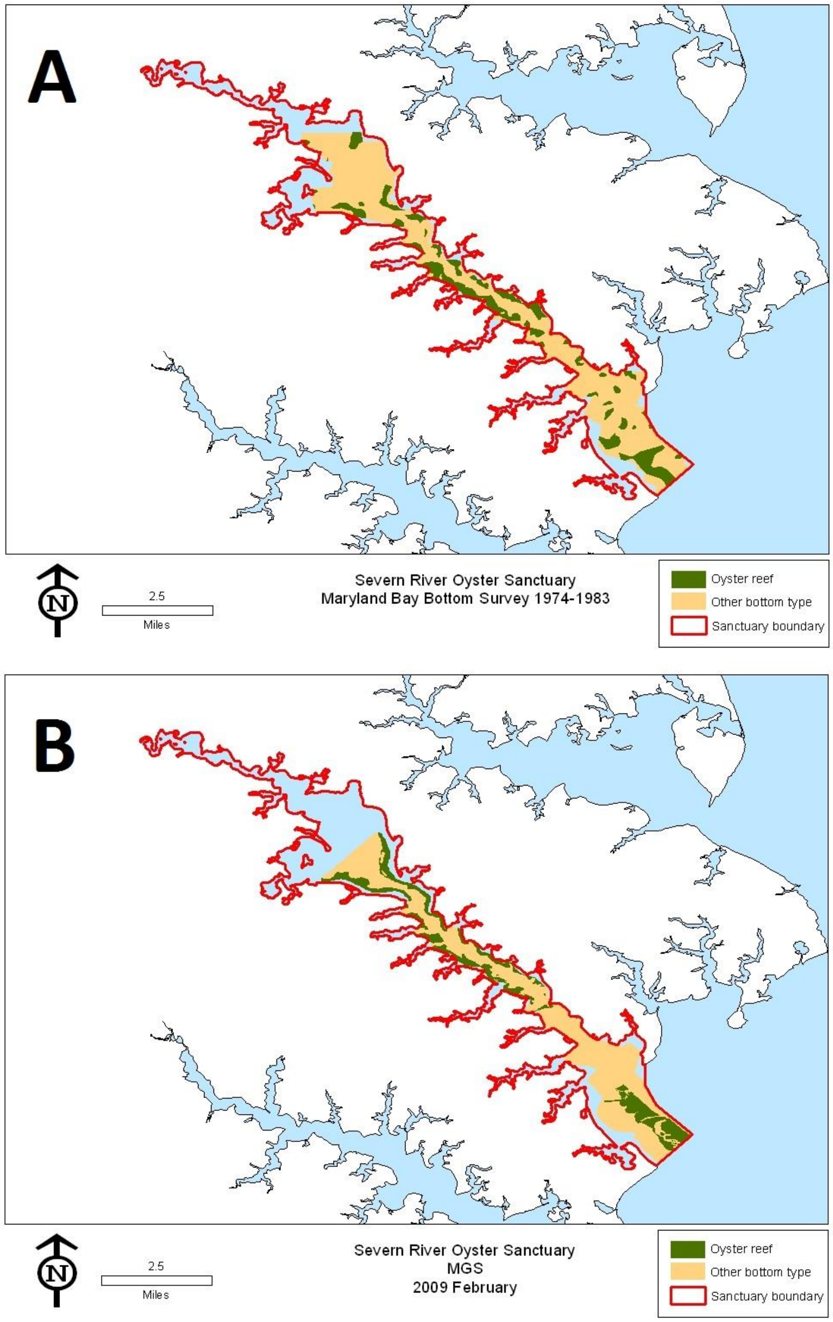


Figure A.39 -2. Severn River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from Maryland Geological Survey in 2009. Tan and green colored areas depict areas examined during the surveys.

Table A.39-1. Replenishment and restoration planting activities occurring since 1990 in the area that is now the Severn River Sanctuary. S = planting activity occurring after the area was established as a sanctuary in 1998. ND = No Data.				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1992	Wild Seed	1.66	2.02	-
1996	Dredged Shell	4.12	ND	-
1996	Fresh Shell	2.48	3.90	-
1998 (S)	Dredged Shell	7.87	56.24	-
1999 (S)	Dredged Shell	27.32	222.12	-
1999 (S)	Wild Seed	2	3.73	1
1999 (S)	Hatchery Spat-On-Shell	2	-	2.4
2001 (S)	Dredged Shell	0.39	12.19	-
2001 (S)	Hatchery Spat-On-Shell	0.39	-	1.5
2002 (S)	Hatchery Spat-On-Shell	10	-	1.2
2005 (S)	Dredged Shell	2.93	26.59	-
2005 (S)	Wild Seed	0.61	-	2.37
2006 (S)	Hatchery Spat-On-Shell	10.06	-	7.08
2007 (S)	Hatchery Spat-On-Shell	5.90	-	1.67
2008 (S)	Hatchery Spat-On-Shell	21.39	-	44.86
2009 (S)	Hatchery Spat-On-Shell	21.01	-	46.51
2009 (S)	Concrete, Granite, Slag, Fresh Shell	13.4	430.6	-
2010 (S)	Hatchery Spat-On-Shell	36.16	-	60.53
2012 (S)	Hatchery Spat-On-Shell	8.72	-	16.94
2013 (S)	Hatchery Spat-On-Shell	ND	-	44.43

Oyster Population Characteristics

The Fall Survey has sampled one to two oyster bars in this area since in 1991 and each year since 1998, with an average of two oyster bars sampled annually. The average number of live oysters per bushel (market, small, and spat) increased after the restriction on harvest by Maryland Department of the Environment and the sanctuary was established (Table A.39.2; Figure A.39-3). Results must be interpreted cautiously as only one sample was taken prior to the establishment of the sanctuary.

Table A.39-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Severn River Sanctuary in 1997. ND = No Data. Values are given as mean ± standard error.		
	1990-1997	**1998-2015**
Number of Years Sampled / Number of Samples	1 / 1	18 / 33
Number of Live Oysters per Bushel	30	88 ± 18
Number of Live Small-Sized Oysters per Bushel	0	34 ± 17
Number of Live Market-Sized Oysters per Bushel	26	51 ± 8
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	0	14.6 ± 4.1

A patent tong population survey was conducted in 2012 (Figure A.39-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 2.17 ± 0.99 oysters m^{-2} (mean ± standard error, n = 228). The density of small-sized oysters was greater than the density of market-sized oysters (1.69 ± 0.96 and 0.49 ± 0.16 oysters m^{-2}, respectively). Eighty-eight percent of the samples collected contained no live oysters or boxes. Oyster density tended to increase with increase in shell volume (Figure A.39-5).

Paynter and colleagues[80, 81, 82] have been monitoring oyster plantings in the Severn River Sanctuary. Average density several weeks after planting was 127.6 oysters m^{-2}. Average densities declined to 1.2-1.8 oysters m^{-2} three years after planting, although a planting on Tolly Point had an average density of 5.1 oysters m^{-2} six years post-planting.

Oyster Size Structure

The Fall Survey has not collected information about oyster shell height in this area since 1990. Shell heights of oysters collected by the patent tong population survey were measured (Figure A.23-6). Small and market-sized oysters were present, but no spat. Paynter and colleagues have been monitoring growth of oysters on the alternative substrates placed by the Army Corps of Engineers, as well as on natural shell. Oysters grew at the same rate on all substrates examined[83].

[80] Paynter, K.T. 2011. 2008 Sanctuary Assessment. Report to the U.S. Army Corps of Engineers, Baltimore District. 67 pp. http://www.nab.usace.army.mil/Portals/63/docs/Environmental/Oysters/2008SanctuaryAssessment.pdf

[81] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

[82] Paynter, K., H. Lane, and A. Michaelis. 2013. Paynter Lab Annual Monitoring and Research Summary 2012. Report to the Oyster Recovery Partnership. 110 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2012%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

[83] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

Biomass

Biomass has not been calculated for Fall Survey samples in this area since 1990. Paynter et al. have been monitoring biomass of plantings in the Severn River and have found biomass densities of 1.3-2.3 g m^{-2} three years after planting and 8 g m^{-2} six years after planting[84, 85, 86].

Recruitment (Spatfall)

Spatfall has been sparse in this area (Figure A.38-3). Based on the Fall Survey data, natural spat were found only in 1991 (4 spat per bushel) and 2002 (1 spat per bushel). The spat collected in 2007 sample were hatchery spat-on-shell. No spat were collected during the 2012 patent tong population survey.

Mortality

Mortality ranged from 0% to 59%, with the greatest mortality in 2002. The 2002 mortality corresponded to bay-wide disease event (Figure A.39-7).

Disease

Oysters collected by the Fall Survey in this area were not analyzed for disease. Paynter et al. have been monitoring dermo disease on plantings and found prevalence from 20-100%[87,88,89].

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[84] Paynter, K.T. 2011. 2008 Sanctuary Assessment. Report to the U.S. Army Corps of Engineers, Baltimore District. 67 pp. http://www.nab.usace.army.mil/Portals/63/docs/Environmental/Oysters/2008SanctuaryAssessment.pdf

[85] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

[86] Paynter, K., H. Lane, and A. Michaelis. 2013. Paynter Lab Annual Monitoring and Research Summary 2012. Report to the Oyster Recovery Partnership. 110 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2012%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

[87] Paynter, K.T. 2011. 2008 Sanctuary Assessment. Report to the U.S. Army Corps of Engineers, Baltimore District. 67 pp. http://www.nab.usace.army.mil/Portals/63/docs/Environmental/Oysters/2008SanctuaryAssessment.pdf

[88] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

[89] Paynter, K., H. Lane, and A. Michaelis. 2013. Paynter Lab Annual Monitoring and Research Summary 2012. Report to the Oyster Recovery Partnership. 110 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2012%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

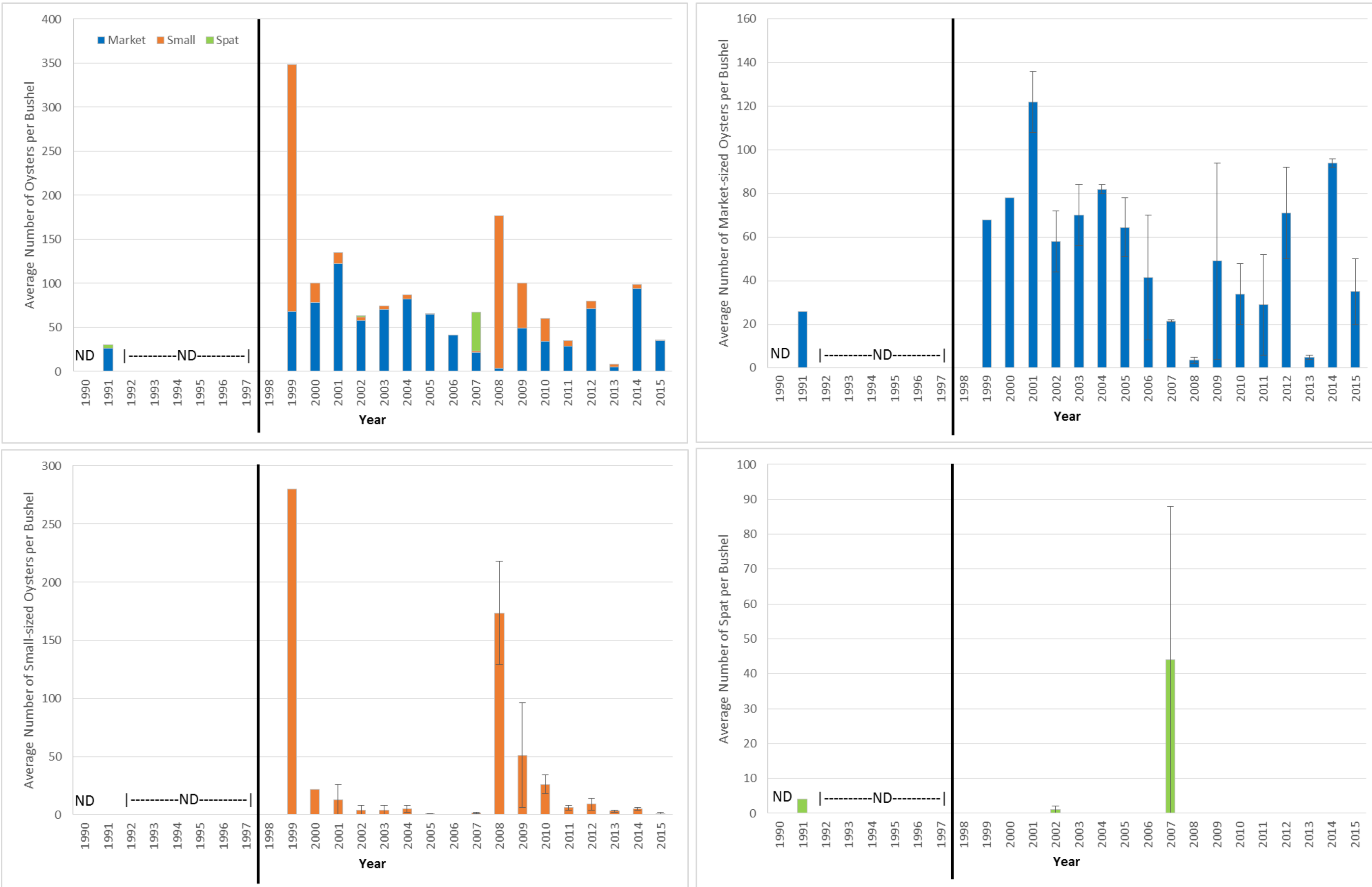

Figure A.39-3. Average number of live oysters per bushel of material by size class in the Severn River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data

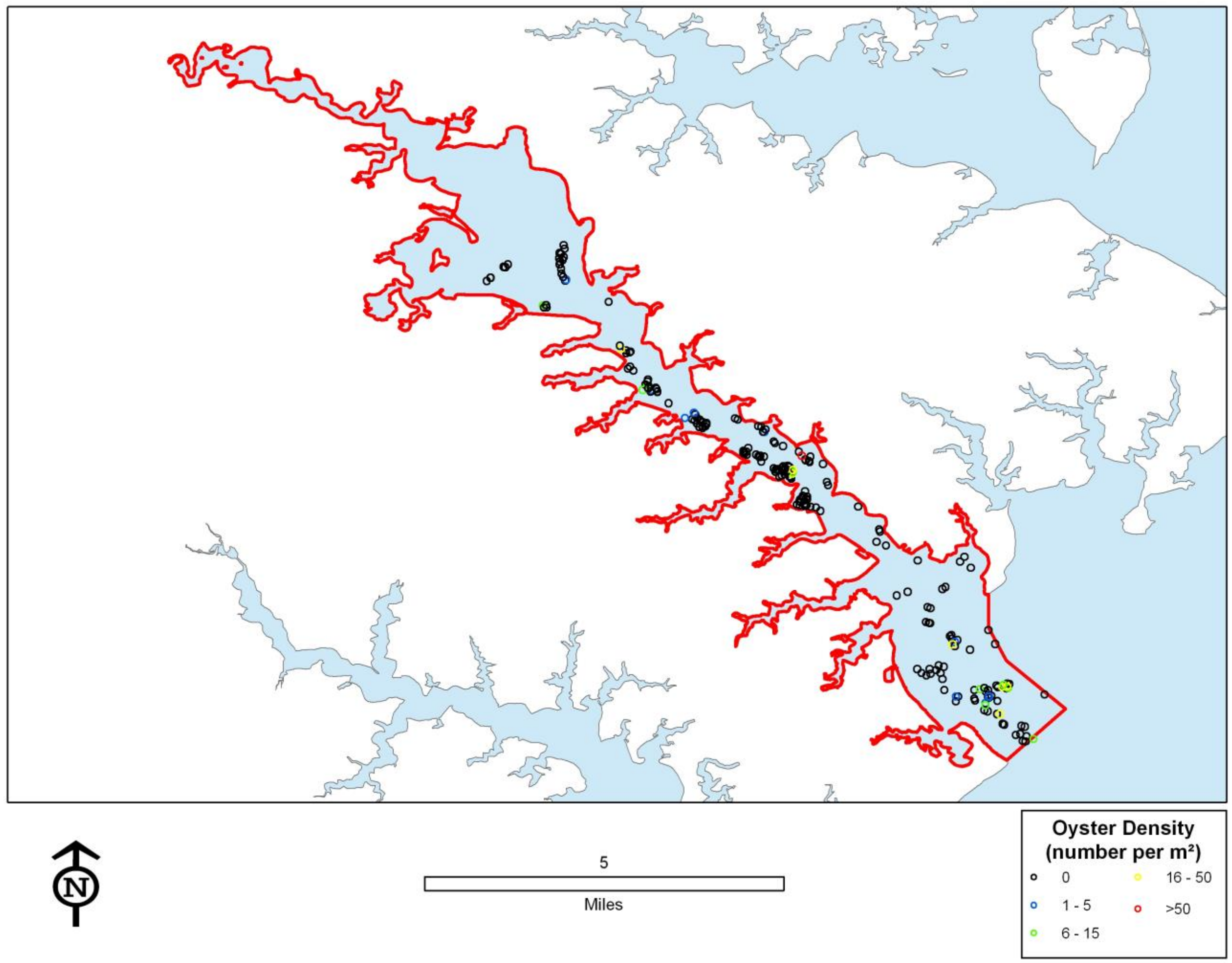

Figure A.39-4. Map of 2012 oyster density in the Severn River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

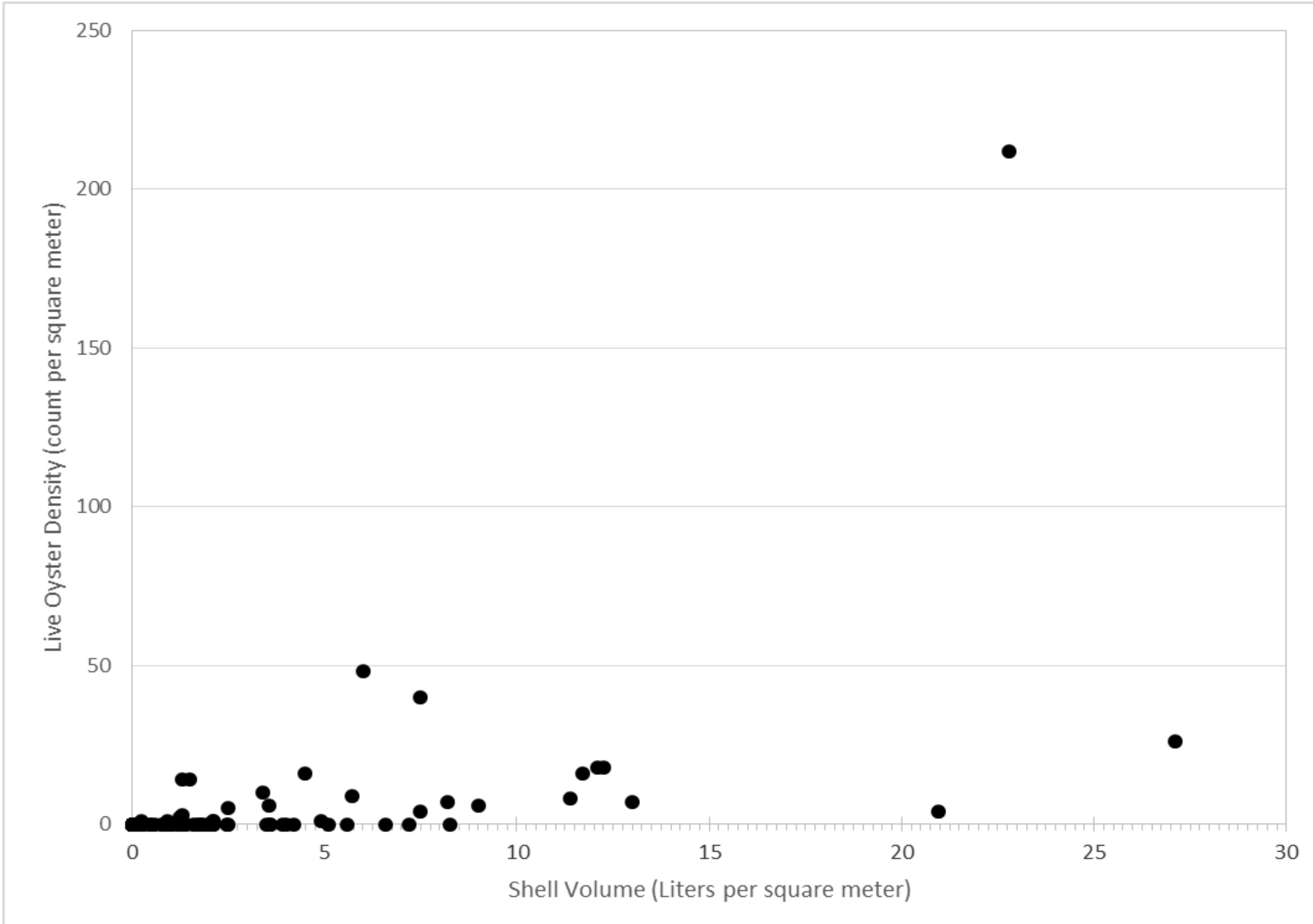

Figure A.39-5. 2012 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Severn River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

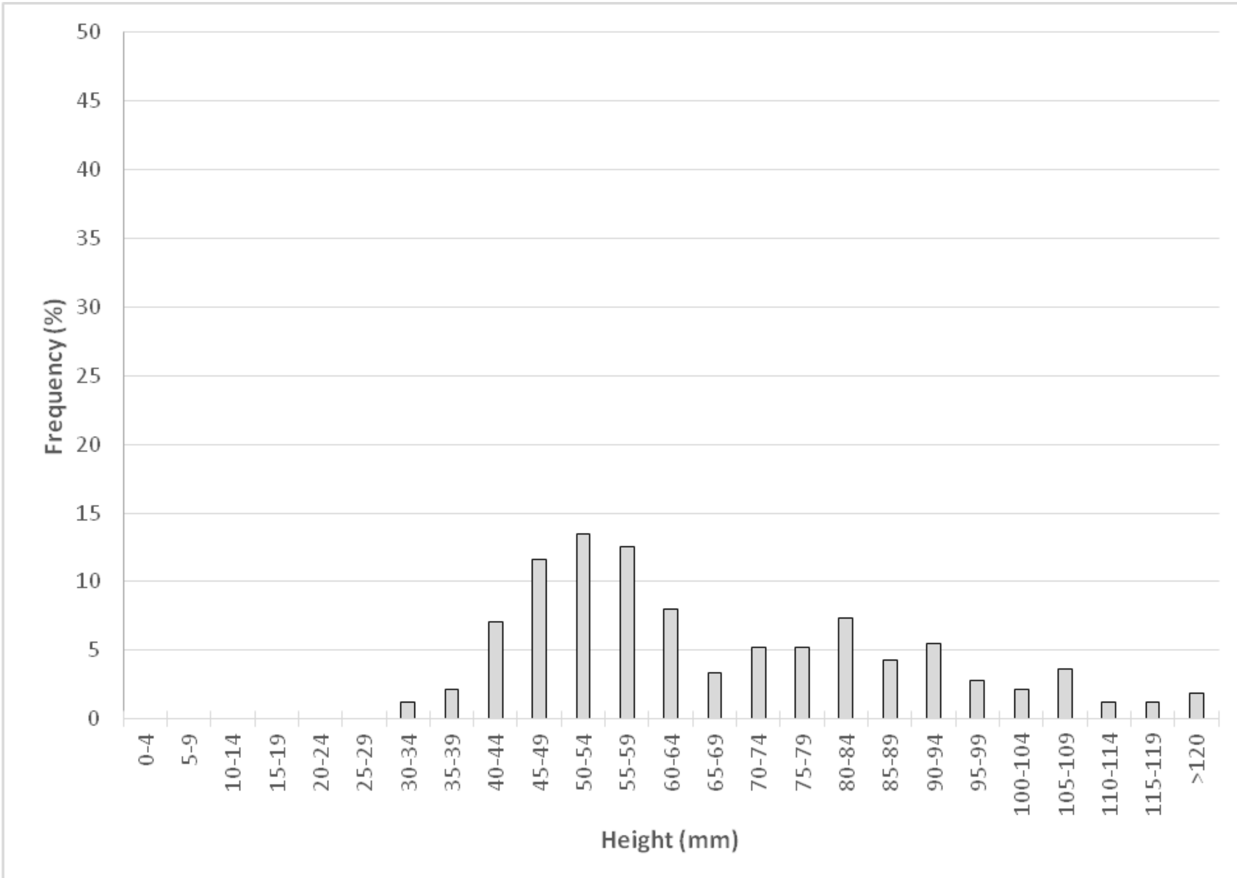

Figure A.39-6. Shell height frequencies of live oysters in the Severn River Sanctuary in 2012. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

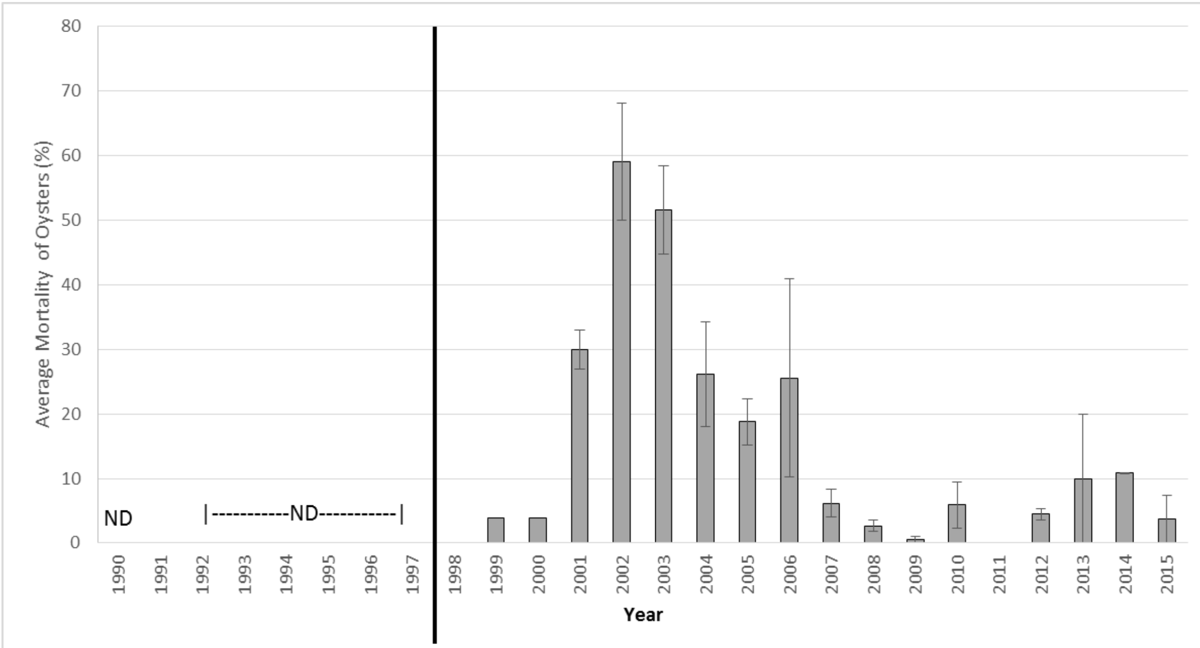

Figure A.39-7. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Severn River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error. ND = No Data.

Harvest

The sanctuary encompassed 98% of the 7,711 acres in NOAA Code 082 in 1998 and all of the NOAA Code in 2010. Approximately, 252 acres of the Severn River Sanctuary are in NOAA Code 082, however, that area is classified by Maryland Department of the Environment as restricted so harvest is not allowed. After 1998 only 556 bushels were harvested from the area (Figure A.39-8).

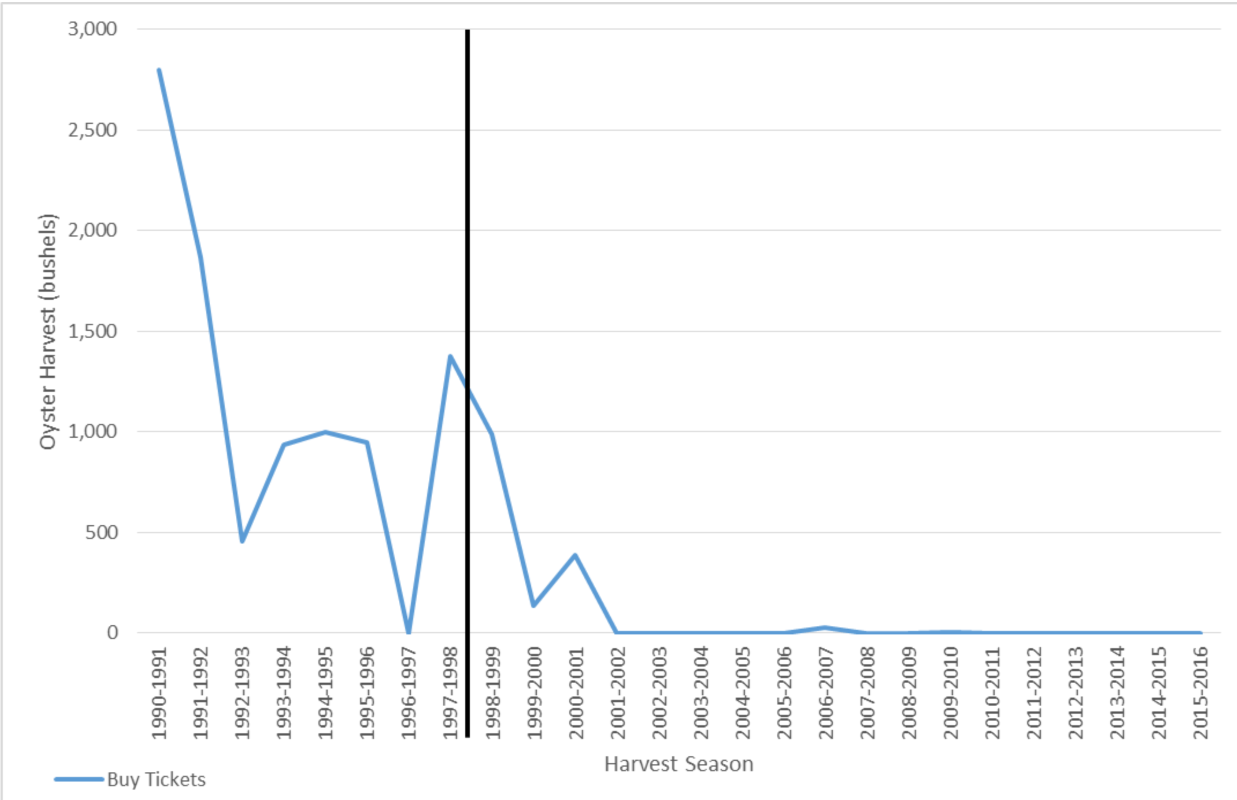

Figure A.39-8. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 082 (Severn River). In 1998, 98% of the NOAA Code became an oyster sanctuary (denoted by the black line) where harvest is prohibited. In 2010, the entire NOAA Code became a sanctuary.

Environmental Conditions and Ecosystem Services

Maryland's Eyes on the Bay Program monitors monthly water quality at station WT7.1 (39.00764, -76.5035) in this area (Figure A.39-9). Water quality was generally suitable for oysters except for brief periods of low salinity.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

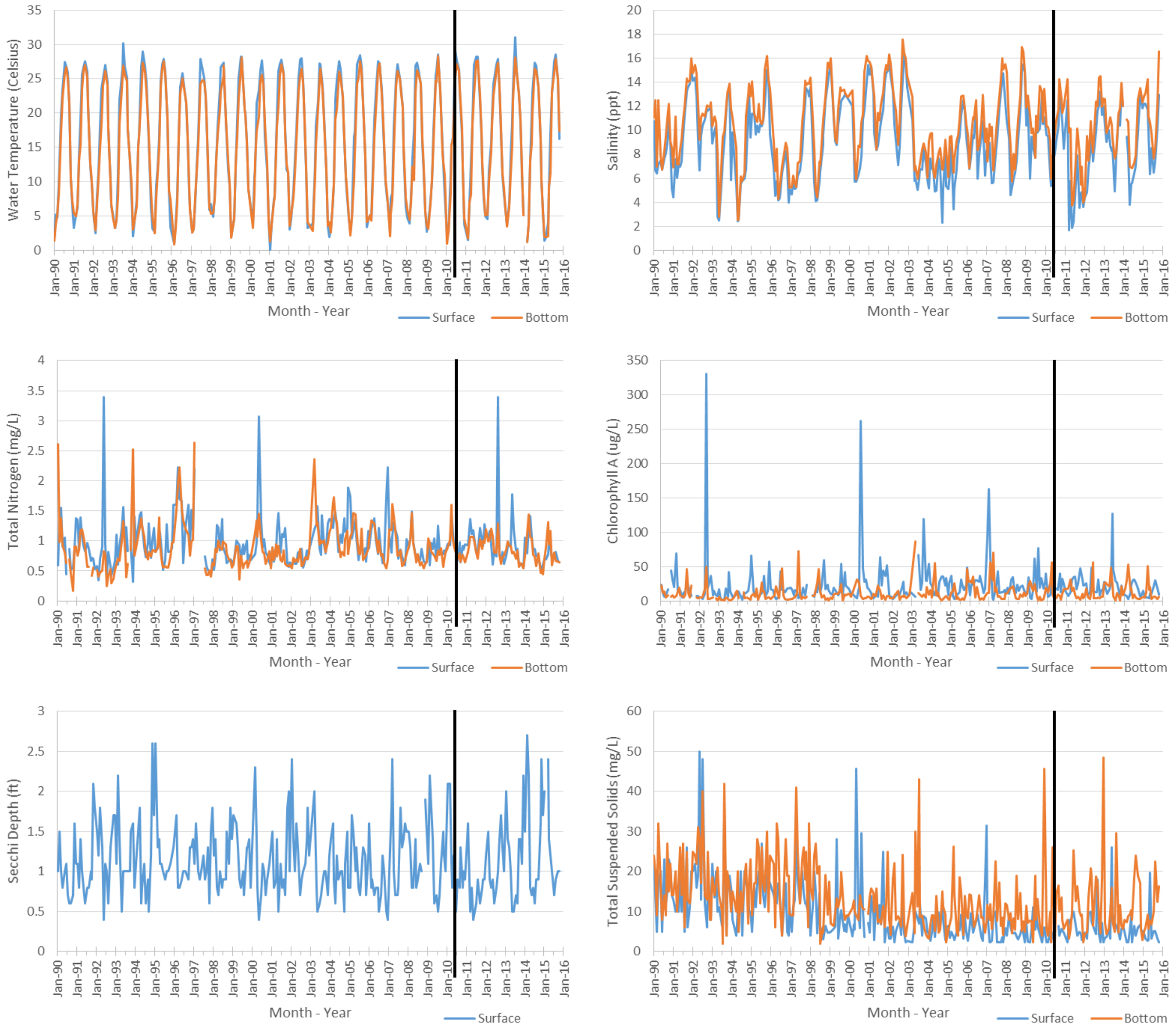

Figure A.39-9. Water quality data collected at Station WT7.1 in Severn River. Black line denotes the date the sanctuary was established.

Section A.40: Solomons Creeks Sanctuary

The Solomons Creeks Sanctuary is located in the lower Patuxent River, a high salinity (greater than 14 ppt) region (Figure A.40-1). The sanctuary was created in 2010 to accommodate oysters produced by the Southern Maryland Oyster Cultivation Society, a citizen-sponsored restoration group. It encompasses 617 acres of which only 5 acres (0.8%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). The sanctuary contains all of the Shell Pile historic oyster bar and a portion of the Cherry Tree bar. In 1964, Solomons Creek Sanctuary is classified by MDE as a restricted shellfish harvest area due to the potential for contamination of shellfish by fecal coliform and other bacteria.

Bottom Habitat Characteristics

No bottom mapping has been conducted in this area.

Restoration and Replenishment Activities

Chesapeake Bay Foundation, Coastal Conservation Association, and Southern Maryland Oyster Cultivation Society planted 7.2 million oysters in the sanctuary from 2008-2012. This planting program has been officially discontinued, but individuals continue to plant cage-reared oysters in the creek through Marylanders Grow Oysters.

Oyster Population Characteristics

The Fall Survey has not sampled any oyster bars within this area, nor has a patent tong population survey been conducted by the Department since 1990.

Harvest

The sanctuary encompasses 7% of the 8,880 acres in NOAA Code 168. Because harvest from NOAA Code 231 is likely to have come from areas other than the sanctuary, seafood dealer reports from this NOAA Code cannot be used to assess harvest in this area. Harvester reporting was not implemented until after the establishment of sanctuary, therefore harvester reports for this area are not available.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

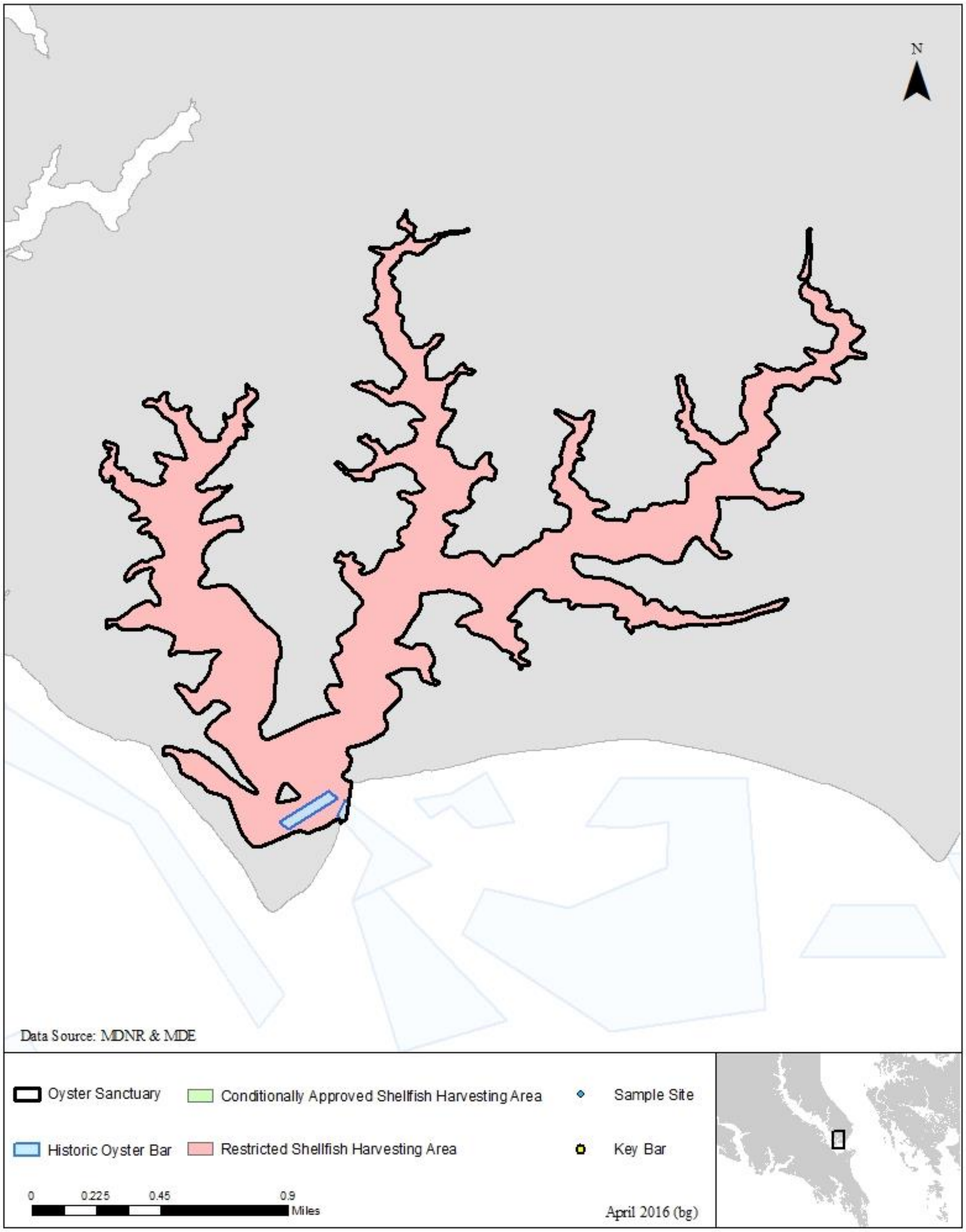

Figure A.40 -1. Solomons Creeks Sanctuary. Note: the grey triangle is an island.

Section A.41: Somerset Sanctuary

The Somerset Sanctuary is located in Tangier Sound, a high salinity (greater than 14 ppt) region (Figure A.41-1). The sanctuary was created in 1999 and encompasses 101 acres of which 6 acres (6%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There is one historic oyster bar (Piney Island East Addition) within the sanctuary. This was one of four oyster sanctuaries created in 1999 as mitigation for the opening of new power dredge harvest areas.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.41-2). The entire area was classified as oyster reef habitat. There has not been any additional bottom mapping using side scan sonar to date.

Restoration and Replenishment Activities

No replenishment activities took place while the area was open to harvest. Since 1999, restoration plantings consisting of wild seed and reef balls have occurred (Table A.41-1). Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, twelve cages were tended and approximately 3,000 oysters were planted.

Table A.41-1. Restoration planting activities occurring since 1990 in Somerset Sanctuary. S = Planting activity after the area was established as a sanctuary in 1999. ND = No Data.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1999 (S)	Wild Seed	106.34	ND	-
2000 (S)	Wild Seed	4.95	133.69	-
2002 (S)	Wild Seed	10.58	ND	-
2002 (S)	Wild Seed	14.72	120.22	-
2003 (S)	Wild Seed	1.17	25 Reef Balls	

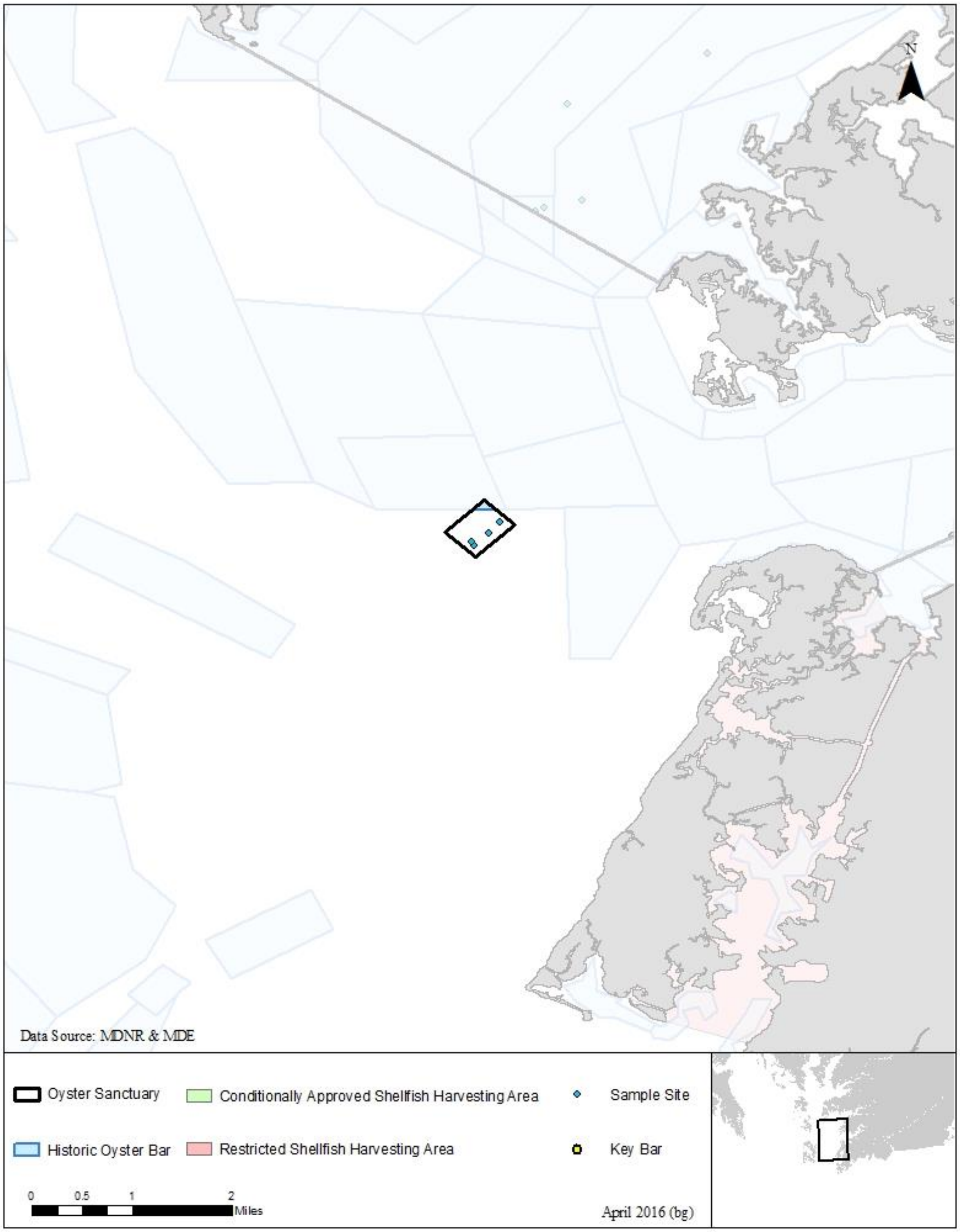

Figure A.41 -1. Somerset Sanctuary.

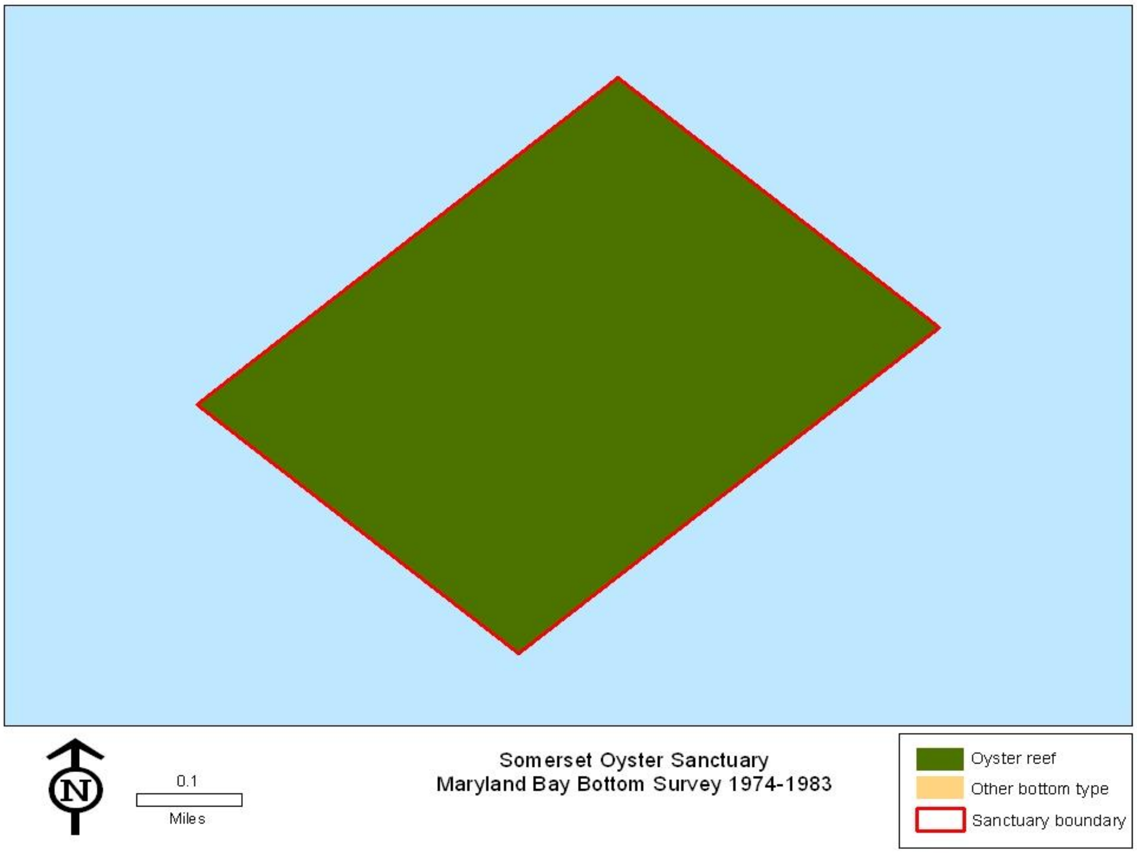

Figure A.41 -2. Somerset Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled the oyster bar in this area in four different locations since 2004. No samples were collected prior to the area becoming a sanctuary. The number of live oysters per bushel (market, small, and spat) ranged from 100 to 379 with an average of 192 (Table A.41-2; Figure A.41-3). The average number of small-sized oysters per bushel ranged from 20 to 144. The average number of market-sized oysters per bushel ranged from 25 to 64.

Table A.41-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Somerset Sanctuary in 1999. ND = No Data. Values are given as mean ± standard error.

	1990-1998	**1999-2015**
Number of Years Sampled / Number of Samples	0 / 0	12 / 36
Number of Live Oysters per Bushel	ND	192 ± 22
Number of Live Small-Sized Oysters per Bushel	ND	79 ± 12
Number of Live Market-Sized Oysters per Bushel	ND	41 ± 5
Live Oyster Biomass (g Dry Weight per Bushel)	ND	141 ± 12.2
Mortality (%)	ND	20.7 ± 3.1

A patent tong population survey was conducted in 2015 (Figures A.41-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 6.39 ± 1.14 oysters m^{-2} (mean ± standard error, n = 75). The density of small-sized oysters was less than the density of market-sized oysters (2.56 ± 0.53 and 3.61 ± 0.68 oysters m^{-2}, respectively). Twenty-nine percent of the samples collected contained no live oysters or boxes. Oyster density increased with volume of shell (Figure A.41.5).

Oyster Size Structure

The Fall Survey has measured oyster shell heights in this area at Piney Island East Addition bar since 2011 (Figure A.41-6). Shell heights were also measured during the patent tong population survey (Figure A.23-7). Spat, small, and market-sized oysters were present each year.

Biomass

Biomass has been calculated from Fall Survey samples from Piney Island East Addition bar since 2011 (Figure A.41-8). Biomass ranged from 108 to 182 grams of dry weight per bushel, with the highest biomass occurring in 2014.

Recruitment (Spatfall)

Based on Fall Survey data from 2004 to 2015, spat fall ranged from 10 to 228 spat per bushel, with the highest spat set occurring in 2006 and 2010 (Figure A.41-3). Spatfall has been observed every year since 2004. The average count is 72 ± 12 per bushel. Spat density from the 2015 patent tong survey was 0.21 ± 0.08 m^{-2}.

Mortality

Based on Fall Survey box counts, the average mortality is 20.7 ± 3.1% (Table A.41-2; Figure A.41-9). Mortality peaked at 57% in 2005 and has been less than 20% since 2007.

Disease

Oysters collected by the Fall Survey from this area have not been analyzed for disease since 1990.

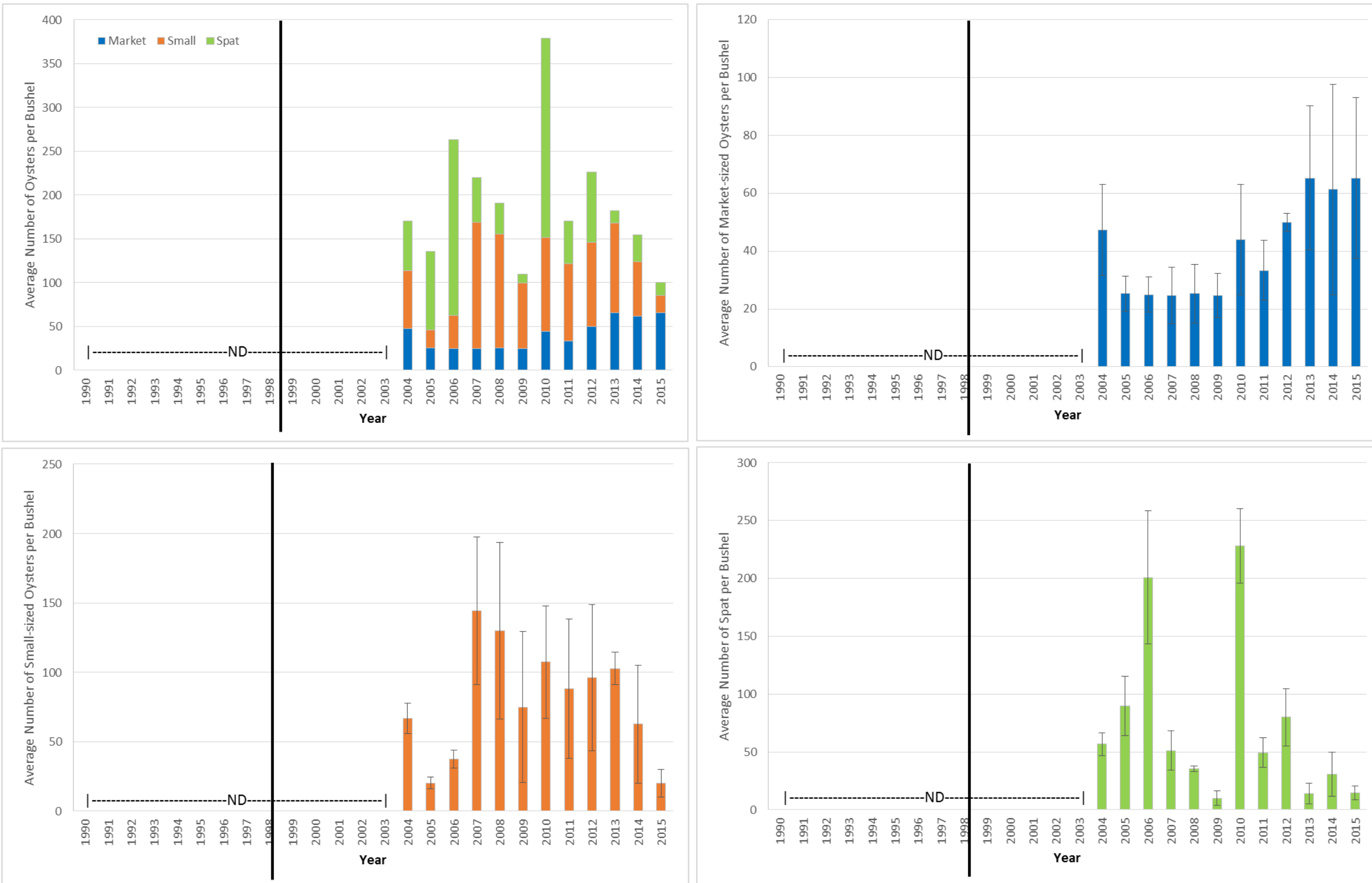

Figure A.41-3. Average number of live oysters per bushel of material by size class in the Somerset Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales. ND = No Data.

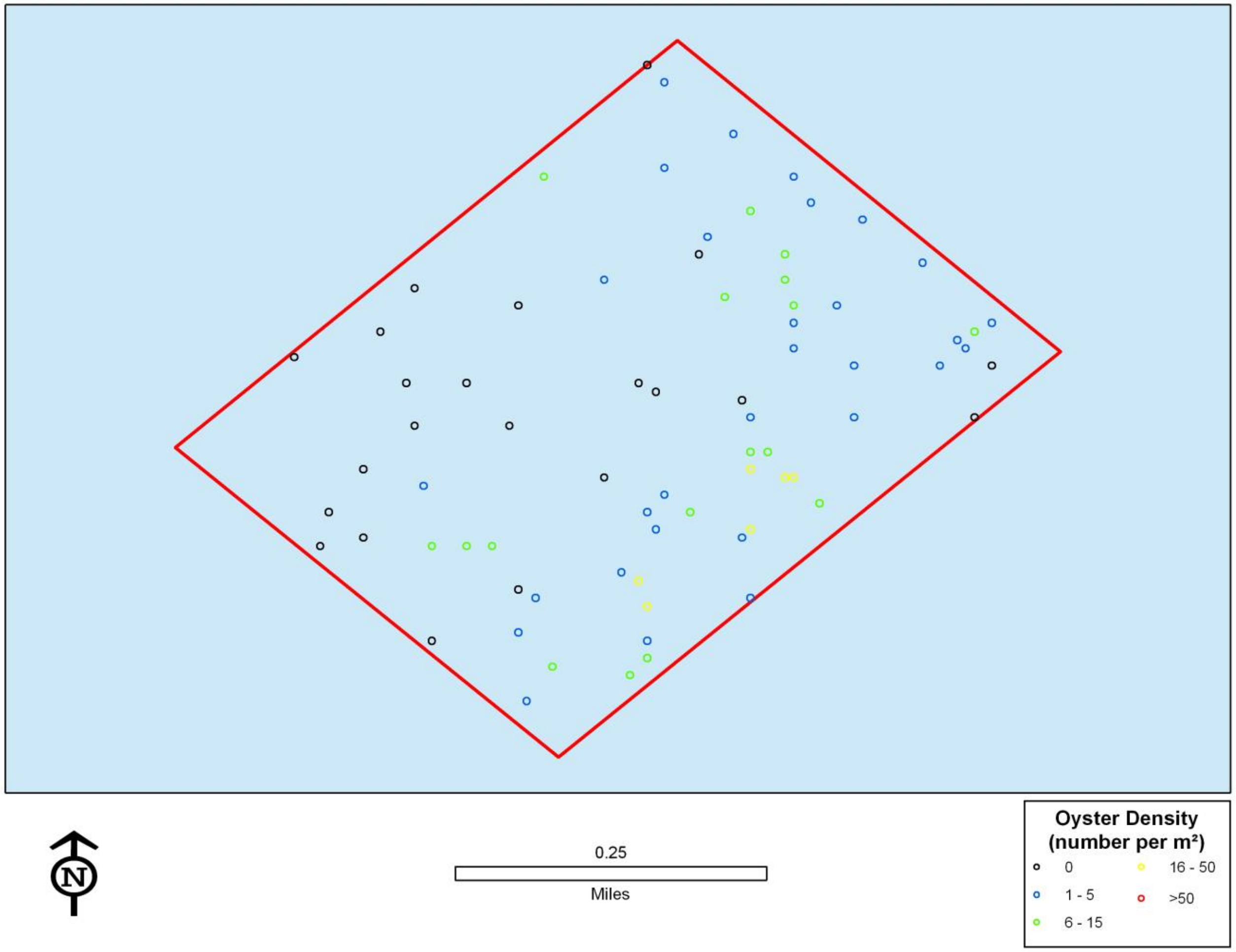

Figure A.41-4. Map of 2015 oyster density in the Somerset Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

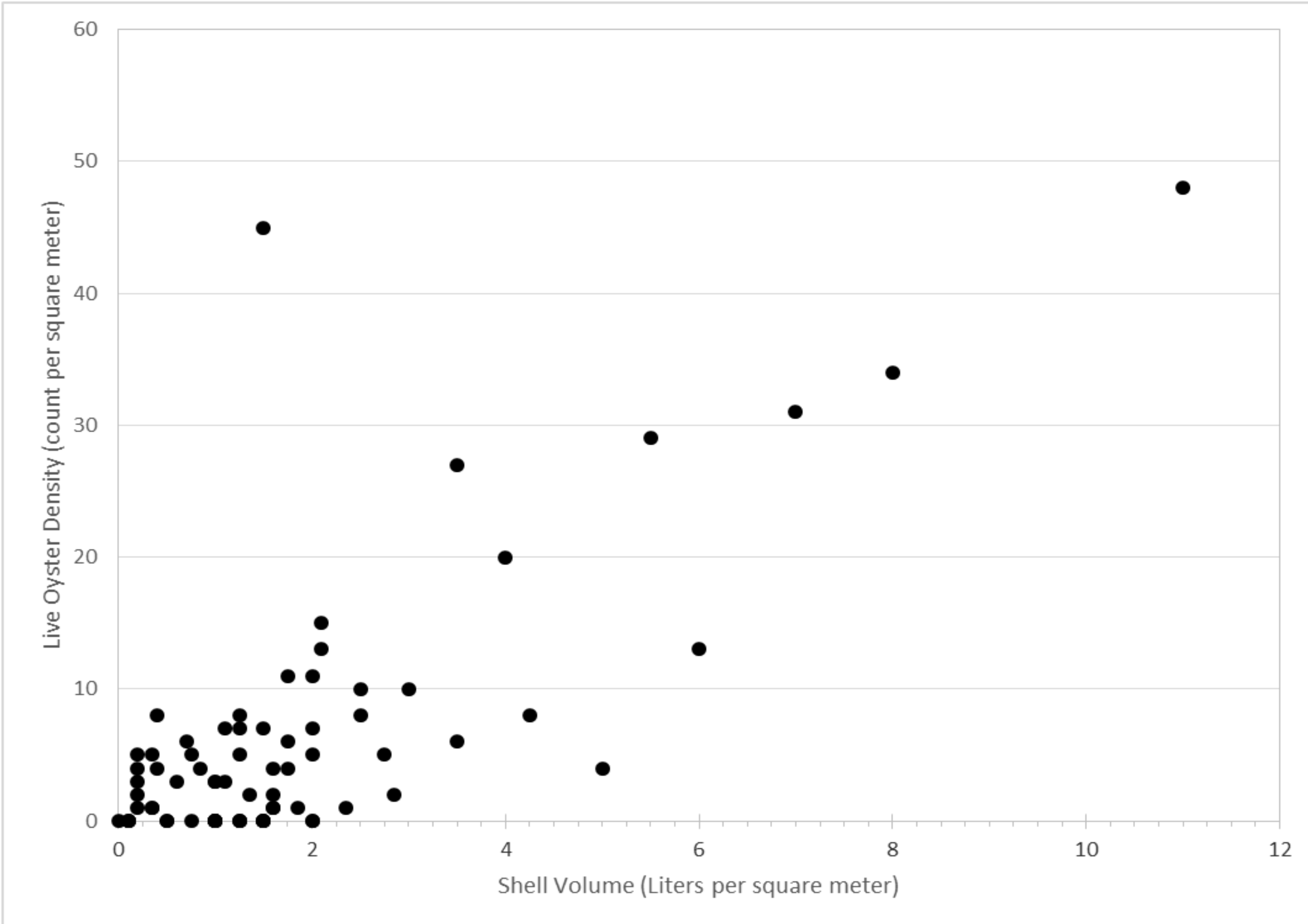

Figure A.41-5. 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Somerset Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

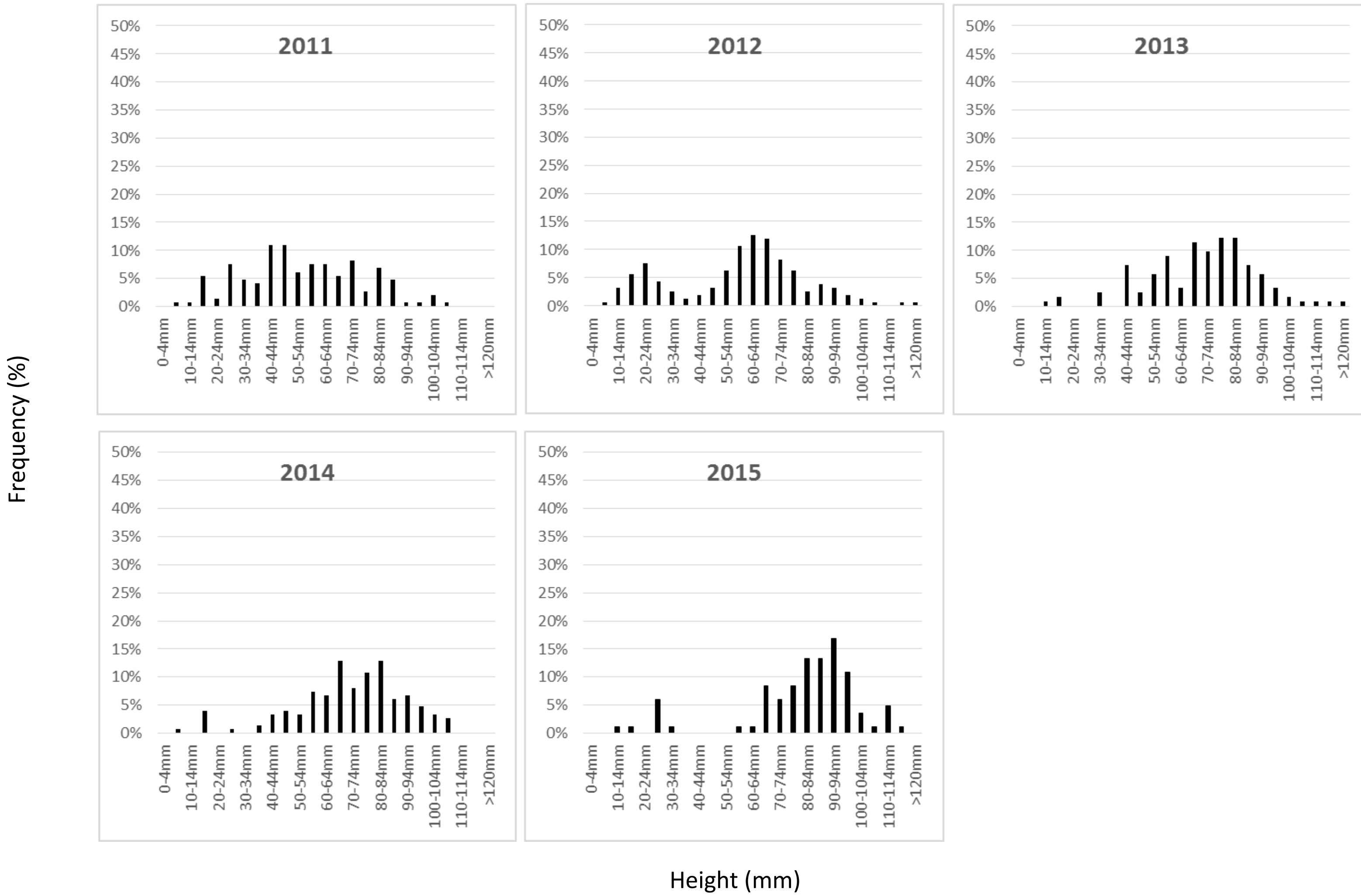

Figure A.41-6. Shell height frequencies of live oysters per bushel of material from 2011 to 2015 in the Somerset Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Piney Island East Addition bar. Shell heights were not measured prior to 2011.

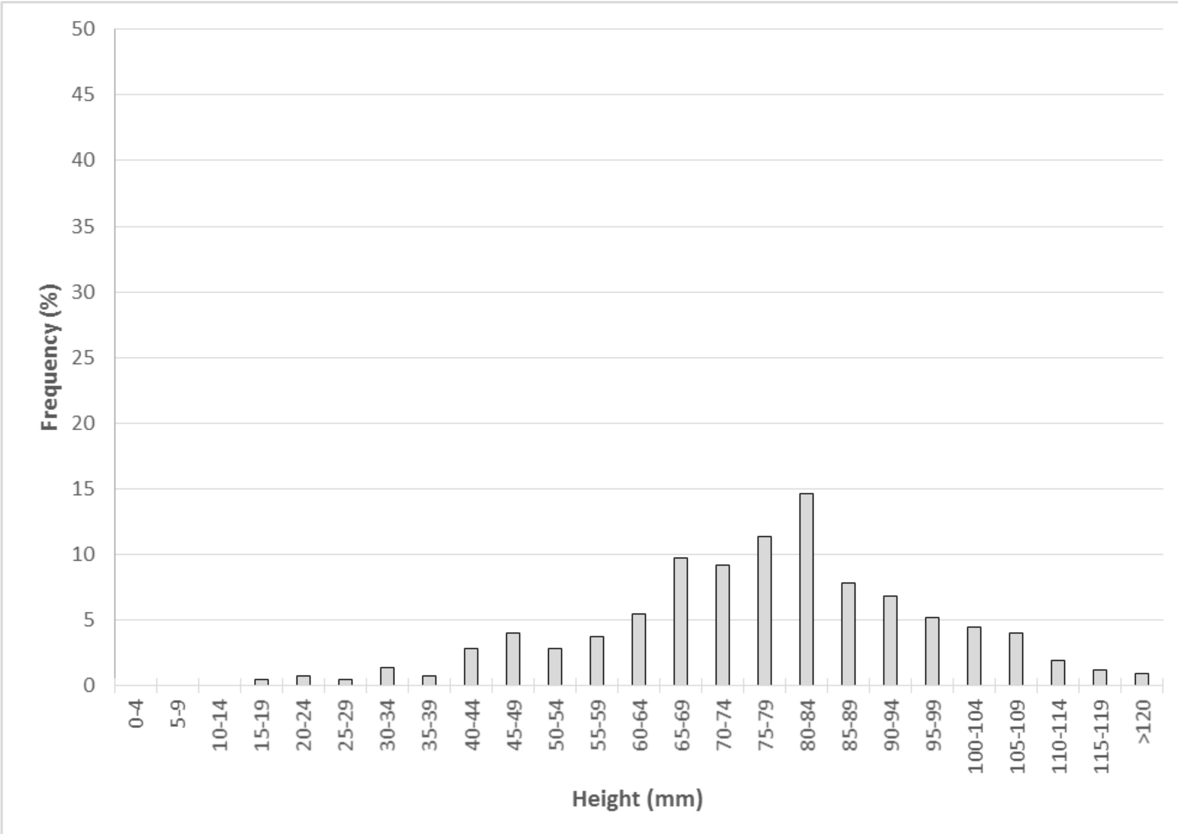

Figure A.41-7. Shell height frequencies of live oysters in the Somerset Sanctuary in 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

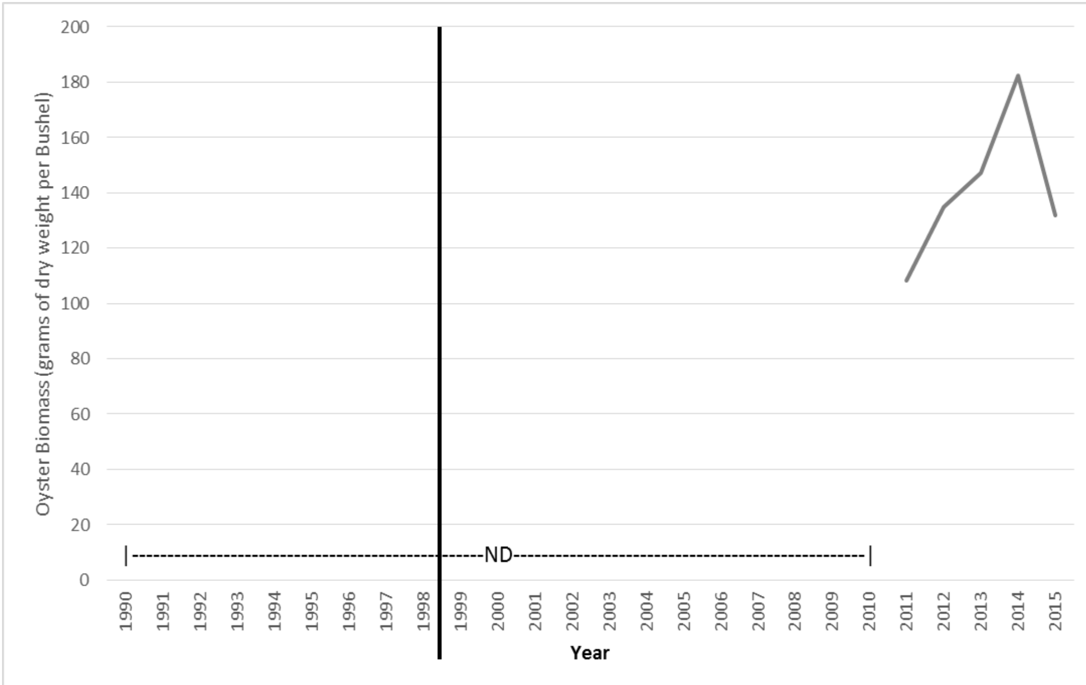

Figure A.41-8 Oyster biomass (grams of dry weight per bushel of material) from 2011 to 2015 in the Somerset Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Piney Island East Addition bar. Black line indicates the date the sanctuary was established. ND = No Data.

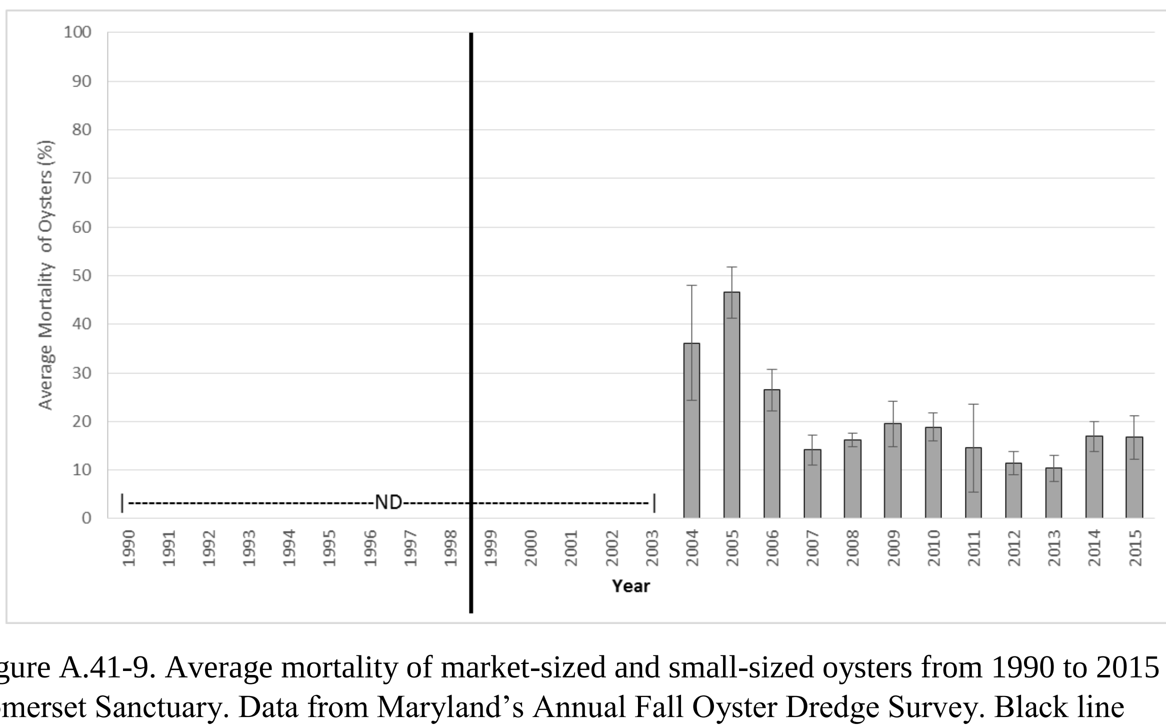

Figure A.41-9. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Somerset Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error. ND = No Data.

Harvest

The sanctuary encompasses less than 1% of the 90,266 acres in NOAA Code 192). Because harvest from NOAA Code 192 is likely to have come from areas outside the sanctuary, harvest reported by seafood dealers for this area cannot be used to assess harvest in this area.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.42: South River Sanctuary

The South River Sanctuary is located in the upstream part of the South River, a tributary of the upper western shore of Chesapeake Bay (Figure A.42-1). The sanctuary is in a low salinity (less than 12 ppt) region. The South River Sanctuary was created in 2000 and encompasses 2,327 acres of which 141 (6%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 7 historic oyster bars within the sanctuary[90]. Areas of the sanctuary are designated by Maryland Department of the Environment (MDE) as either restricted or conditionally restricted shellfish harvest areas based on the potential for contamination of shellfish with fecal coliform and other bacteria. As a result of the restricted harvest designation, that portion of the South River was officially designated by the Department as a sanctuary.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.42-2). Of the 727 acres surveyed within the sanctuary, 28 acres (4%) were classified as oyster habitat. In 2006, NOAA Chesapeake Bay Office conducted a side scan sonar survey of a small portion of the sanctuary. Of the 84 acres surveyed, 23 acres (27%) were classified as oyster reef. Differences between the coverage areas of the Bay Bottom Survey and NOAA Chesapeake Bay's side scan sonar work in the sanctuary precludes comparison of the two surveys.

Restoration and Replenishment Activities

This area has received both replenishment and restoration efforts since1990 (Table A.42-1). Wild seed and fresh shell were planted to enhance the public fishery and hatchery spat-on-shell was planted after the sanctuary was established. The Army Corps of Engineers was a partner in the 2001 and 2004 restoration plantings.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 400 cages and planted approximately 120,000 oysters.

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[90] See chart 9 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

Table A.42-1. Replenishment and restoration planting activities occurring since 1990 in the area that is now the South River Sanctuary. S = planting activities occurring after the area was established as a sanctuary.				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1997	Wild Seed	1.28	2.57	-
1997	Fresh Shell	1.73	6.36	-
2001 (S)	Dredged Shell	0.46	10	
2001 (S)	Hatchery Spat-on-Shell	0.46	-	1.7
2004 (S)	Hatchery Spat-on-Shell	-	-	0.2
2006 (S)	Hatchery Spat-on-Shell	3.31	-	1.49
2007 (S)	Hatchery Spat-on-Shell	1.39	-	2.80

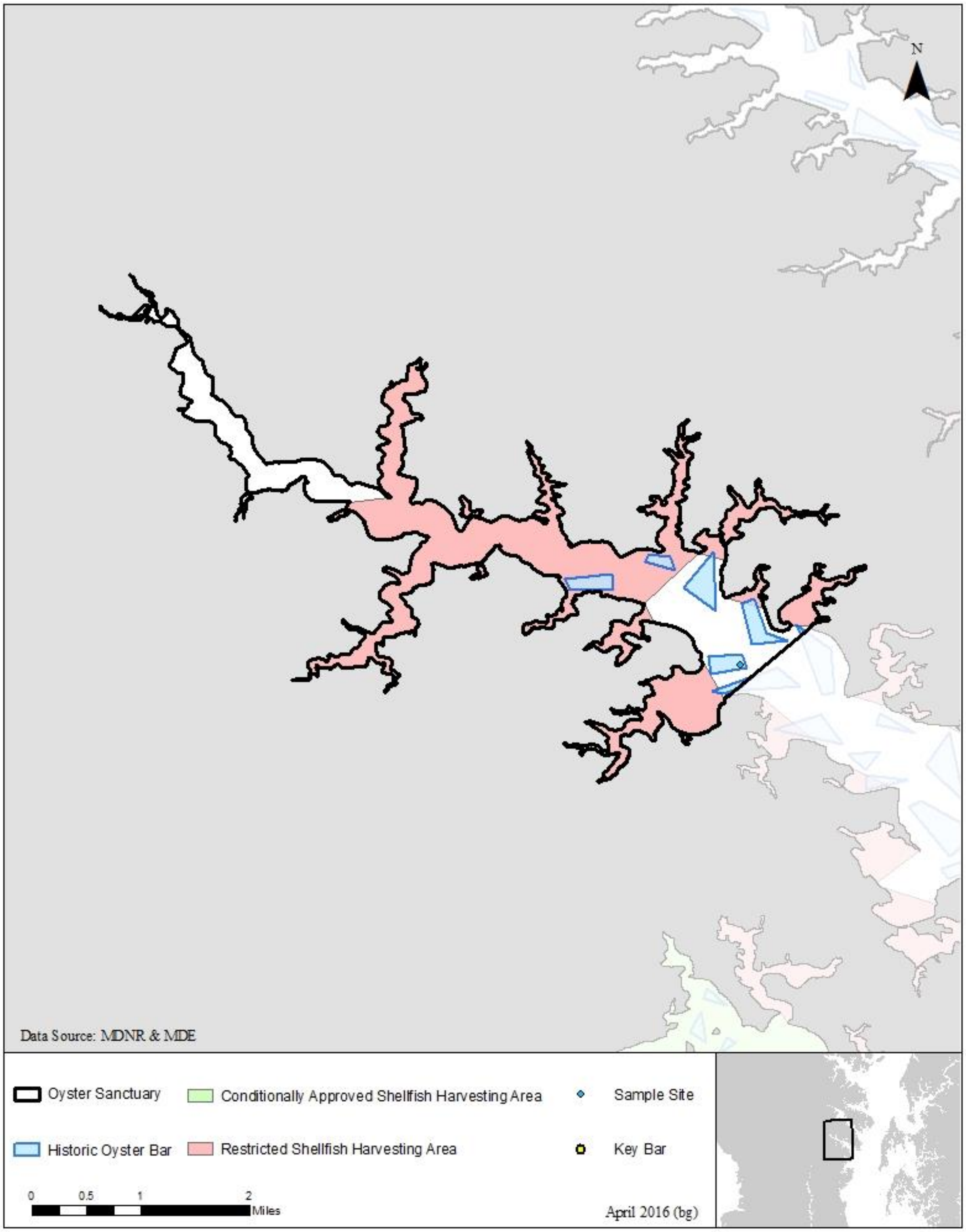
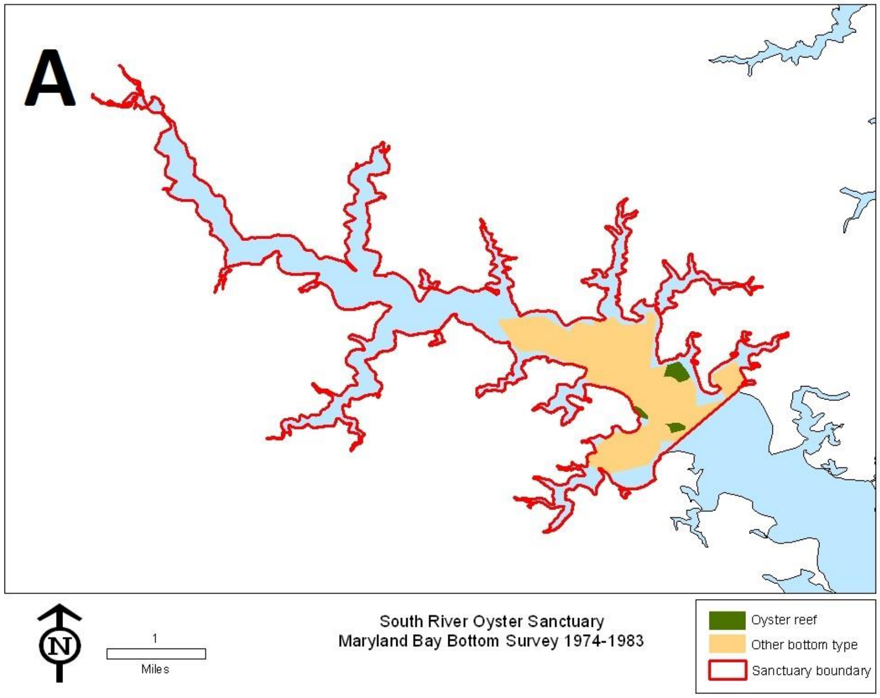


Figure A.42 -1. South River Sanctuary.



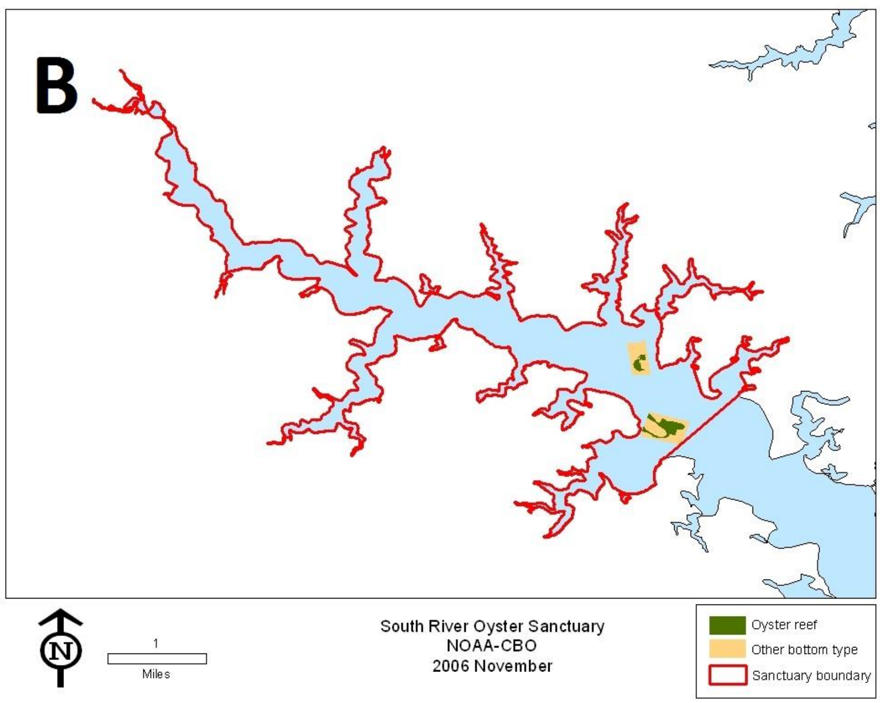


Figure A.42 -2. South River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from NOAA Chesapeake Bay from 2006. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled one oyster bar in this area since 1990, but it was only sampled in 1997, 1999, 2000, and 2001 (Figures A.42-3). The number of live oysters ranged from 0 to 44, with the number of market-sized oysters always greater than the number of small oysters.

A patent tong population survey was conducted in 2014 (Figures A.42-4). No such population survey was conducted prior to the establishment of the sanctuary. Oysters were only found in one small area. The average density of live oysters was 0.57 ± 0.44 oysters m^{-2} (mean ± standard error, n = 49). The density of small-sized oysters was less than the density of market-sized oysters (0.14 ± 0.10 and 0.43 ± 0.37 oysters m^{-2}, respectively). Ninety-four percent of the samples collected contained no live oysters or boxes. Oyster density tended to increase with volume of shell (Figure A.42.5).

Oyster Size Structure

The Fall Survey has not collect information on oyster shell height in this area since 1990.

Shell heights were measured during the patent tong population survey (Figure A.42-6). No spat were observed, but small and market-sized oysters were present.

Biomass

The Fall Survey has not collect information on oyster biomass in this area since 1990.

Recruitment (Spatfall)

No spat were seen in the Fall Survey samples from 1997, 1999, 2000, and 2001 (Figures A.42-3), nor were any spat collected during the 2014 patent tong population survey.

Mortality

Based on Fall Survey box counts, mortality ranged from 0- 60%, with the highest mortality occurring in 2001 (Figure A.42-3).

Disease

The Fall Survey has not collect information on oyster diseases in this area since 1990.

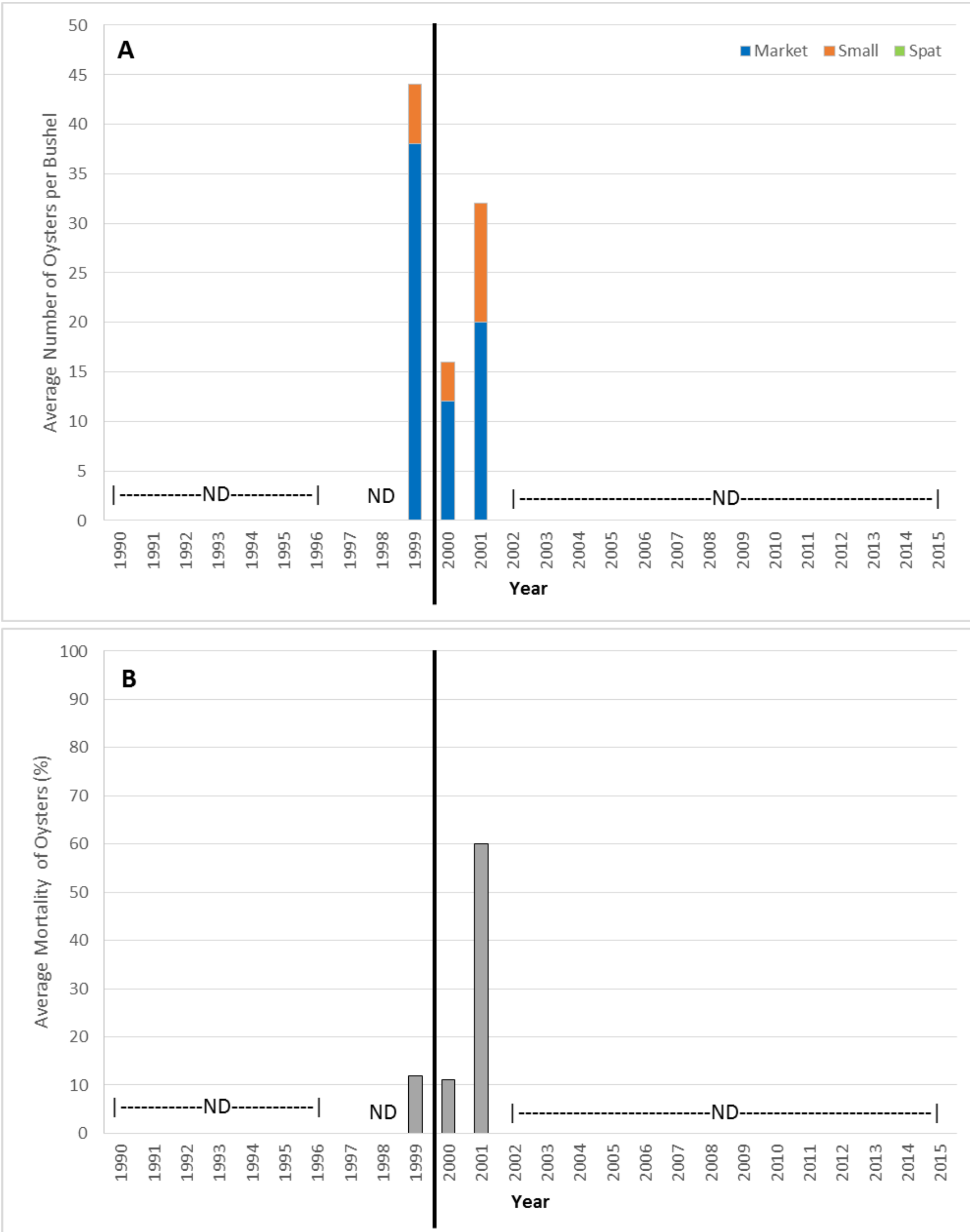


Figure A.42-3. (A) Average number of live oysters per bushel of material by size class in the South River Sanctuary. (B) Average mortality of market-sized and small-sized oysters from 1990 to 2015 in South River Sanctuary. The black line denotes the year the sanctuary was established. Data from Maryland's Annual Fall Oyster Dredge Survey. ND = No Data.

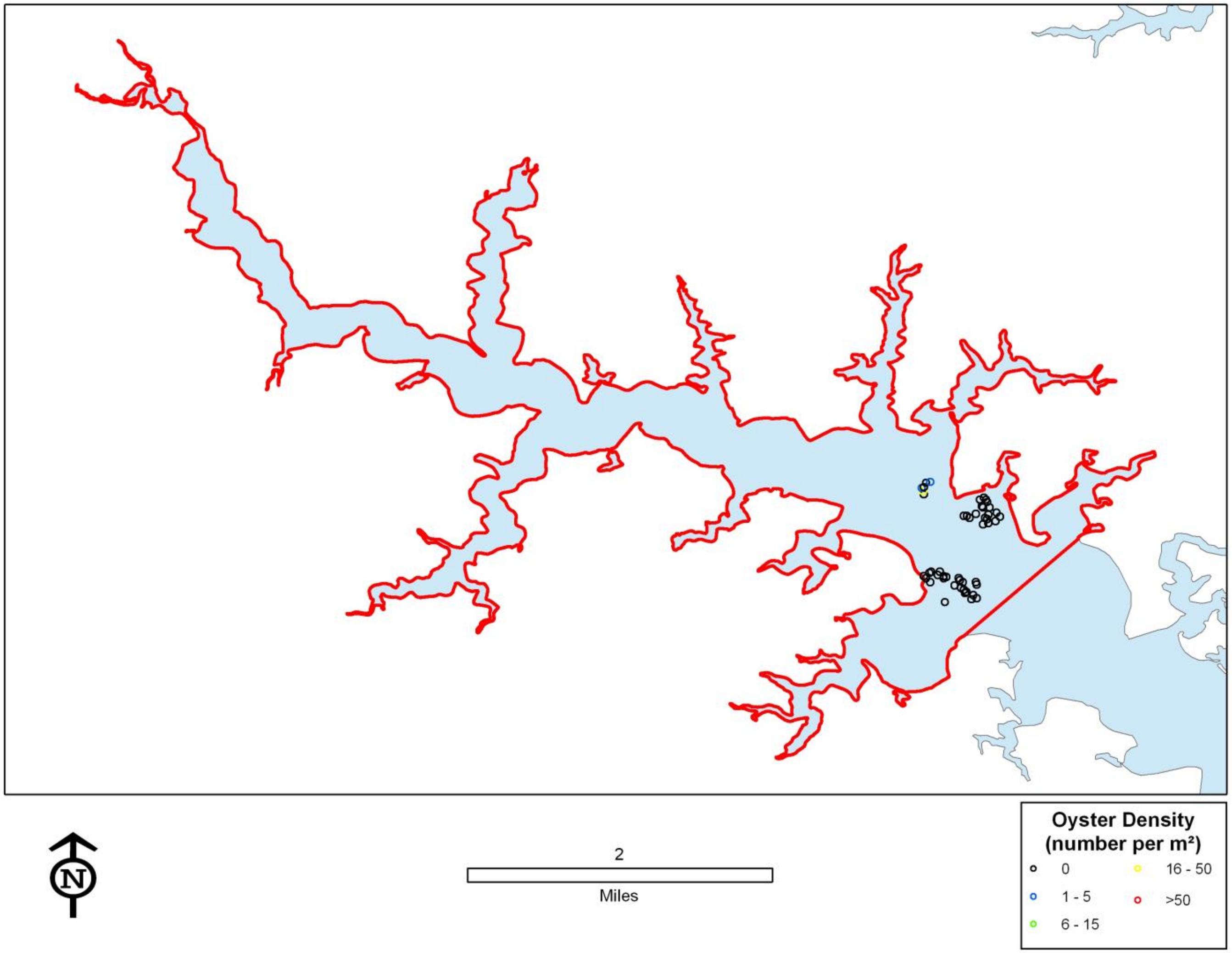


Figure A.42-4. Map of 2014 oyster density in the South River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

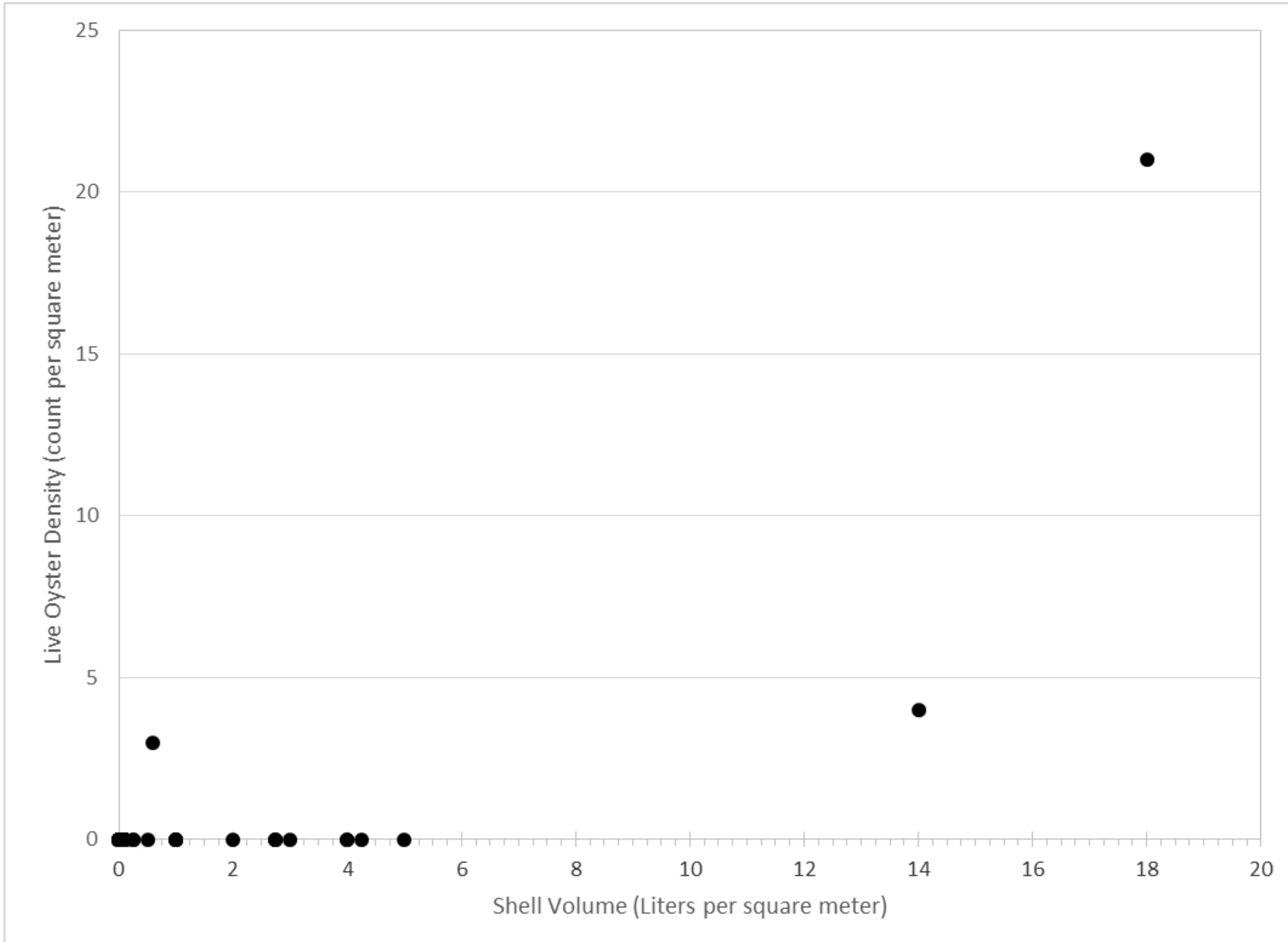


Figure A.42-5. 2014 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the South River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

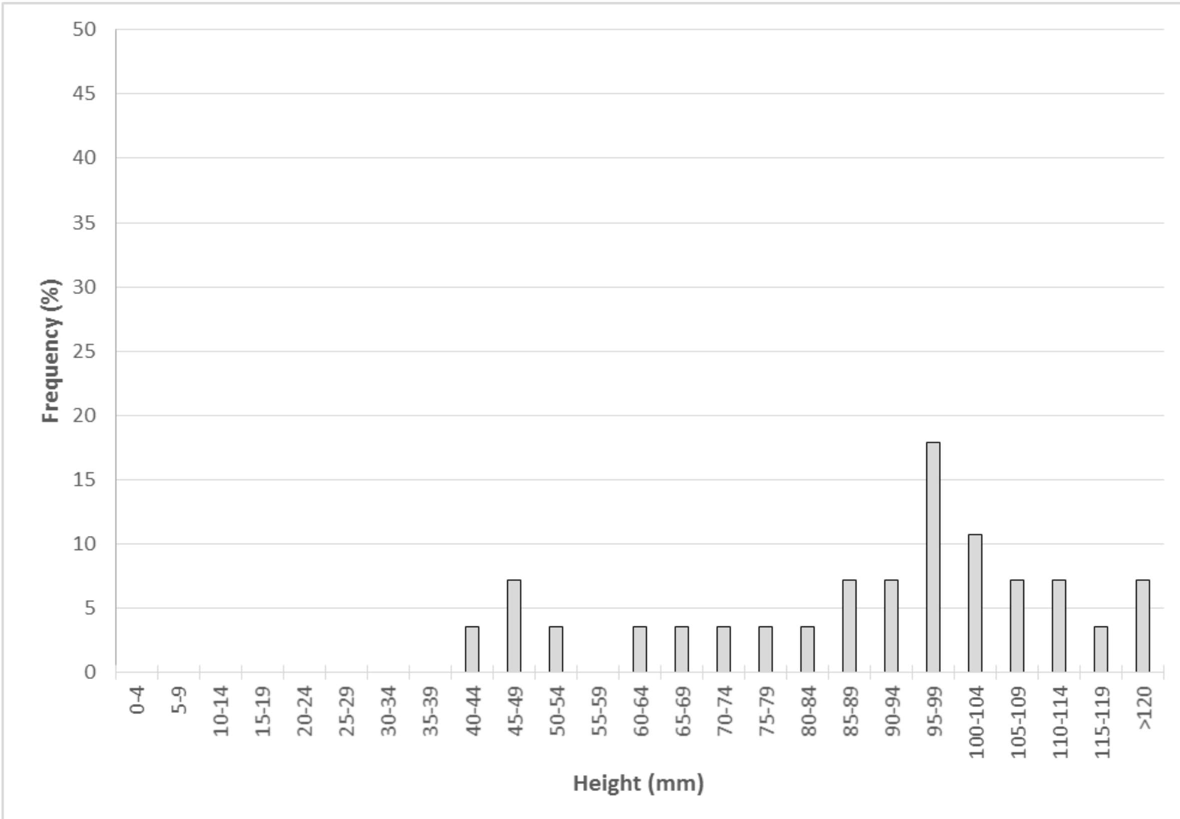


Figure A.42-6. Shell height frequencies of live oysters in the South River Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

Harvest

The sanctuary encompasses 38% of the 6,099 acres in NOAA Code 088. Because harvest from NOAA Code 088 may have come from places outside the area that became the sanctuary, seafood dealer reports for this NOAA Code cannot be used to assess harvest in this area.

Environmental Conditions and Ecosystem Services

Maryland's Eyes on the Bay Program monitors monthly water quality at station WT8.1 (38.9496, -76.5461) in this area (Figure A.42-7). Water quality was favorable for oysters except for brief periods of low salinity.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

Figure A.42-7. Water quality data collected at Station WT8.1 in South River. Black line denotes the date the sanctuary was established.

Section A.43: St Mary's River Sanctuary

The St Mary's River Sanctuary is located in the upstream portion of the St. Mary's River, a medium salinity (between 12 to 14 ppt) region (Figure A.43-1). The mouth of the river empties into the Potomac River. The sanctuary was created in 2010 and encompasses 1,304 acres of which 89 (9%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 10 historic oyster bars within the sanctuary[91]. The area is classified as a conditionally restricted shellfish harvest area by Maryland Department of the Environment due to the potential for contamination of shellfish by fecal coliform and other bacteria.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.43-2). Of the 88 acres surveyed within the sanctuary, 87 acres (98%) were classified as oyster reef habitat. In 2010, Maryland Geological Survey conducted a more thorough side scan sonar survey of the area. Of the 1,039 acres surveyed, 260 acres (25%) were classified as oyster reef habitat. Differences between the coverage areas of the Bay Bottom Survey and Maryland Geological Survey's side scan sonar work in the sanctuary precludes comparison of the two surveys.

Restoration and Replenishment Activities

Prior to the establishment of the sanctuary, dredged shell was planted in the area to enhance the public fishery (Table A.43-1). After the sanctuary was established, the St. Mary's Watershed Association applied for and was granted a permit to construct an oyster reef in the sanctuary. The association has planted reefballs, concrete rubble, shell piles, and spat-on-shell.

Marylanders Grow Oysters, a public outreach program, plants oysters at four sites in the sanctuary. In 2016, growers tended 580 cages and planted approximately 150,000 oysters. Saint Mary's College also plants spat in the sanctuary annually as part of their orientation program for incoming students.

[91] See chart 38 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

Table A.43-1. Replenishment planting activities occurring since 1990 in the area that is now established as St Mary's River Sanctuary. S = a planting occurring after that area was established as a sanctuary.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1999	Dredged Shell	7.33	87.07	-
2000	Dredged Shell	3.84	46.90	-
2010 (S)	Hatchery Spat-On-Shell	0.6	-	0.8
2011 (S)	Hatchery Spat-On-Shell	0.9	-	1.1
2012-2016 (S)	Reef Balls	0.12	603 reef balls	
2012-2016 (S)	Shell Piles	0.01	0.27	
2012-2016 (S)	Concrete Rubble	0.1	186.5 tons	
2013 (S)	Hatchery Spat-On-Shell	-	-	10
2014 (S)	Hatchery Spat-On-Shell	-	-	8
2015 (S)	Hatchery Spat-On-Shell	-	-	8

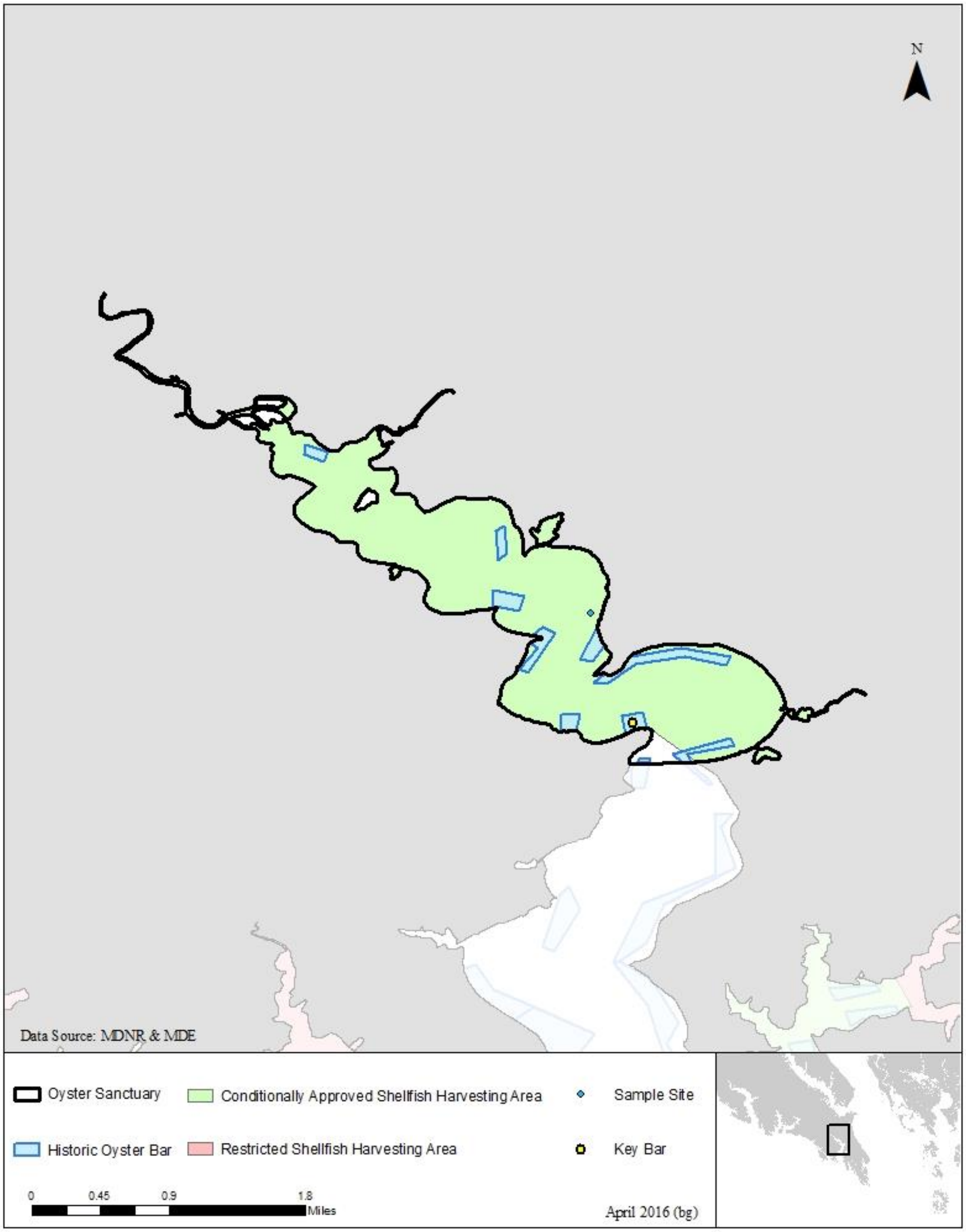


Figure A.43 -1. St Mary's River Sanctuary.

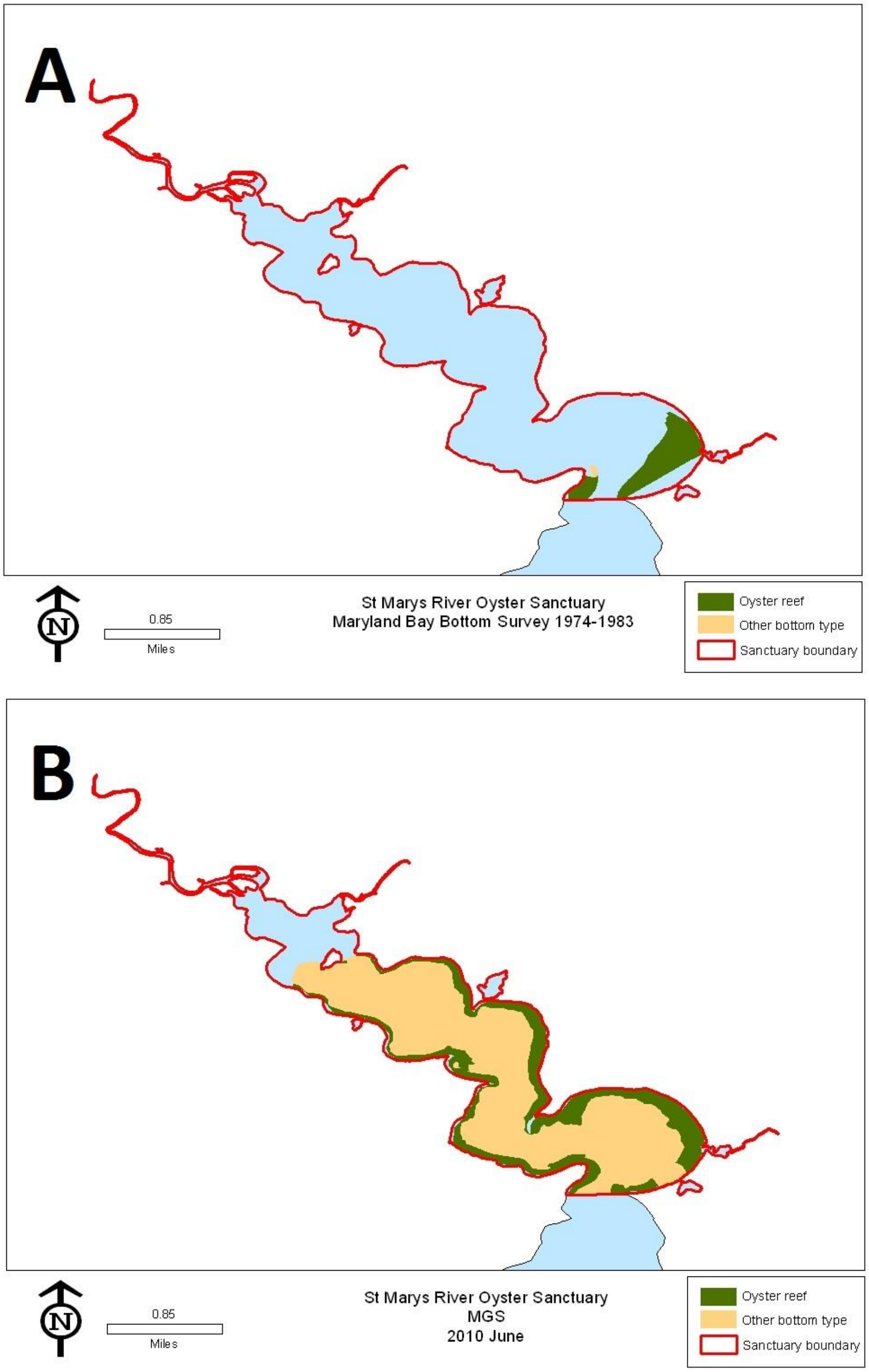


Figure A.51 -2. St. Mary's River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from Maryland Geological Survey in 2010. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled one to three oyster bars in this area since 1990 with an average of two oyster bars sampled annually. The average number of live oysters per bushel (market, small, and spat) was similar before and after sanctuary creation (Table A.43-2; Figure A.43-3). The average number of market-sized oysters increased after sanctuary establishment and the highest counts since 1990 were in 2013, 2014, and 2015.

Table A.43-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the St. Mary's River Sanctuary in 2010. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 41	6 / 12
Number of Live Oysters per Bushel	482 ± 63	477 ± 53
Number of Live Small-Sized Oysters per Bushel	256 ± 36	285 ± 44
Number of Live Market-Sized Oysters per Bushel	21 ± 4	64 ± 15
Live Oyster Biomass (g Dry Weight per Bushel)	156 ± 19.7	256 ± 18
Mortality (%)	24.1 ± 4.9	11.5 ± 2.6

Patent tong population surveys were conducted in 2012 and 2015 (Figures A.43-4 and A.43-5). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters increased from 19.74 ± 2.66 (mean ± standard error, n = 265) oysters m^{-2} in 2012 to 39.79 ± 3.87 (n = 261) oysters m^{-2} in 2015. The density of small-sized oysters increased from 16.06 ± 2.20 m^{-2} in 2012 to 23.01 ± 2.56 m^{-2} in 2015. The density of market-sized oysters increased from 3.65 ± 0.53 m^{-2} in 2012 to 14.45 ± 1.32 m^{-2} in 2015.The percentage of samples having no oysters decreased slightly from 2012 (51%) to 2015 (44%). Live oyster density increased with volume of shell and leveled off at approximately 225 oysters m^{-2} at a shell volume of approximately 40 liters per m^{-2} (Figure A.43.6).

Oyster Size Structure

Oysters collected by the Fall Survey in this area have been measured on Pagan bar since 1990 (Figure A.43-7). Oysters were also measured during the two patent tong population surveys (Figure A.43-8). Larger oysters have been are present since the establishment of the sanctuary due to strong spat sets in 2010 and 2012 as well as the cessation of harvest.

Biomass

Biomass of oysters from Pagan bar collected by the Fall Survey fluctuated prior to sanctuary creation. Since 2009, biomass has shown an increasing trend due the increase in both number and size of oysters (Figure A.43-9).

Recruitment (Spatfall)

Based on the Fall Survey data, this area has high annual spatfall relative to other areas of Maryland's portion of the bay. Average spatfall since 1990 ranged from 0 to 997 spat per bushel, with the highest occurring in 1997 (Figure A.43-4). All of the 26 years had spatfall except for 2008.

Based on the patent tong population survey, spat density increased from $0.02 \pm 0.01\ m^{-2}$ in 2012 to $2.23 \pm 0.50\ m^{-2}$ in 2015.

Mortality

Based on Fall Survey box counts, the average mortality after sanctuary creation was lower than before sanctuary creation. (Table A.43-2; Figure A.43-10). Mortality ranged from 2% to 92%, with the highest value occurring in 2002, a year of high disease prevalence throughout the bay.

Disease

From 1990 to 2015, dermo prevalence ranged from 10% to 100% (Figure A.43-11) and was greater than 80% in 19 of the 26 years disease was examined. Dermo intensity ranged from 0.3 to 4.6 from 1990 to 2015, with near-lethal levels seen in 2001. MSX prevalence ranged from 0% to 40% from 1990 to 2015. MSX was detected primarily over a period from 1999 to 2002.

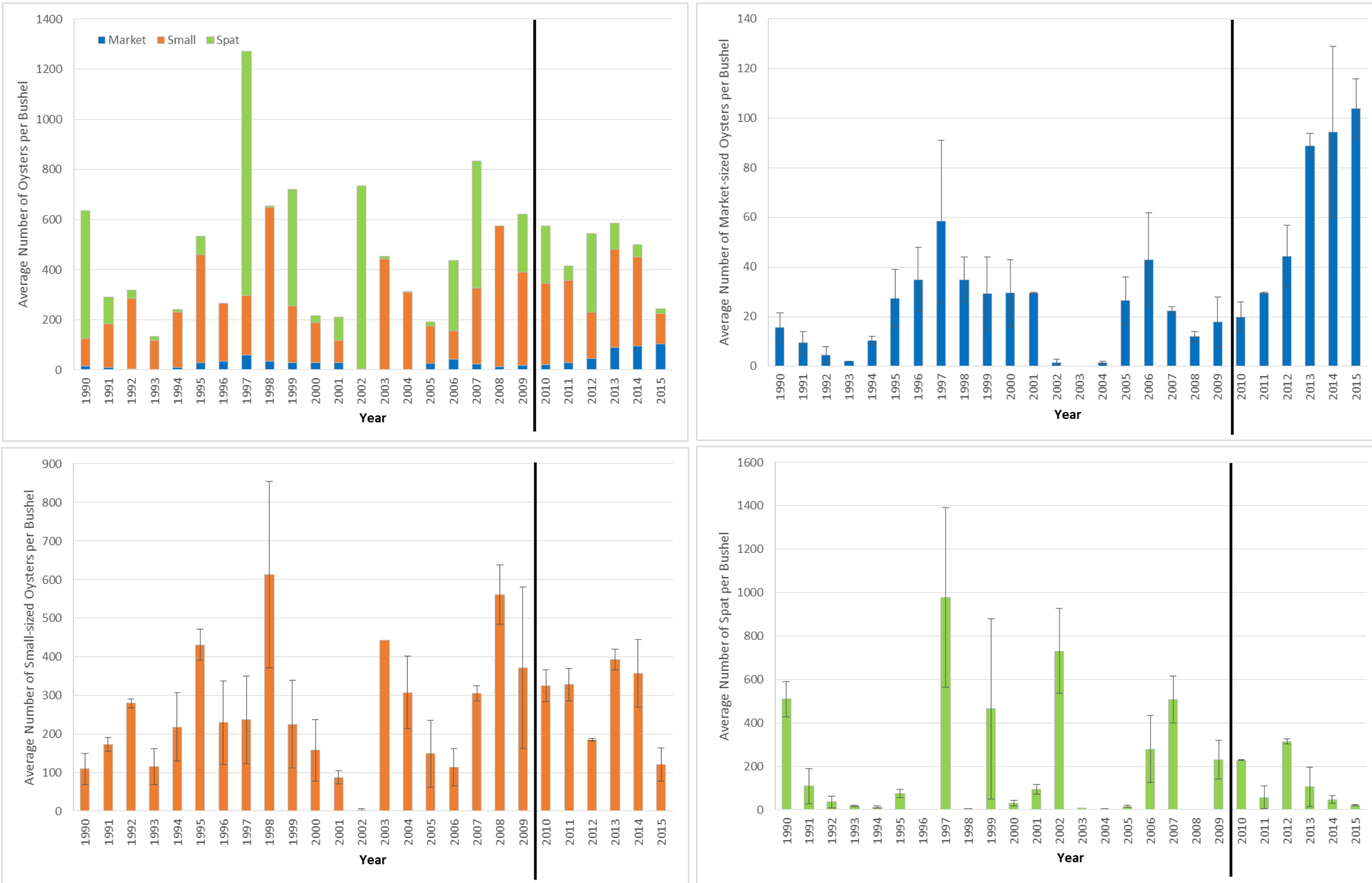


Figure A.43-4. Average number of live oysters per bushel of material by size class in the St Mary's River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

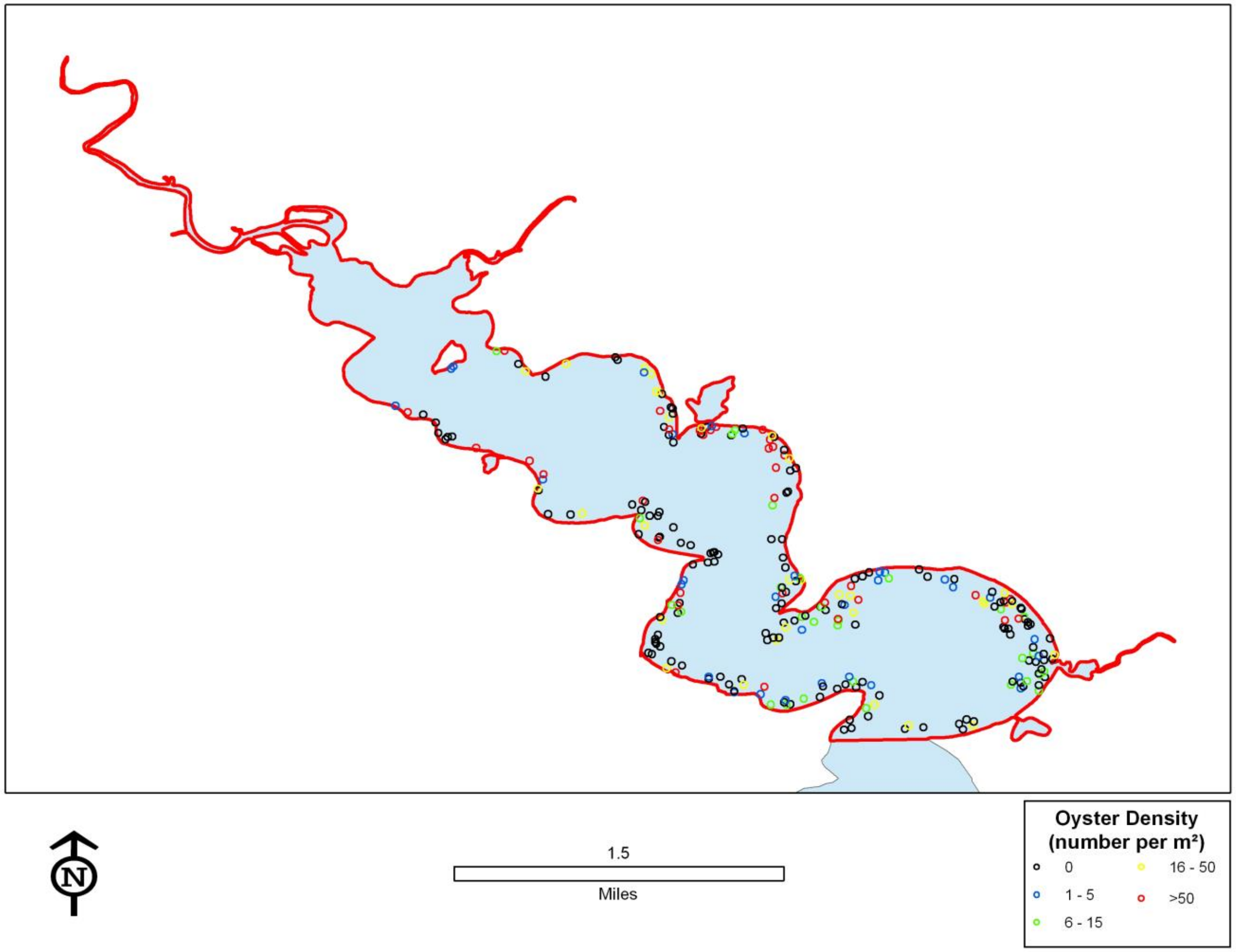


Figure A.43-5. Map of 2012 oyster density in the St Mary's River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

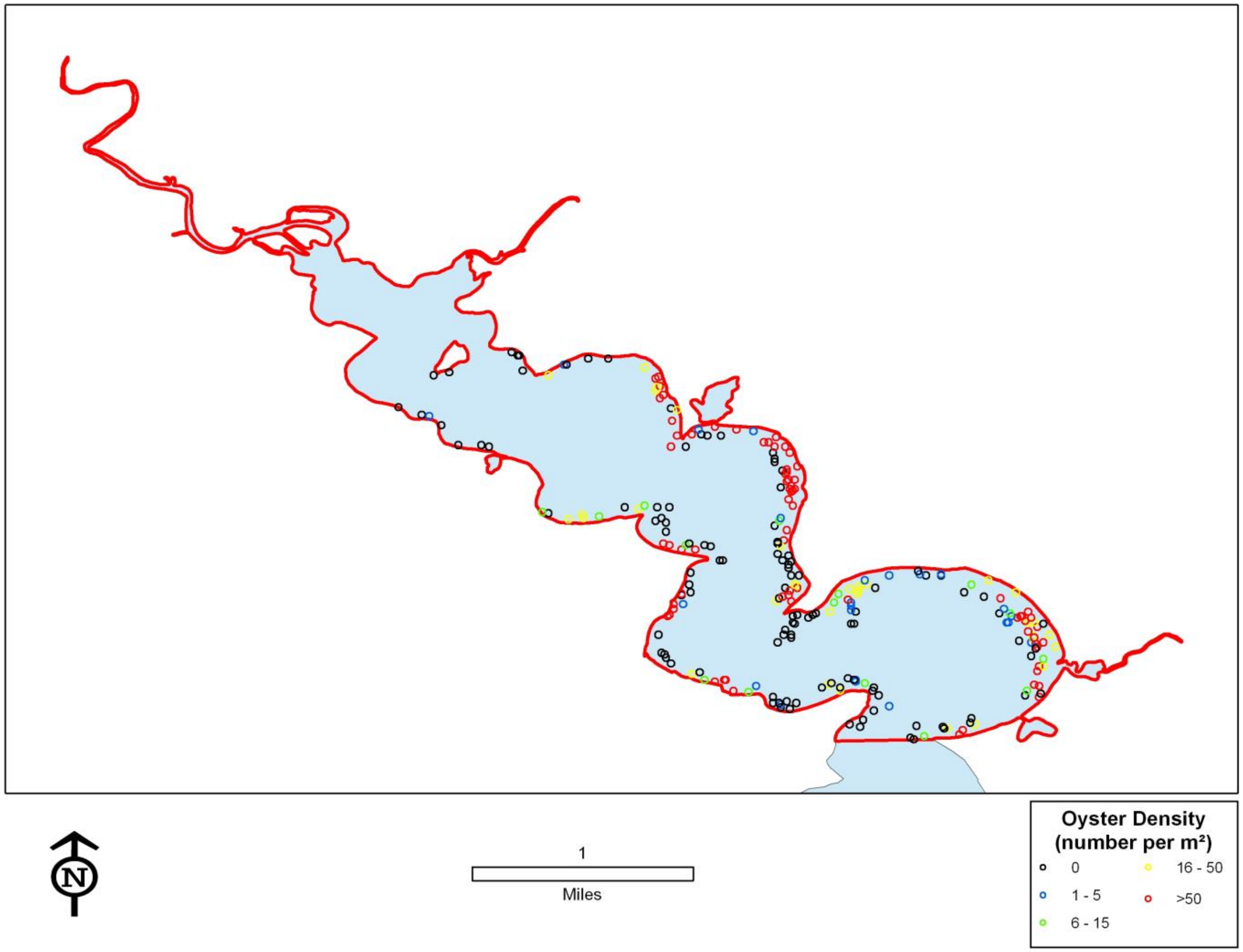


Figure A.43-6. Map of 2015 oyster density in the St Mary's River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

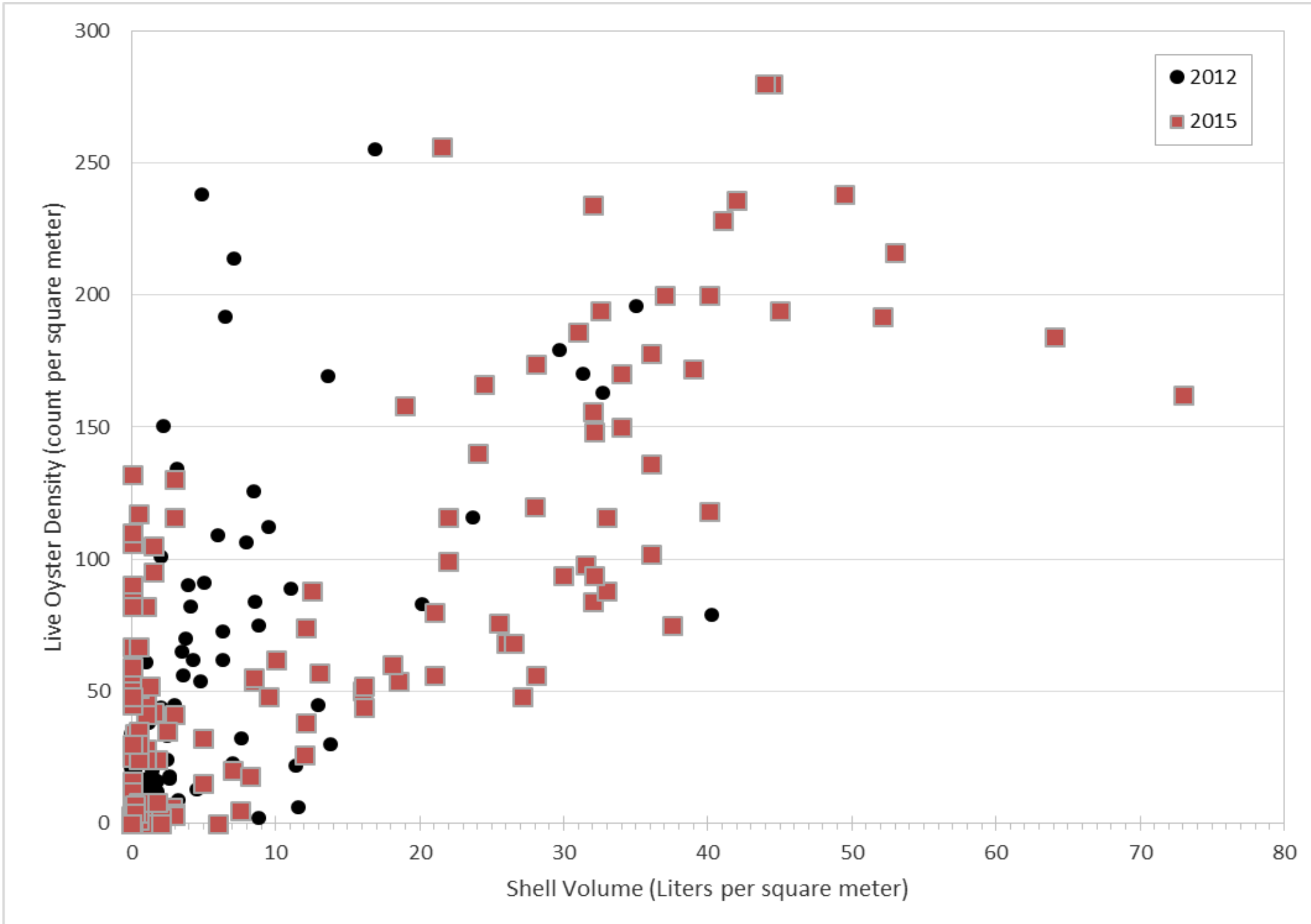


Figure A.43-7. 2012 and 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the St Mary's River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

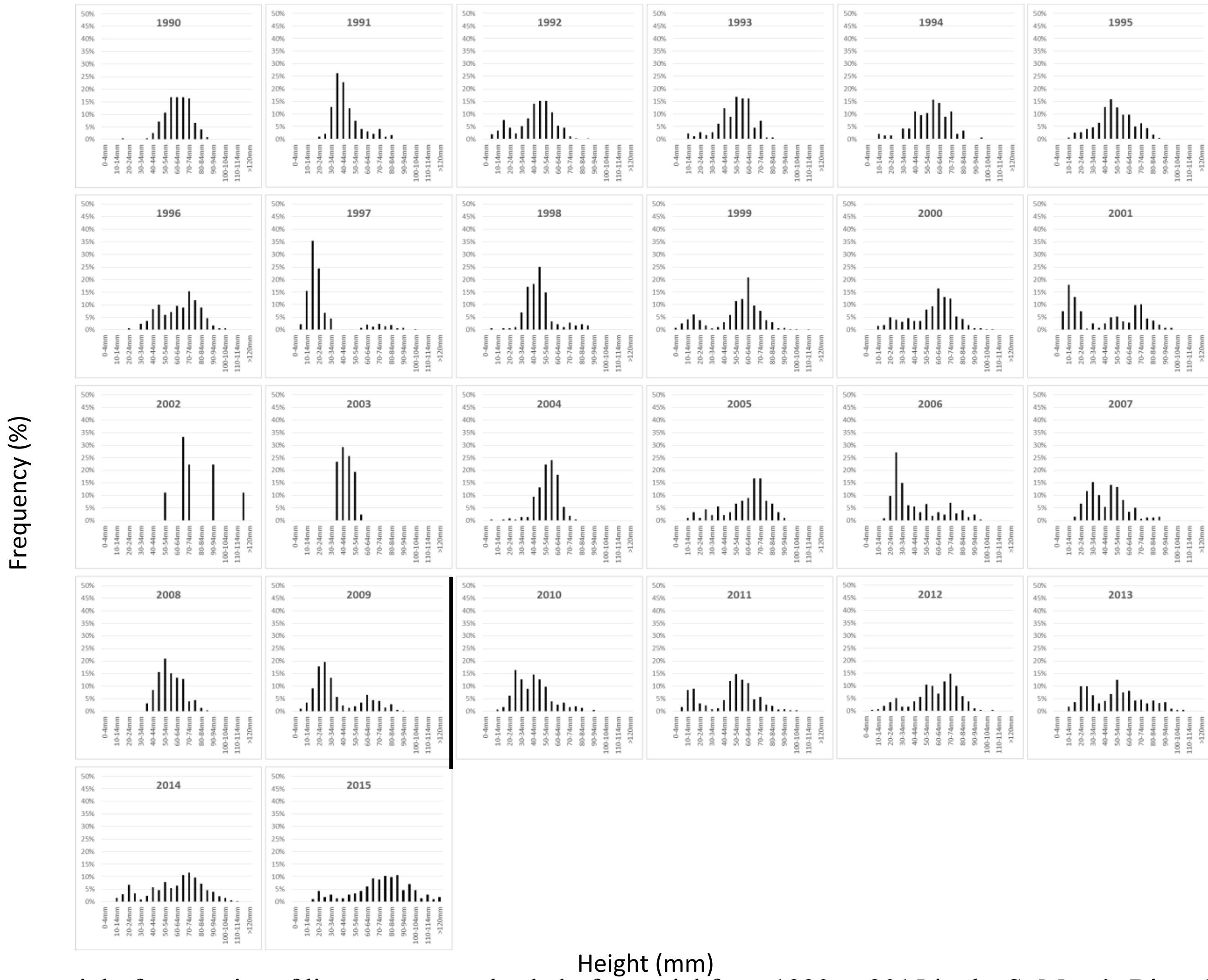


Figure A.44-8. Shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the St Mary's River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Pagan bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

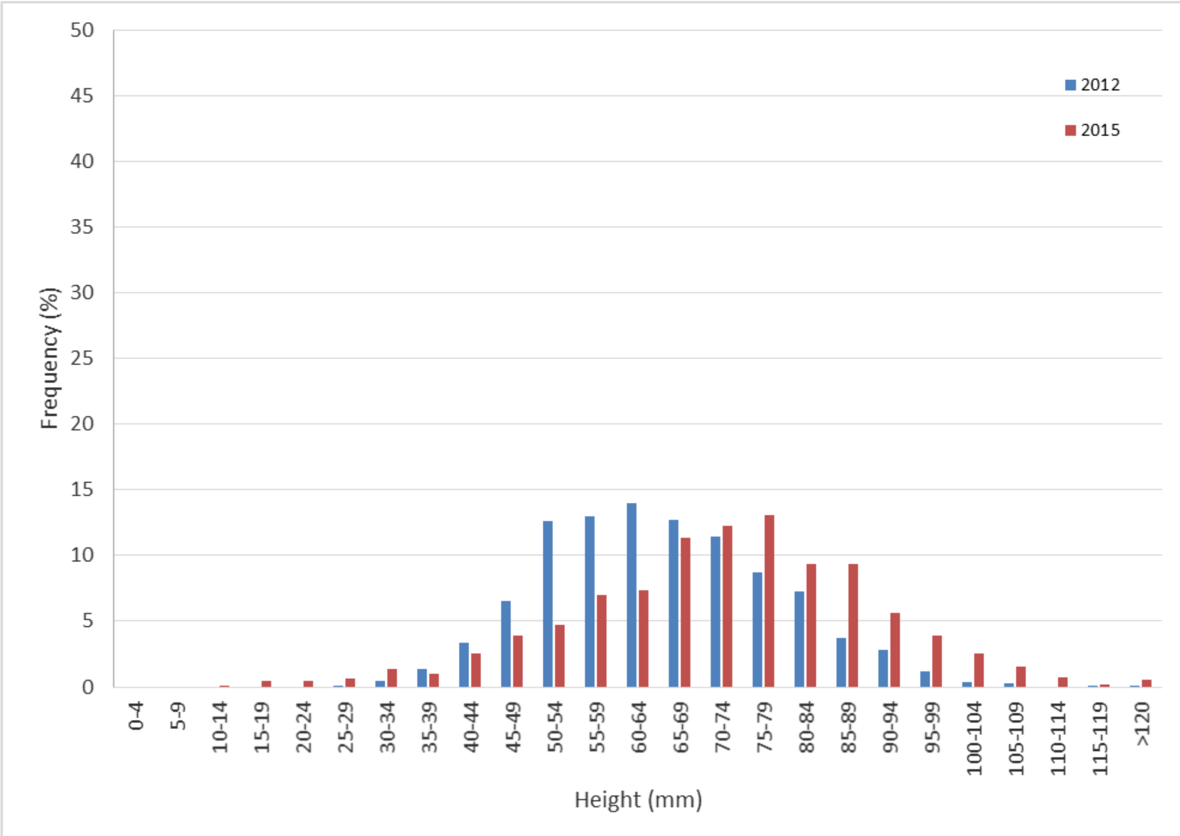


Figure A.43-9. Shell height frequencies of live oysters in the St Mary's River Sanctuary, 2012 and 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

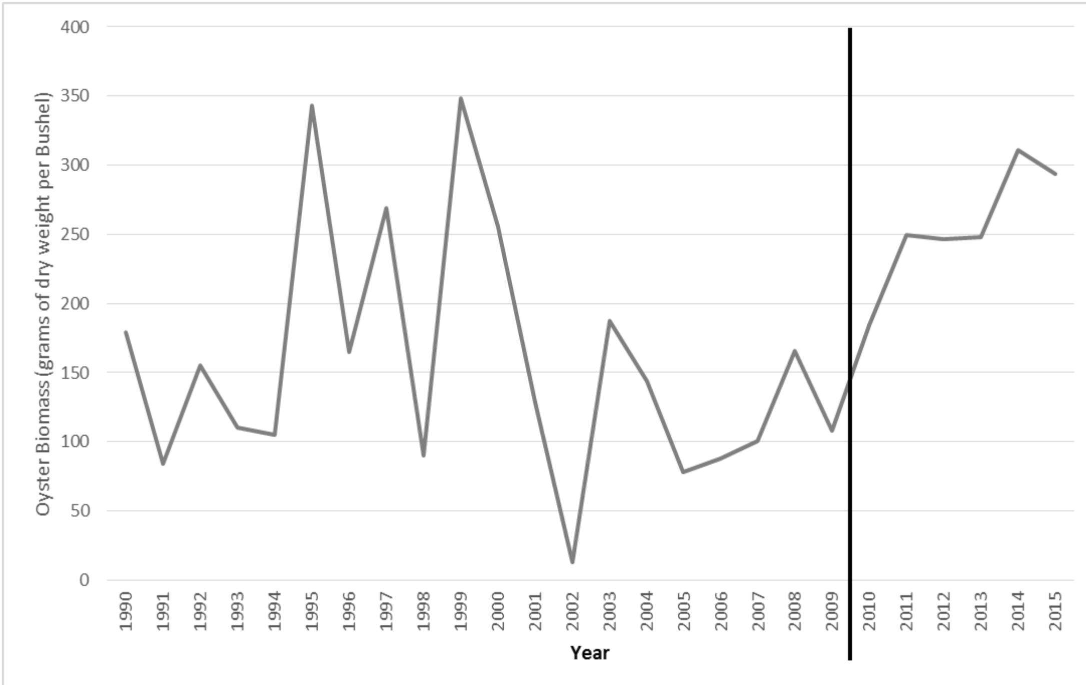


Figure A.44-10. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the St Mary's River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Pagan bar. Black line indicates the date the sanctuary was established.

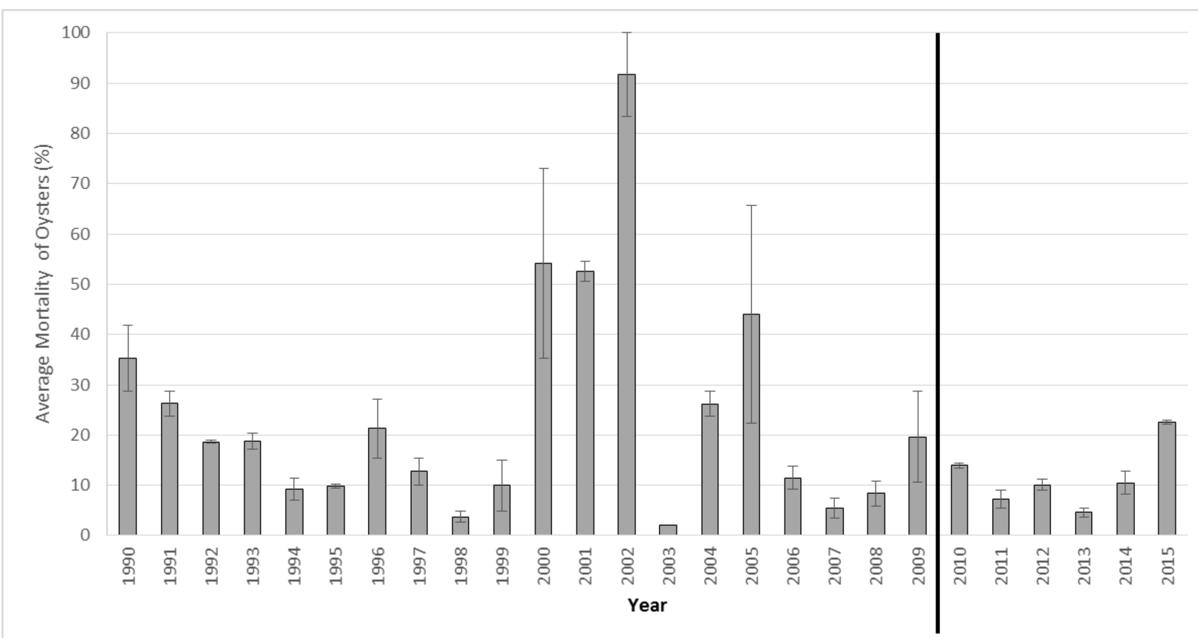


Figure A.43-11. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in St Mary's River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

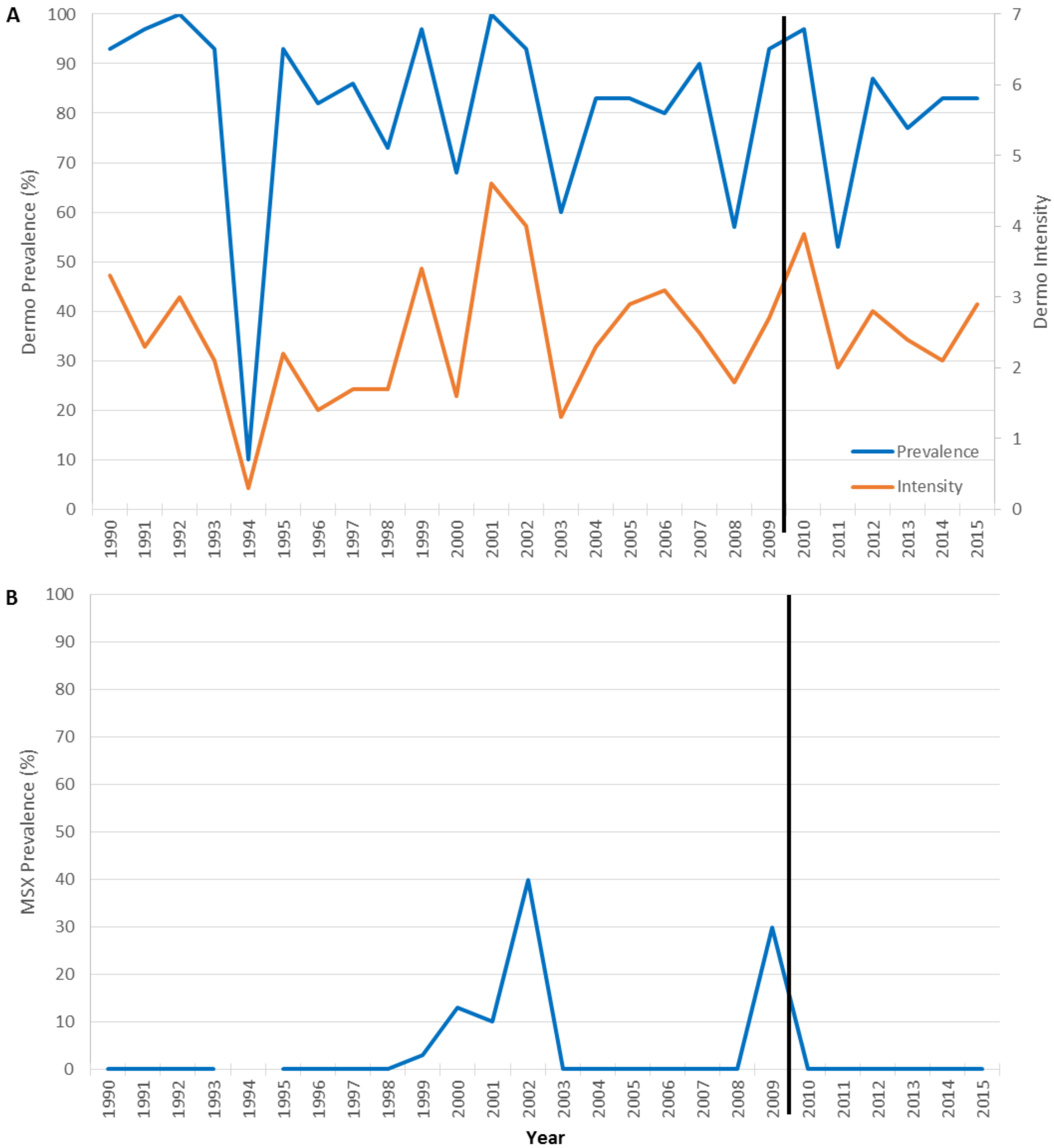


Figure A.43-12. Oyster disease prevalence and intensity from 1990 to 2015 in the St Mary's River Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Pagan bar.

Harvest

The sanctuary encompasses 21% of the 6,124 acres in NOAA Code 078. Because harvest may have come from places other than the area that became the sanctuary, seafood dealer reports from NOAA Code 078 cannot be used to assess harvest in this area. Commercial watermen reported a catch of 341 bushels in the 2009-2010 season from bars in the area that would become the sanctuary.

Environmental Conditions and Ecosystem Services

Chesapeake Bay Program Data Hub records monthly water quality at multiple stations in this area; however, data were only collected from 1999 to 2009 and there is no information for the period after the sanctuary was established (Figure A.43-13). Stations located in the sanctuary are: SMSMC (38.18933;-76.43367), SMT02 (38.21017;-76.46567), SMT03 (38.2;-76.44933), SMT04 (38.18867;-76.43984), XCF1336 (38.1887;-76.4398), XCF1440 (38.1893;-76.4339), XCF2621 (38.21017;-76.46567). Water was analyzed for salinity, temperature, secchi disk depth, total suspended solids, total nitrogen, and chlorophyll a. Water quality was suitable for oysters except for brief periods of low salinity.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

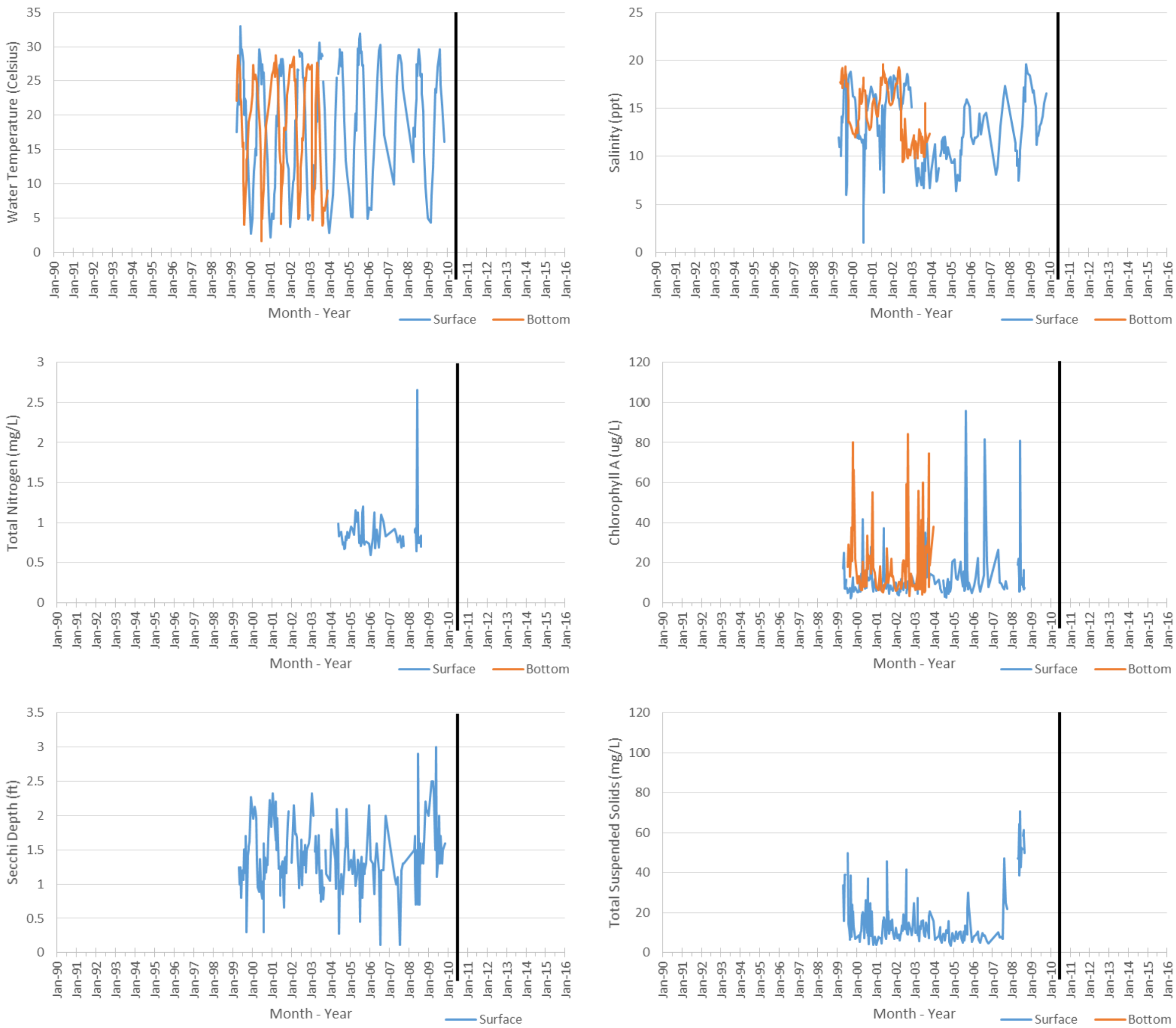


Figure A.43-13. Water quality data collected at stations within the area now established as St Mary's Sanctuary. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.

Section A.44: Tilghman Island Sanctuary

The Tilghman Island Sanctuary is located in the middle eastern portion of Maryland's Chesapeake Bay, a low salinity (less than 12 ppt) region (Figure A.44-1). The sanctuary was created in 2010 and encompasses 2,534 acres of which 1,345 acres (53%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 2 historic oyster bars (Bay Hundred and Pone bars) within the sanctuary.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.44-2). Of the 1,703 acres surveyed within the sanctuary, 807 acres (47%) were classified as oyster reef habitat. There has not been any updated bottom mapping using side scan sonar to date.

Restoration and Replenishment Activities

No replenishment or restoration planting activities have occurred in the area since 1990.

Oyster Population Characteristics

The Fall Survey has not collected oyster information in the area of the sanctuary since 1990.

A patent tong population survey was conducted in 2015 (Figures A.44-3). No such population survey was conducted prior to the establishment of the sanctuary. Only two oysters were found during the survey; one small-sized oyster (65 mm) and one market-sized oyster (96 mm). The average density of live oysters was 0.01± 0.01 (mean ± standard error, n = 152 152). No spat or boxes were found. Ninety-nine percent of the samples collected had no live oysters or boxes. Due to the small number of oysters collected, a relationship between oyster density and shell volume cannot be discerned (Figure A.44.4).

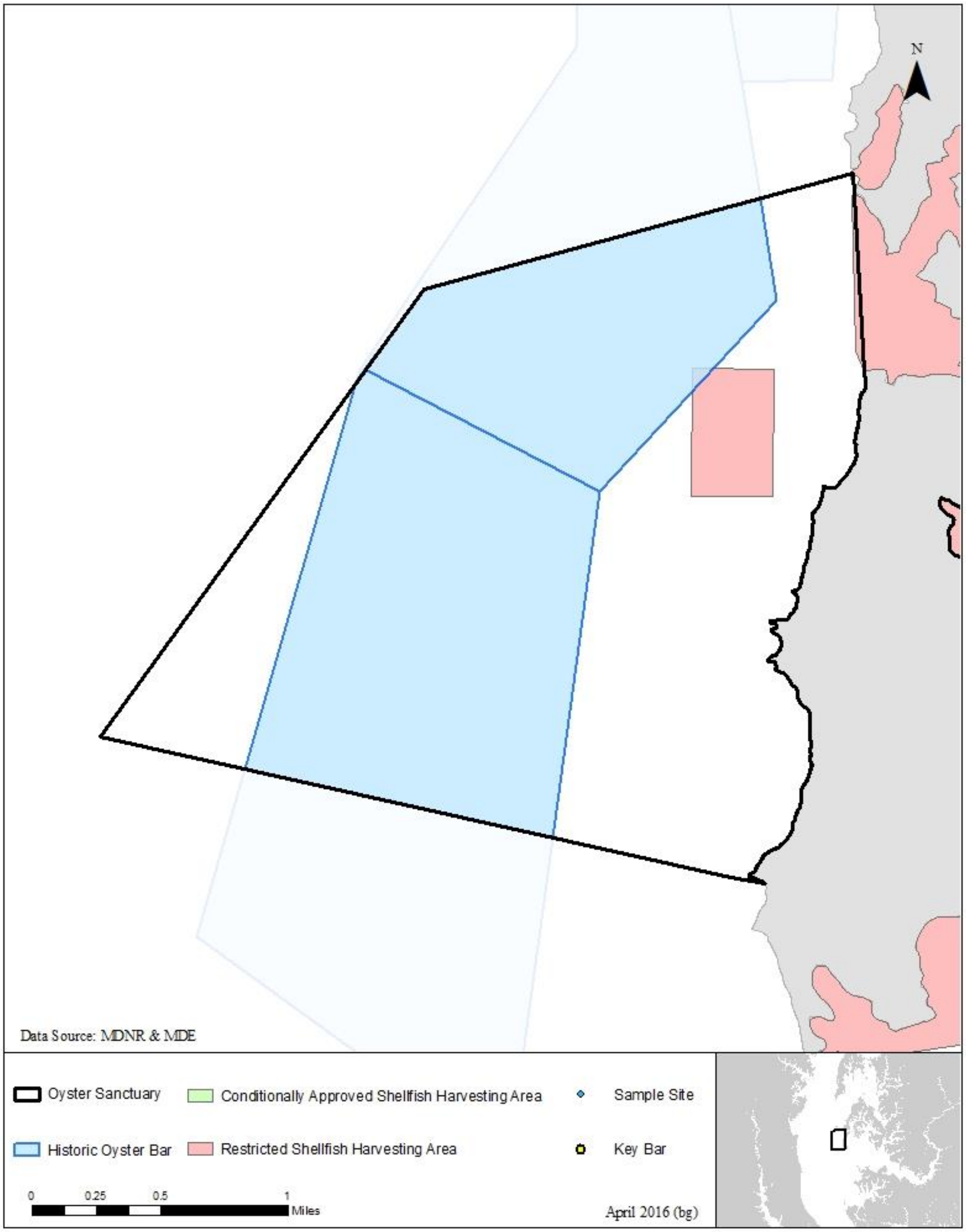


Figure A.44 -1. Tilghman Island Sanctuary.

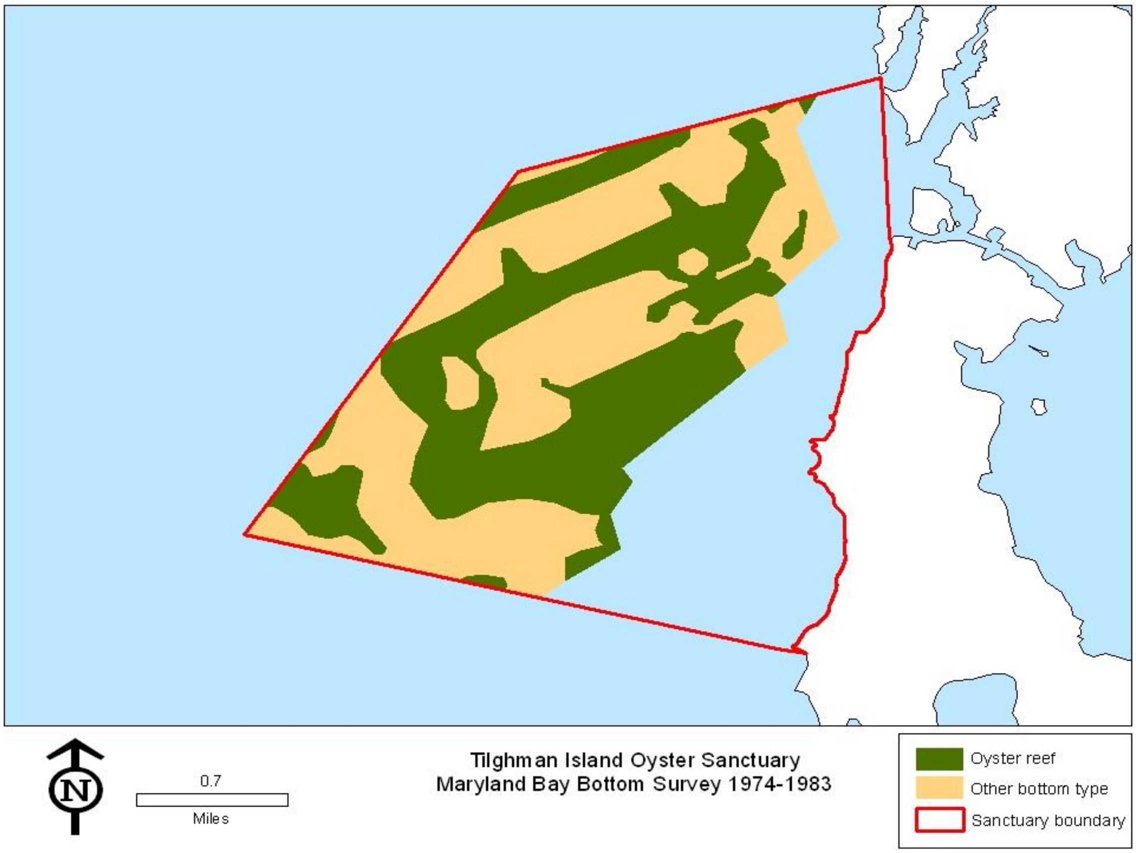


Figure A.44 -2. Tilghman Island Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict areas examined during the surveys.

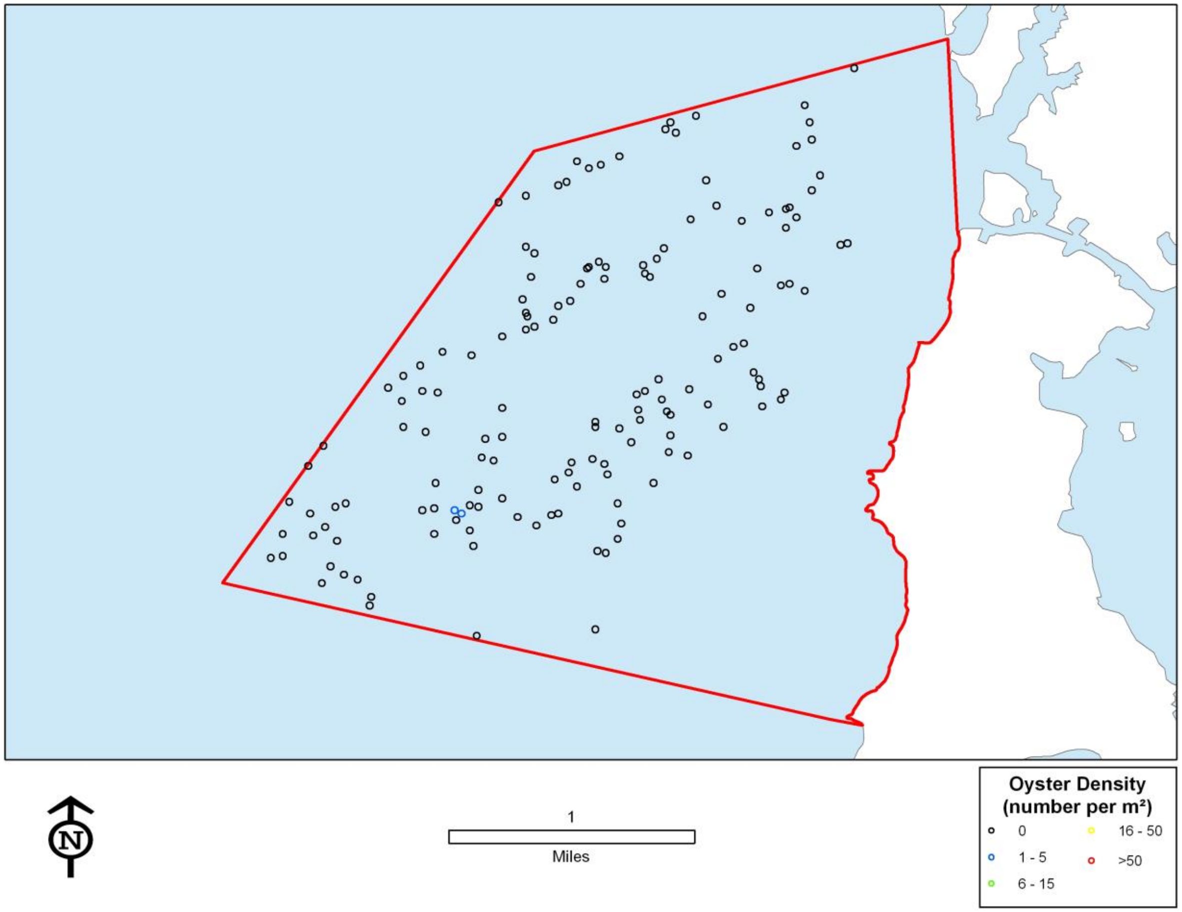


Figure A.44-3. Map of 2015 oyster density in the Tilghman Island Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

Figure A.44-4. 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Tilghman Island Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

Harvest

The sanctuary encompasses 1% of the 186,830 acres in NOAA Code 027. Because harvest from NOAA Code 027 is likely to have come from places other than the area that became the sanctuary, seafood dealer reports from this NOAA Code cannot be used to assess harvest in this area. Commercial watermen reported no harvest on bars in the area that would become the sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

Section A.45: Tred Avon River Sanctuary

The Tred Avon River Sanctuary, created in 2010, is located in the upper reaches of the Tred Avon River, a tributary of the Choptank River (Figure A.45-1). The sanctuary is in a low salinity (less than 12 ppt) region and encompasses 4,149 acres of which 1,152 (28%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 27 historic oyster bars within the sanctuary[92]. The Tred Avon River Sanctuary is one of the sanctuaries chosen for large-scale oyster restoration under the Chesapeake Watershed Agreement. A proportion of the sanctuary are designated by Maryland Department of the Environment (MDE) as restricted shellfish harvest areas based on the potential for contamination of shellfish with fecal coliform and other bacteria.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.45-2). Of the 1,513 acres surveyed within the sanctuary, 962 acres (64%) were classified as oyster reef habitat. In 2008, Maryland Geological Survey conducted a side scan sonar survey of the area. Of the 1,622 acres surveyed, 241 (15%) were classified as oyster reef habitat, indicating a substantial loss of oyster habitat since the Bay Bottom Survey.

Restoration and Replenishment Activities

Between 1990 and the establishment of the sanctuary in 2010, approximately 305,000 bushels of dredged and fresh shell and 34,000 bushels of wild seed were planted (Table A.23-1). As part of large-scale oyster restoration in support of the Chesapeake Bay Agreement, the U.S. Army Corps of Engineers constructed 16 acres of granite and shell reefs in 2015. A portion of these reefs was then seeded with hatchery-reared spat on shell.

Marylanders Grow Oysters, a public outreach program, has planted oysters since 2008 at two sites in the Tred Avon River Sanctuary. A third planting site within the Tred Avon River is located within the Oxford Laboratory Sanctuary. In 2016, growers tended 750 cages and planted approximately 220,000 oysters in both sanctuaries within the Tred Avon River.

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[92] See chart 16 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

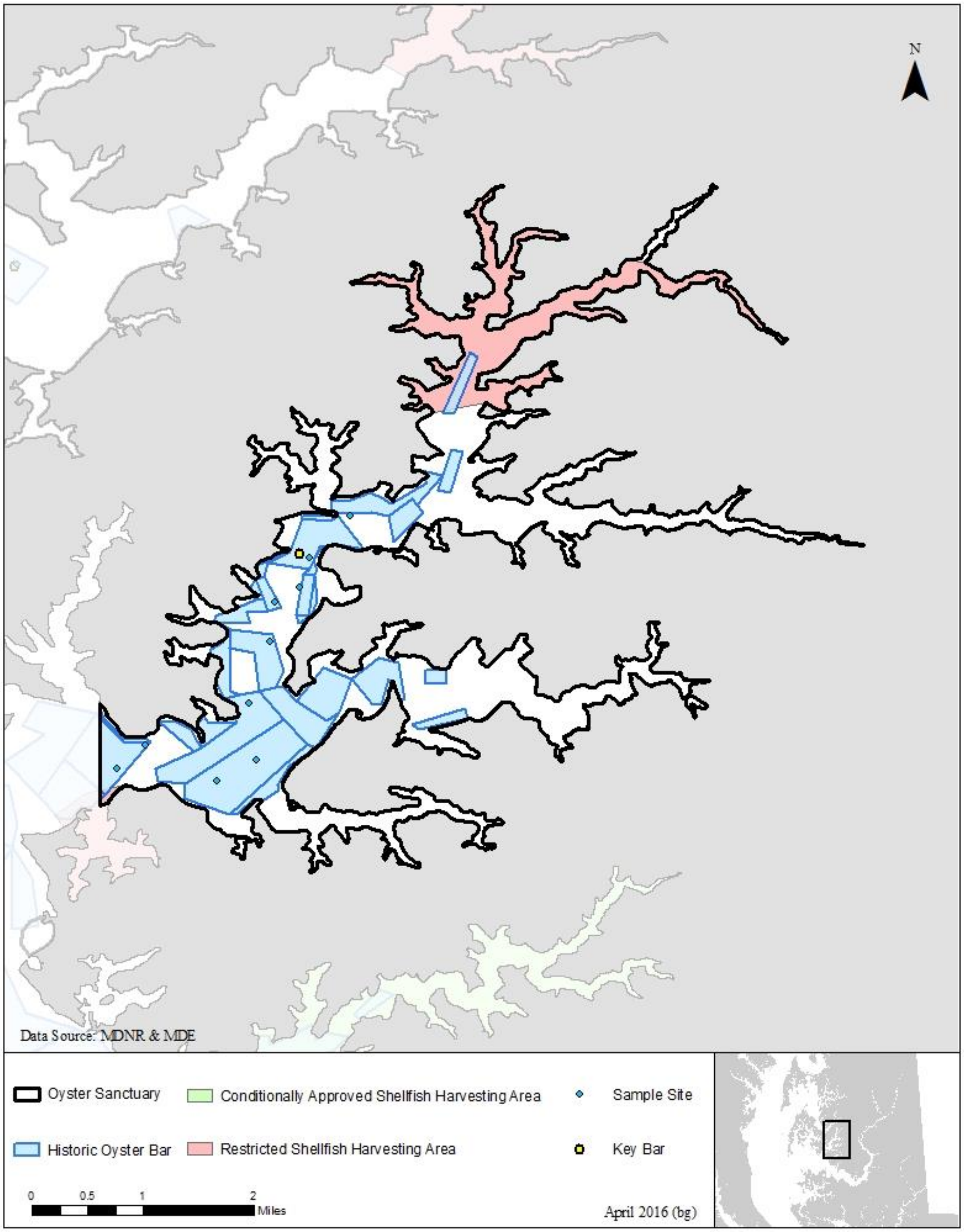

Figure A.45 -1. Tred Avon River Sanctuary.

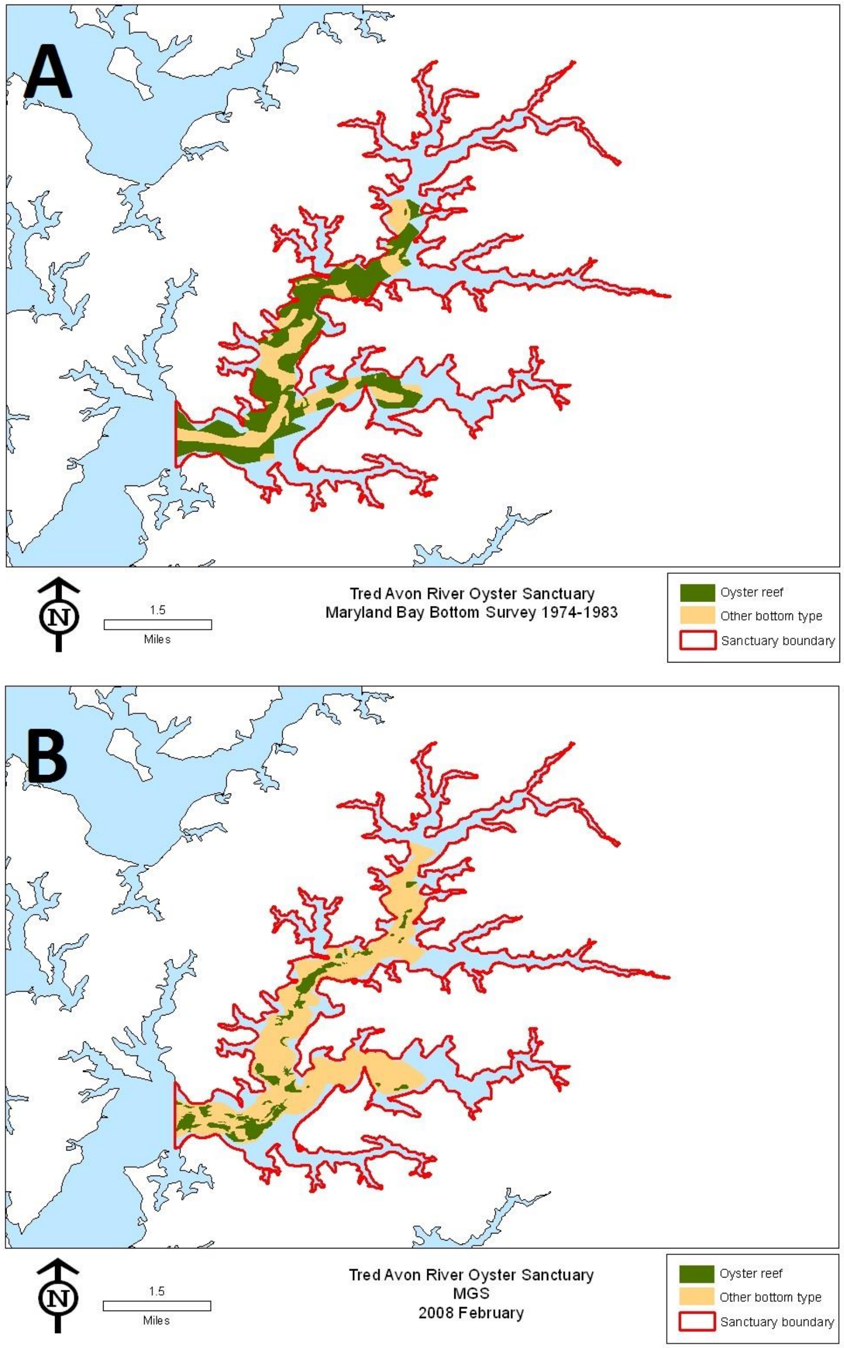

Figure A.45 -2. Tred Avon River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from Maryland Geological Survey in 2008. Tan and green colored areas depict areas examined during the surveys.

Table A.44-1. Replenishment and restoration planting activities occurring since 1990 in the area now established as the Tred Avon River Sanctuary. S = planting activity occurring after the sanctuary was established in 2010.				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1996	Dredged Shell	23.39	148.1	-
1997	Dredged Shell	34.92	102.5	-
1998	Fresh Shell	2.60	6.3	-
1998	Wild Seed	28.19	17.0	-
2000	Dredged Shell	4.38	48.6	-
2001	Wild Seed	8.29	15.0	-
2002	Wild Seed	3.35	2.5	-
2009	Hatchery Spat-on-Shell	6.92	-	14.07
2015 (S)	Stone	10	262.3	-
2015 (S)	Mixed Shell	6	146.6	-
2015 (S)	Hatchery Spat-on-Shell	2.57	-	10.18

Oyster Population Characteristics

The Fall Survey has sampled two to six oyster bars in this area since 1990 with an average of five oyster bars sampled annually. Some of the samples were taken on sites slated for large-scale restoration, although none of these had been restored as of the writing of this report. The average number of live oysters per bushel (market, small, and spat) was similar before and after sanctuary creation (Table A.45-2; Figure A.45-3). The average number of small-sized oysters per bushel decreased slightly after sanctuary establishment, whereas the number of market-sized oysters increased during this time period. The increase in market-sized oysters may be due to cessation of harvest.

Table A.45-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Tred Avon River Sanctuary in 2010. Values are given as mean ± standard error.		
	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 88	6 / 35
Number of Live Oysters per Bushel	90 ± 14	82 ± 4
Number of Live Small-Sized Oysters per Bushel	33 ± 7	22 ± 8
Number of Live Market-Sized Oysters per Bushel	36 ± 4	57 ± 11
Live Oyster Biomass (g Dry Weight per Bushel)	96 ± 12.4	168 ± 19.4
Mortality (%)	26.3 ± 4.6	8.1 ± 1.5

Patent tong population surveys were conducted different areas within the sanctuary in 2012 and 2013 (Figures A.45-4), prior to any large-scale restoration work. The samples of these two surveys were combined in the results of this section. The average density of live oysters was 3.46 ± 0.48 oysters m^{-2} (mean ± standard error, n= 222). The density of small-sized oysters was similar to the density of market-sized oysters (1.71 ± 0.31 and 1.75 ± 0.24 oysters m^{-2}, respectively). Sixty-four percent of the samples collected contained no live oysters or boxes. Oyster density increased with volume of shell (Figure A.45.5).

The actively restored areas (seed plantings on both natural bottom and constructed reefs) within the sanctuary will be monitored at three and six years after the activities occur to determine if the areas meet restoration goals as defined by the Oyster Metrics Team[93]. The first monitoring will occur in 2018. Reference sites within the sanctuary were established to gauge the effectiveness of restoration treatments and will be monitored at the same time as the restoration sites. The reference sites were areas that were suitable for restoration with seed or substrate and seed, but left unrestored. These areas were not true controls in that they were not exact replicates of the treated sites (exact replicates are not possible given variation in flow, salinity, and bottom type). Furthermore, it is not possible to isolate the reference sites from the treated sites, and restoration on treated sites may affect reference sites. For example, as oysters grow on treated sites, they may provide larvae to adjacent reference sites. Given these caveats, reference sites still provide valuable information on effectiveness of restoration efforts, and these sites will be monitored along with actively restored areas.

[93] Allen, S., A.C. Carpenter, M. Luckenbach, K. Paynter, A. Sowers, E. Weissberger, J. Wesson, and S. Westby. 2011. Report of the Oyster Metrics Workgroup. Submitted to the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program. 32 pp. http://chesapeakebay.noaa.gov/images/stories/fisheries/keyFishSpecies/oystermetricsreportfinal.pdf

Oyster Size Structure

Oysters collected by the Fall Survey in this area on the Double Mills bar have measured shell heights since 1990 (Figure A.45-6). Shell heights were also measured during the two patent tong population surveys and were consistent with heights documented in the Fall Survey (Figure A.45-7). There has been an increase in the number of large oysters since the establishment of the sanctuary.

Biomass

Biomass of oysters from Double Mills has been calculated from Fall Survey samples since 1990 (Table A.45-2; Figure A.45-8). Average biomass is greater after the area was established as a sanctuary compared to prior. Annual biomass has increased steadily since 2002, with the highest biomass of 243 grams dry weight per bushel occurring in 2014. This increase is due to the increasing number of larger market sized oysters and low mortality.

Recruitment (Spatfall)

Based on Fall Survey data, spatfall from 1990 to 2015 ranged from 0 to 214 spat per bushel (Figure A.45-3). The highest spatfalls were observed 1991 and 1997, with spat counts being low since then, averaging an annual three spat per bushel.

Spat density from the patent tong population survey increased from 2012 (0.12 ± 0.05 m^{-2}) to 2013 (0.82 ± 0.14 m^{-2}).

Mortality

Based on Fall Survey box counts, the average mortality after sanctuary establishment was lower than the average mortality from before sanctuary establishment (Figure A.45-9). From 1990 to 2015, mortality ranged from 2% to 73%, with the highest mortality occurring during a bay-wide disease event in 2002.

Disease

From 1990 to 2015, dermo prevalence has ranged from 40% to 100%, with prevalence being generally higher prior to 2002 (Figure A.45-10). Dermo intensity ranged from 1.1 to 5.5 during the 26 year time period and in 2001, mean dermo intensity reached a lethal level (greater than5 on a scale of 0 to 7). MSX prevalence has ranged from 0% to 33% but was only observed in 1992, 1999, and 2002.

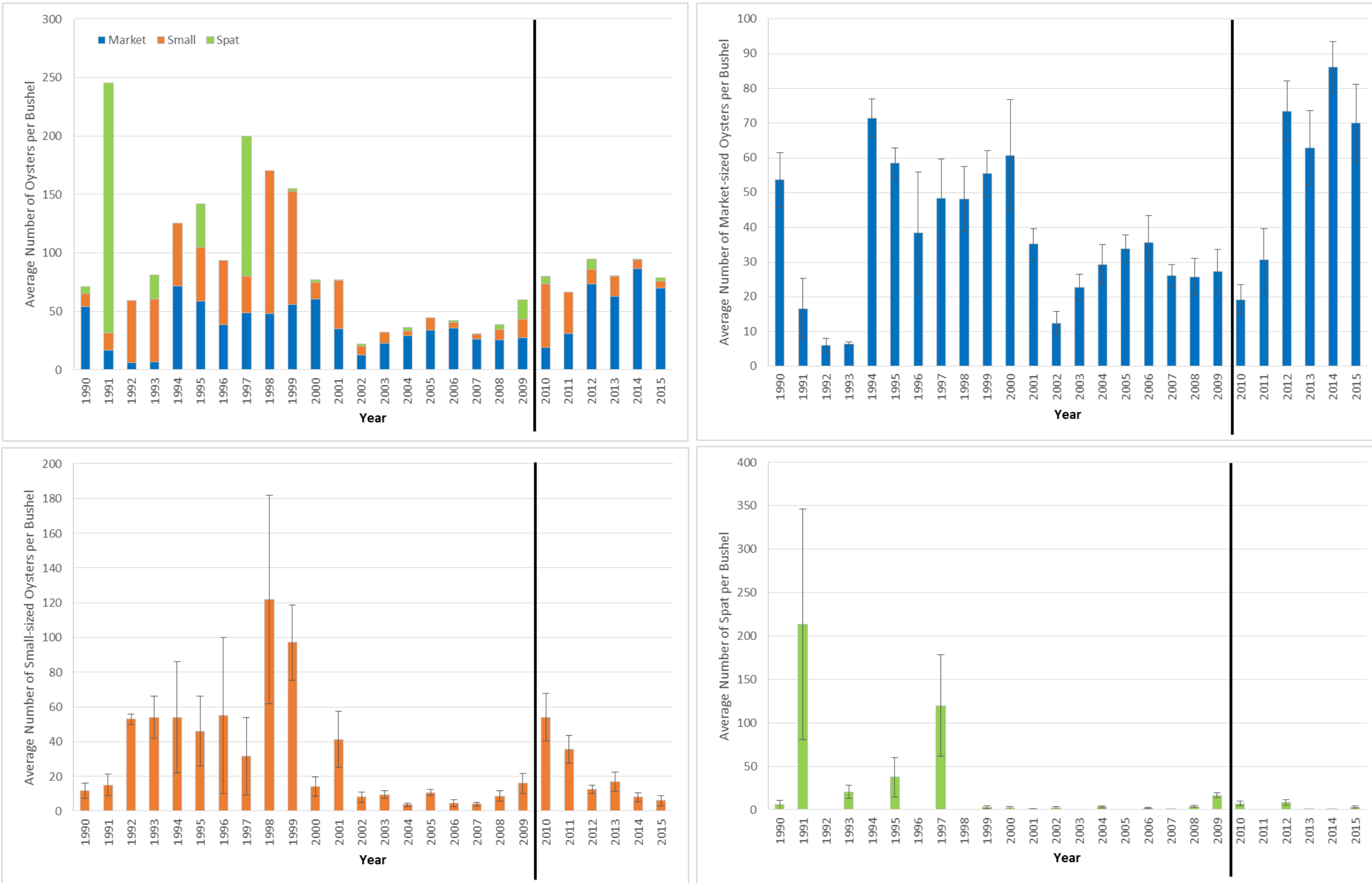

Figure A.45-3. Average number of live oysters per bushel of material by size class in the Tred Avon Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

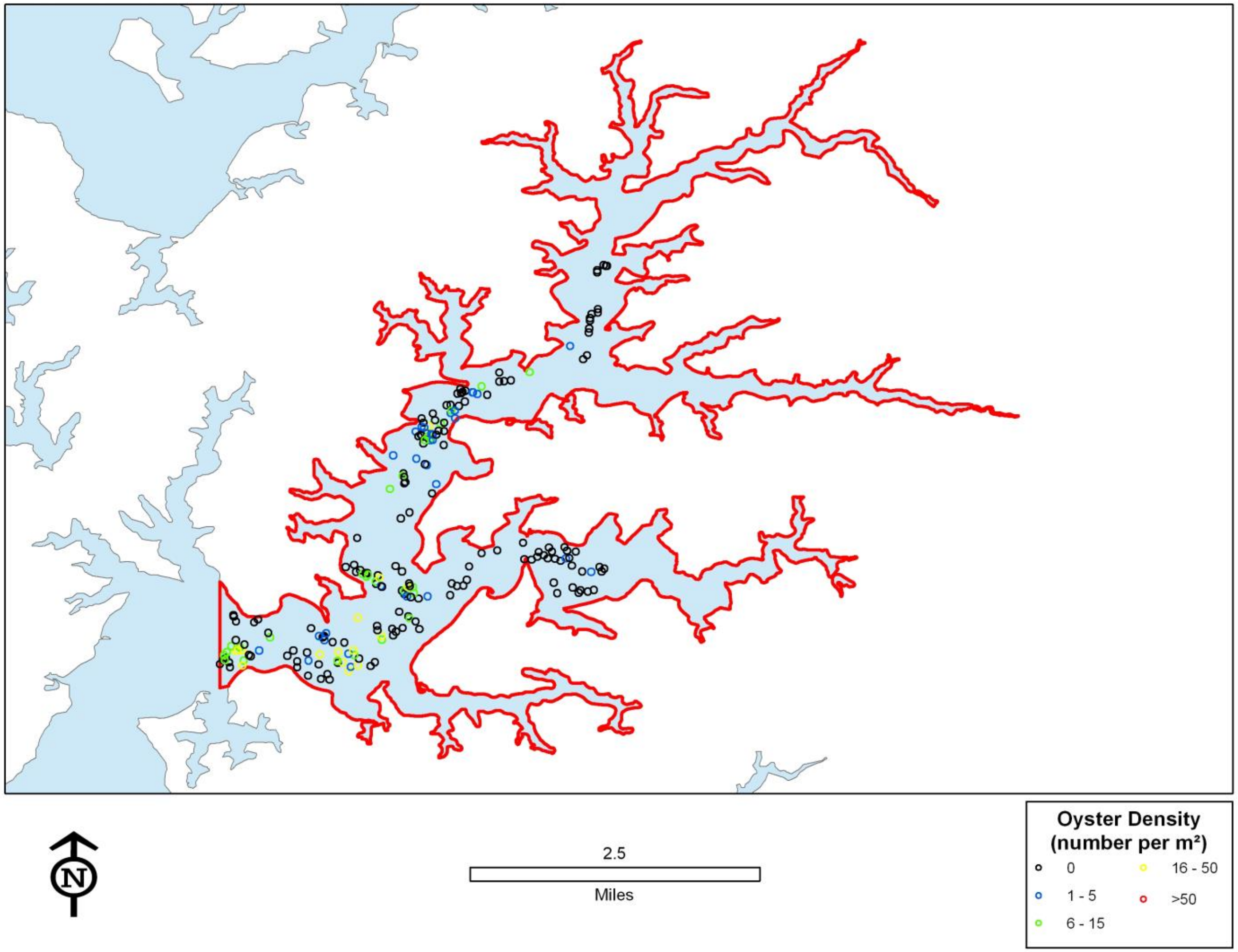

Figure A.45-4. Map of 2012 and 2013 oyster density in the Tred Avon Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

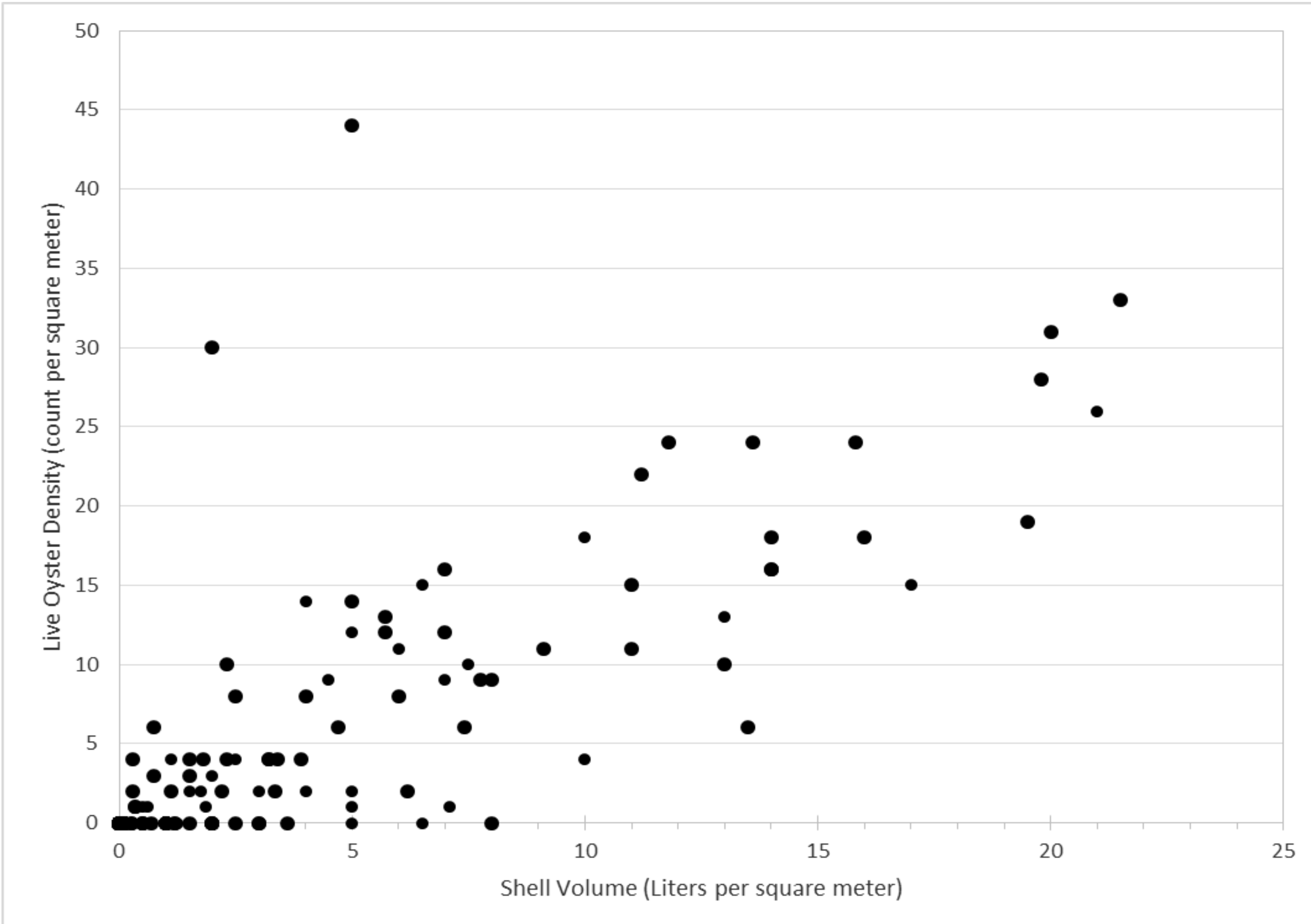

Figure A.45-5. 2012 and 2013 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Tred Avon River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

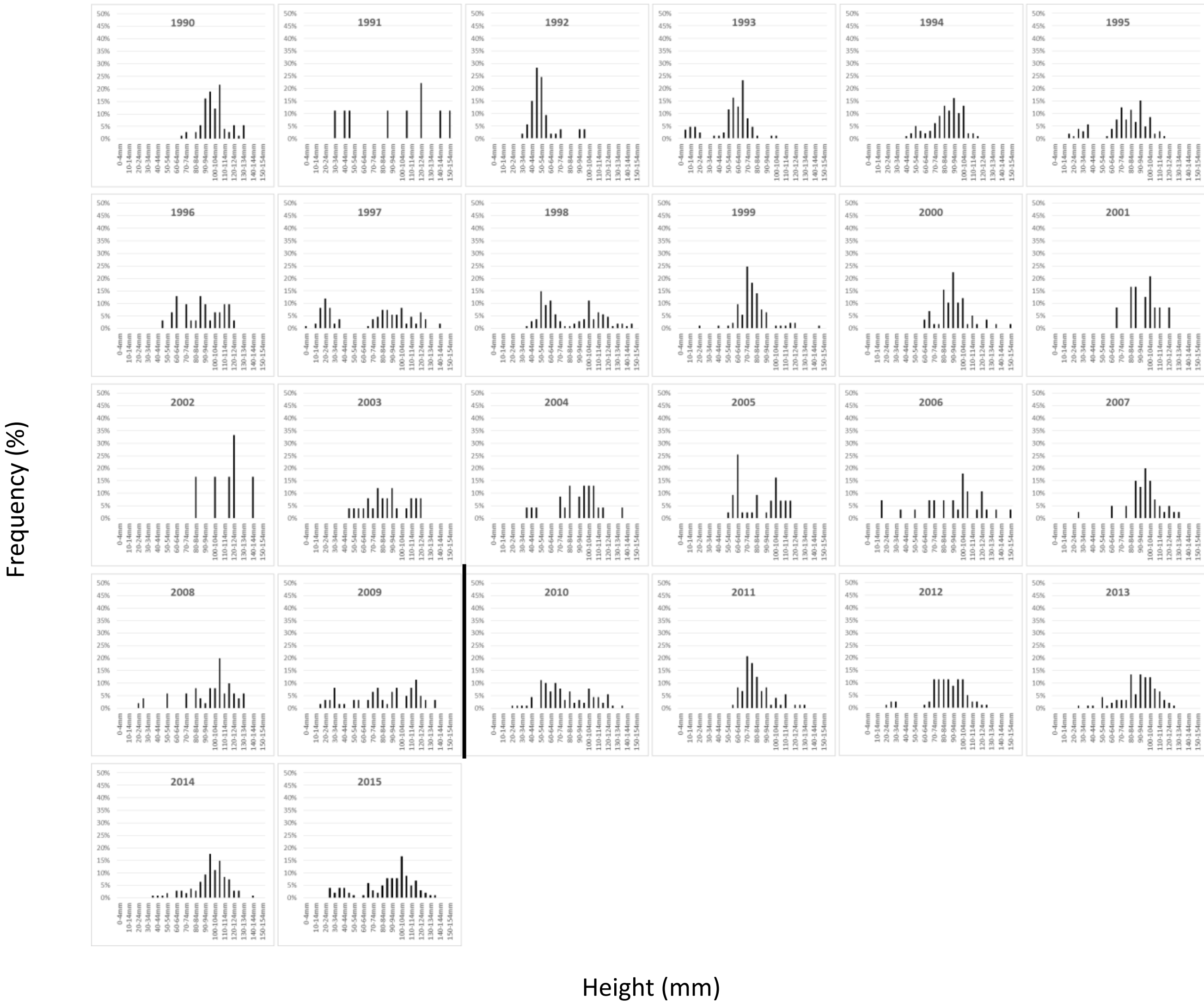

Figure A.45-6. Shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the Tred Avon Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Double Mills bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

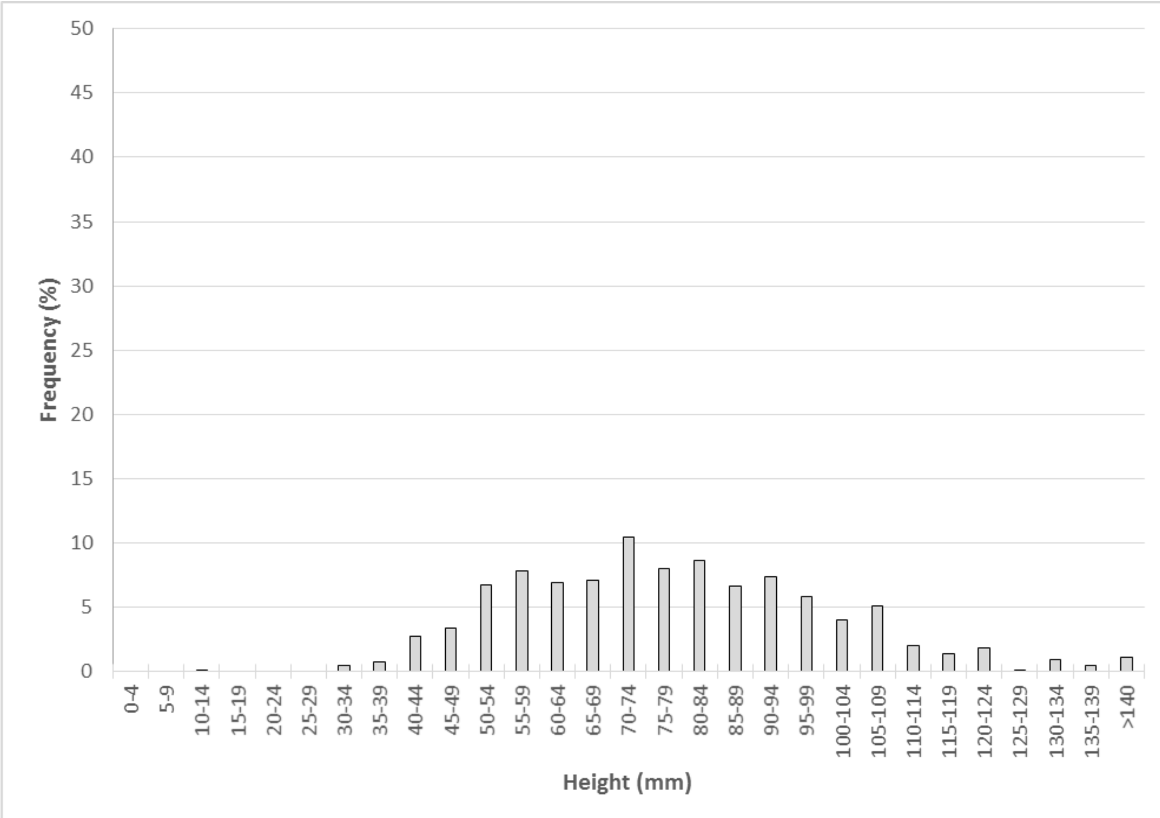

Figure A.45-7. Shell height frequencies of live oysters in the Tred Avon River Sanctuary, 2012 and 2013. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

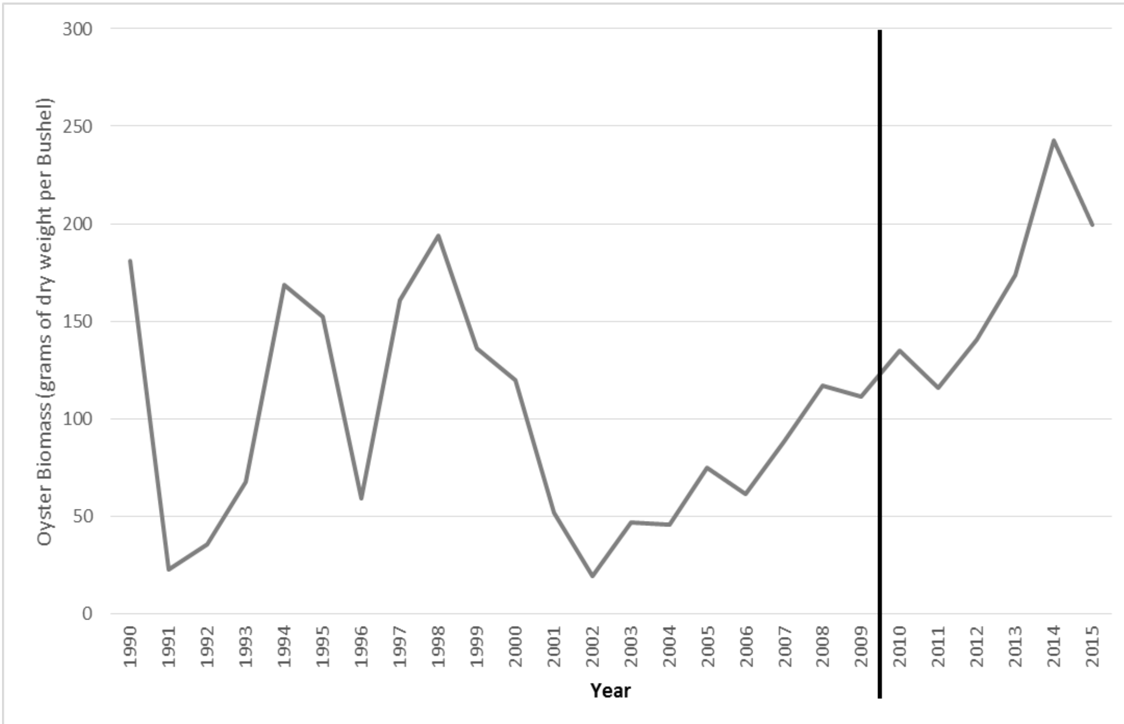

Figure A.45-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Tred Avon Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Double Mills bar. Black line indicates the date the sanctuary was established.

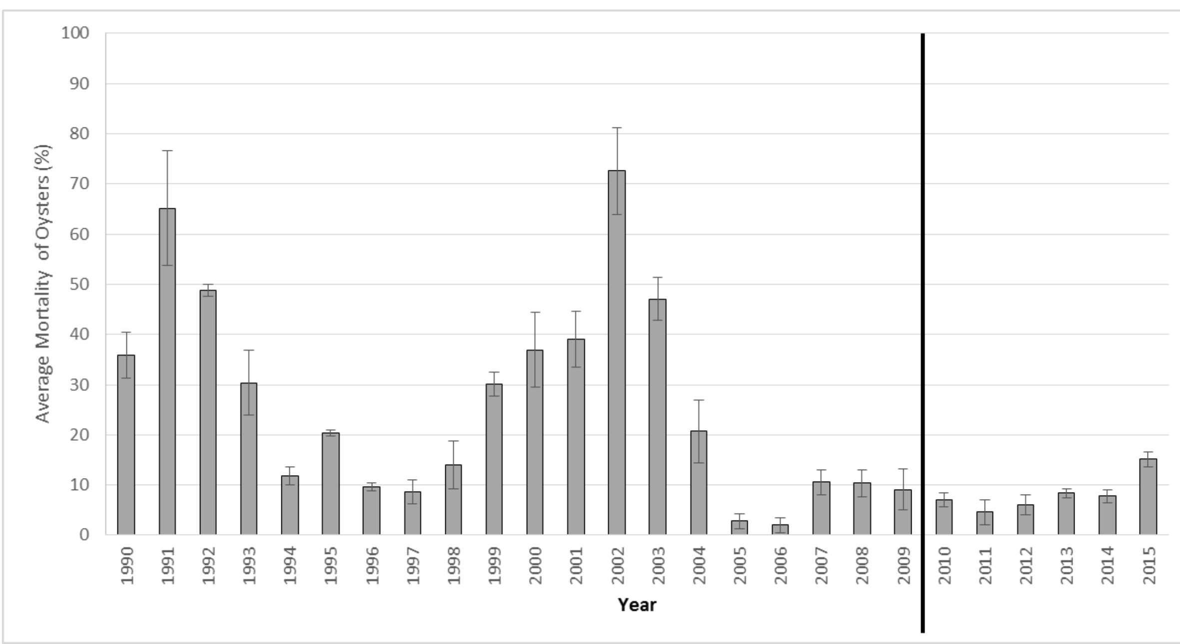

Figure A.45-9. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Tred Avon Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

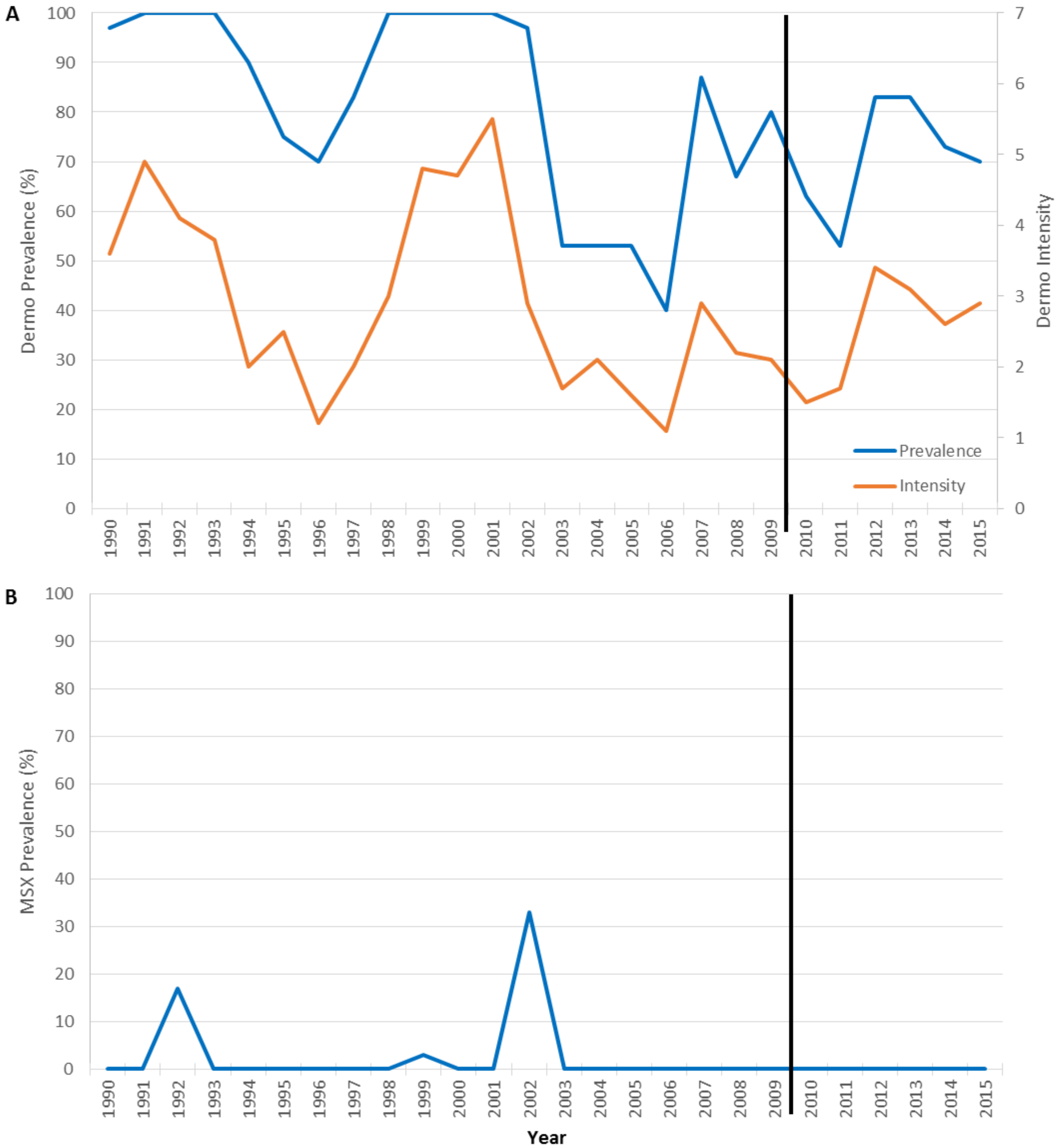

Figure A.45-10. Oyster disease prevalence and intensity from 1990 to 2015 in the Tred Avon Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Double Mills bar.

Harvest

The sanctuary encompasses 60% of the 6,869 acres in NOAA Code 637. Harvest reported by seafood dealers prior to the establishment of the sanctuary was highest in the 1990-1991 season at 22,456 bushels (Figure A.45-11). The second highest harvest of 11,709 occurred during the 1998-1999 season. From 1990 to 2009 the average harvest per season was 3,380 bushels. In the 2009-2010 harvest season, commercial waterman reported a catch of 37 bushels in the NOAA Code.

After the establishment of the sanctuary, harvest reported by both seafood dealers reports and harvesters increased despite the decrease in area open to fishing. In the 2015-2016 season, between 3,206 and 4,008 bushels were harvested in the Tred Avon River outside the sanctuary. Based on seafood dealer reports, this is the highest harvest since the 2000-2001 season.

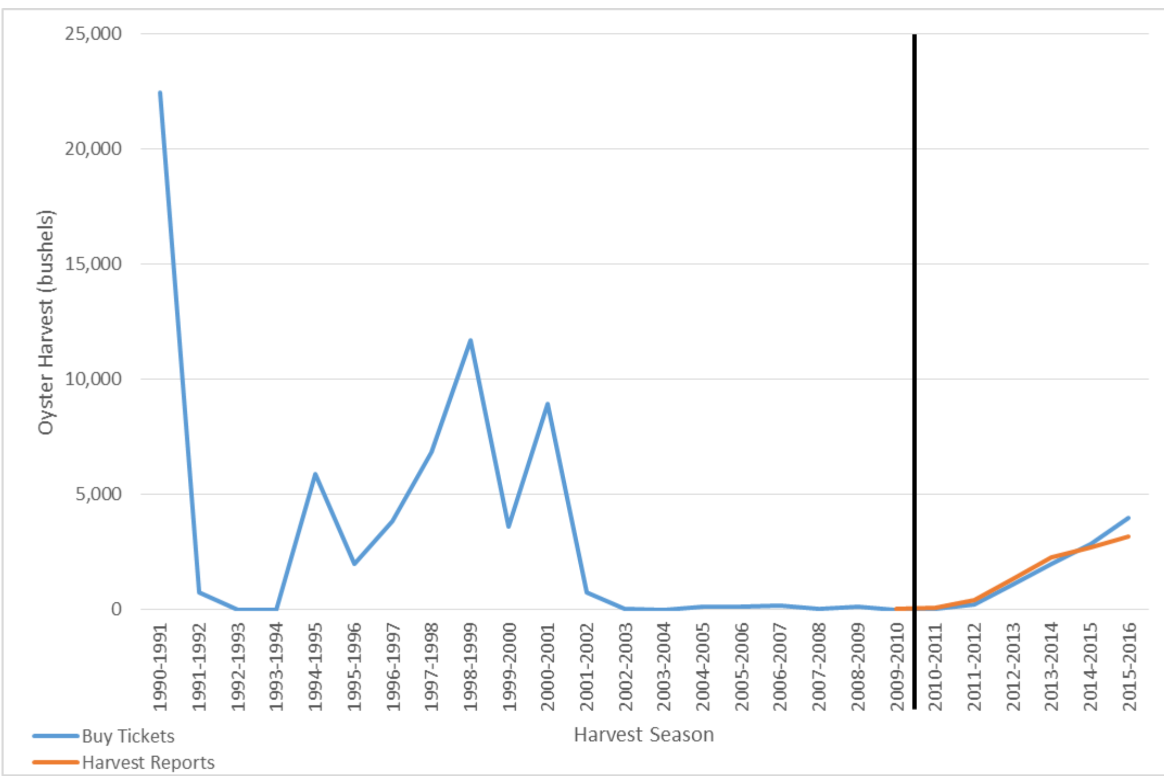

Figure A.45-11. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 637 (Tred Avon River). In 2010, 60% of NOAA Code became an oyster sanctuary (denoted by the black line) where harvest is prohibited.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Data Hub records monthly water quality data at station XFH2312 (38.7052, -76.1468) in this area. Data were only collected from 2006 to 2008 and thus cannot be used to examine water quality before and after sanctuary establishment (Figure A.45-12). Surface water quality was analyzed for salinity, water temperature, secchi disk depth, total suspended solids, total nitrogen, and chlorophyll a. Water quality was favorable for oysters during the period examined.

Researchers from NOAA, Virginia Institute of Marine Sciences, and the Smithsonian Environmental Research Center are studying fish and crustacean usage of restored oyster reefs in the Tred Avon River[94]. Baseline data are currently being collected and will be compared to data collected after restoration activities are complete.

[94] NOAA. 2016. 2016 Oyster Reef Ecosystem Services Research Update. http://chesapeakebay.noaa.gov/images/stories/habitats/2016oresresearchupdate.pdf

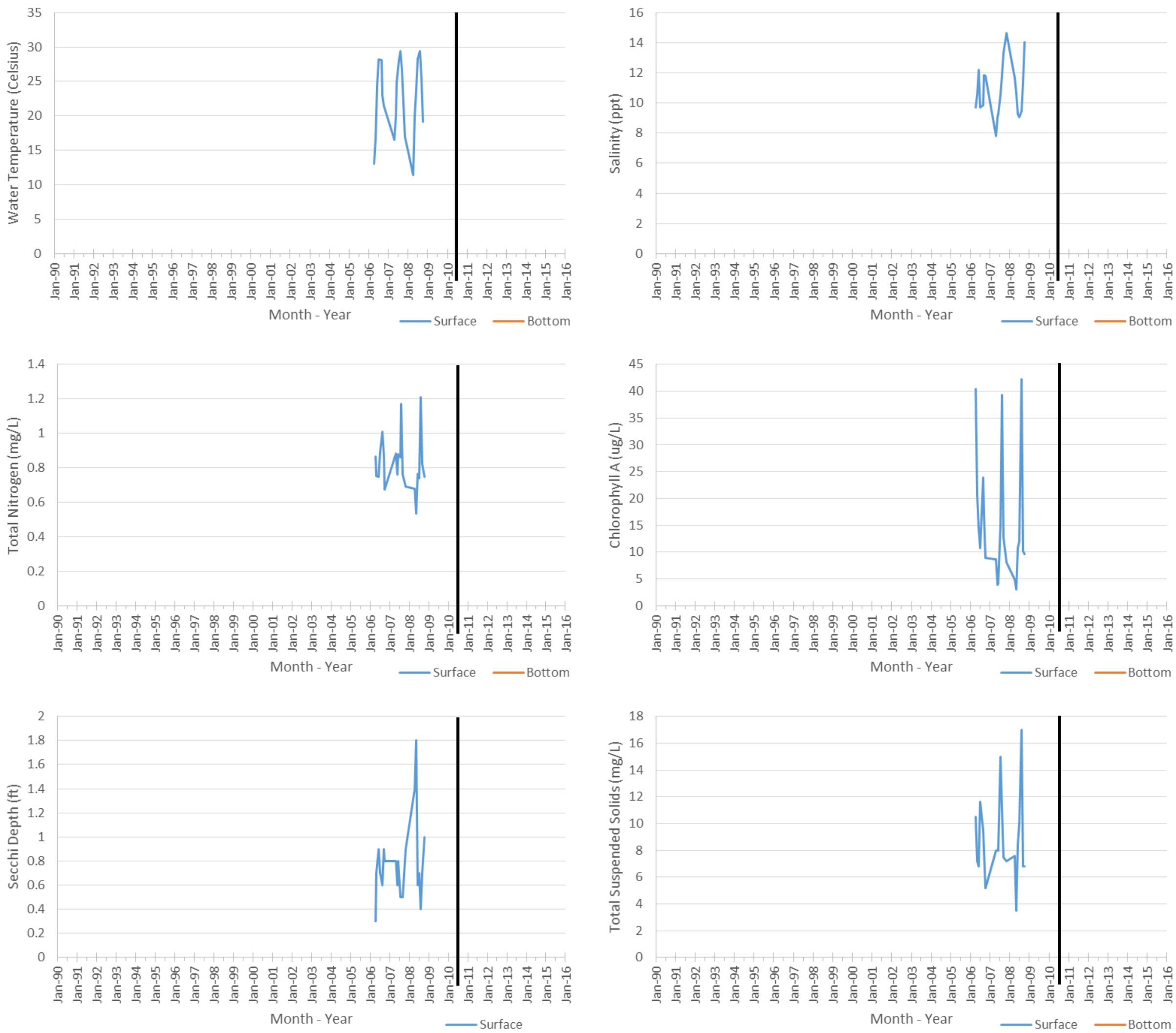

Figure A.45-12. Water quality data collected at Station XFH2312 within the area now established as Tred Avon River Sanctuary from 2006 to 2008. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.

Section A.46: Upper Chester River Sanctuary

The Upper Chester River Sanctuary is located in the Chester River adjacent to the Chester ORA A Sanctuary, creating a large contiguous protected area (Figure A.46-1). The sanctuary is located in a low salinity (less than 12 ppt) region. The sanctuary was created in 2010 and encompasses two smaller sanctuaries created in 2007: Emory Wharf (65 acres) and Possum Point (11 acres). The sanctuary has an area of 9,033 acres of which 2,365 (26%) are historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 31 historic bars within the sanctuary[95].

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) (Figure A.46-2). Of the 4,023 acres surveyed within the sanctuary 3,021 acres (75%) were classified as oyster reef habitat. Between 2003 to 2007 and in 2012, NOAA Chesapeake Bay Office conducted side scan sonar surveys of the area. Of the 5,188 acres surveyed by NOAA, the 965 acres (19%) were classified as oyster reef habitat. There appears to be substantial loss of habitat in the area covered by both surveys.

Restoration and Replenishment Activities

The sanctuary has not received any active restoration efforts since it was established in 2010; however, this area received replenishment efforts prior to 2010, including work by the U.S. Army Corps of Engineers (Table A.46-1). Wild seed was primarily planted prior to 2003 and hatchery spat-on-shell was planted after 2003. In 2008 hatchery spat-on-shell was planted in Emory's Wharf and Possum Point Sanctuaries, areas now encompassed by the Upper Chester River Sanctuary.

Marylanders Grow Oysters, a public outreach program, is active in the sanctuary. In 2016, growers tended 311 cages and planted approximately 93,000 oysters.

[95] See chart 8 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

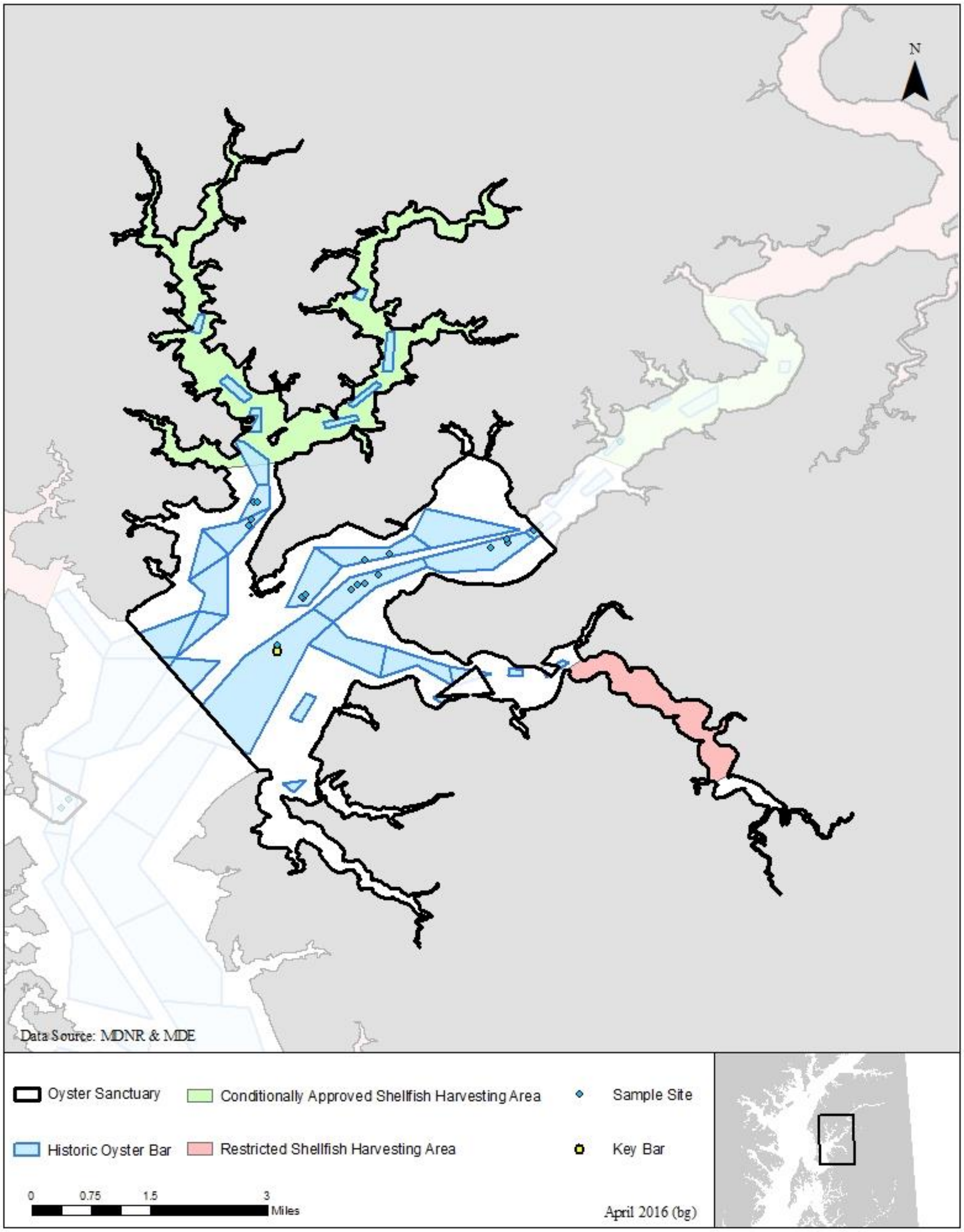

Figure A.46 -1. Upper Chester River Sanctuary.

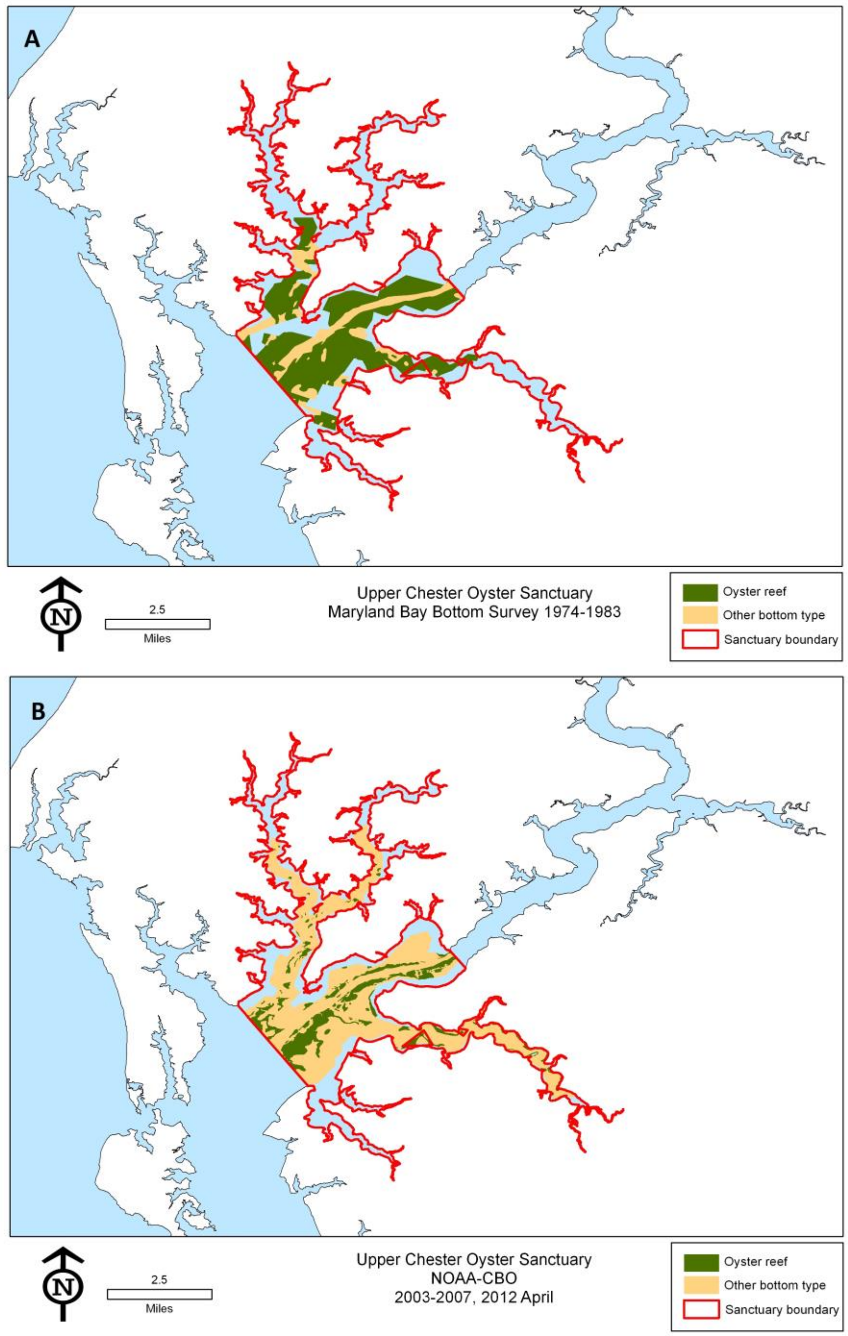

Figure A.46 -2. (A) Upper Chester River Sanctuary bottom types, 1974-1983. Data from Maryland Bay Bottom Survey. (B) Upper Chester River Sanctuary bottom types, 2003-2007 and 2012. Data from NOAA Chesapeake Bay Office. Tan and green colored areas depict areas examined during the surveys.

Table A.46-1. Replenishment planting activities occurring since 1990 in Upper Chester River Sanctuary. S = Planting activity occurring within Emory Wharf Sanctuary and Possum Point Sanctuary which now lie within the Upper Chester River Sanctuary.				
Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Wild Seed	40.48	17.65	-
1991	Wild Seed	106.30	51.76	-
1992	Wild Seed	192.57	85.15	-
1993	Wild Seed	62.33	25.90	-
1994	Wild Seed	88.46	48.24	-
1995	Wild Seed	84.19	46.39	-
1996	Wild Seed	19.11	16.04	-
1997	Wild Seed	29.92	26.56	-
1998	Dredged Shell	2.50	22.55	-
1998	Wild Seed	138.35	64.18	-
1998	Hatchery Spat-on-Shell	0.78	-	1.25
1999	Wild Seed	30.13	21.72	-
2000	Wild Seed	77.79	31.47	-
2001	Wild Seed	52.35	49.48	-
2001	Hatchery Spat-on-Shell	-	-	4.58
2002	Dredged Shell	5	261.45	-
2002	Wild Seed	2.31	7.51	-
2002	Hatchery Spat-on-Shell	-	-	0.65
2003	Hatchery Spat-on-Shell	1.00	-	1.00
2003	Wild Seed	57.64	46.05	-
2004	Hatchery Spat-on-Shell	37.66	-	11.80
2005	Dredged Shell	6.79	72.22	-
2005	Hatchery Spat-on-Shell	15.36	-	20.54
2006	Hatchery Spat-on-Shell	117.19	-	98.23
2007	Hatchery Spat-on-Shell	25.44	-	29.06
2008 (S)	Hatchery Spat-on-Shell	12.58	-	35.24
2008	Hatchery Spat-on-Shell	22.60	-	22.74

Oyster Population Characteristics

The Fall Survey has sampled 7 to 13 oyster bars in this area since 1990 with an average of 10 oyster bars sampled annually. The average number of live oysters per bushel (market, small, and spat) decreased after sanctuary establishment (Table A.46-2; Figure A.46-3). This decrease may be due the cessation of wild seed plantings after 2008, which may have supplemented the population prior to that time. While the number of market-sized oysters was lower after 2010 than before, their abundance has increased annually since 2010 (Figure A.46-3).

Table A.46-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Upper Chester River Sanctuary in 2010. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 213	6 / 54
Number of Live Oysters per Bushel	105 ± 12	30 ± 5
Number of Live Small-Sized Oysters per Bushel	49 ± 9	8 ± 3
Number of Live Market-Sized Oysters per Bushel	53 ± 6	22 ± 3
Live Oyster Biomass (g Dry Weight per Bushel)	178 ± 16.1	64 ± 10.5
Mortality (%)	15.1 ± 2.8	8.7 ± 1.8

A patent tong survey was conducted in 2012 (Figures A.46-4). No such population survey was conducted prior to the establishment of the sanctuary. The average density of live oysters was 0.38 ± 0.10 oysters m^{-2} (mean ± standard error, n=123). The density of small-sized oysters was similar to the density of market-sized oysters (0.20 ± 0.06 and 0.19 ± 0.07 oysters m^{-2}, respectively). Eighty-five percent of the samples contained no live oysters or boxes. Oyster density increased with shell volume, with the exception of a single sample with a large volume of shell and no oysters (Figure A.46.5).

Paynter and colleagues[96,97,98] found densities on hatchery plantings ranging from 0 to 7 oysters m^{-2} three years after planting to 0 to 26 oysters m^{-2} four to five years after planting.

Oyster Size Structure

Oysters collected by the Fall Survey in this area at Old Field bar have been measured since 1990 (Figure A.46-6). Oysters were also measured during the patent tong population survey (Figure A.46-7). The Fall Survey size distributions show the population shifting toward larger oysters over time, with very few spat or small oysters. The patent tong survey, however, shows a more even size distribution than the fall survey.

[96] Paynter, K.T. 2007. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program: 1997-2006. 87 pp.
[97] Lane, H., A. Michaelis, and K.T. Paynter. 2011. Oyster Restoration Monitoring 2010. Report to the Oyster Recovery partnership. 87 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2010%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf
[98] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

Paynter and colleagues[99 100 101] found average oyster shell heights from 80 mm three years after planting to 119 mm four to five years after planting.

Biomass

Biomass of oysters from Old Field bar has been calculated from Fall Survey samples annually since 1990. Average biomass has decreased since the sanctuary establishment (Table A.46-2; Figure A.46-8). This decrease may be due to the cessation of hatchery and wild seed plantings after 2008. The peak biomass of 319 grams dry weight per bushel occurred in 1999.

Paynter et al. (2012)[102], found biomass on plantings to be 0.7-1.2 g m^{-2} 4 years after planting.

Recruitment (Spatfall)

Based on Fall Survey data, spatfall has been relatively low, ranging from 0 to 3 spat per bushel from 1990 to 2015 (Figure A.46-3). The highest spat counts were observed in 2004; however, these samples were taken on a hatchery planting on a harvest reserve. The second highest spat count occurred in 2006, also on a hatchery seed planting. Excluding the hatchery seed plantings, natural recruitment is very low in this area and averaged less than 1 spat per bushel prior to 2010 and 1 spat per bushel after 2010. The high spat count seen in 2010 and 2012 also occurred in the majority of the bars throughout Bay.

Mortality

Based on Fall Survey box counts, average mortality declined after the establishment of the sanctuary (Table A.46-2; Figure A.46-9). Mortality ranged from 4% to 45% from 1990 to 2015, with the highest mortality occurring from 2001 to 2003, high oyster disease years baywide.

Disease

Disease pressure from dermo has fluctuated greatly over the years, with prevalence ranging from 0 to 100% prevalence from 1990-2015 (Figure A.46-10). Dermo intensity ranged from 0 to 4 (0 to 7 scale, greater than5 being lethal) during the same time period. Paynter and colleagues[103 104]

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[99] Paynter, K.T. 2007. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program: 1997-2006. 87 pp.
[100] Lane, H., A. Michaelis, and K.T. Paynter. 2011. Oyster Restoration Monitoring 2010. Report to the Oyster Recovery partnership. 87 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2010%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf
[101] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf
[102] IBID
[103] Paynter, K.T. 2007. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program: 1997-2006. 87 pp.
[104] Lane, H., A. Michaelis, and K.T. Paynter. 2011. Oyster Restoration Monitoring 2010. Report to the Oyster Recovery partnership. 87 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2010%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

[105] found dermo prevalence from 0 to 83% from 2005-2011. MSX has not been detected in oysters collected by the Fall Survey since 1990.

[105] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

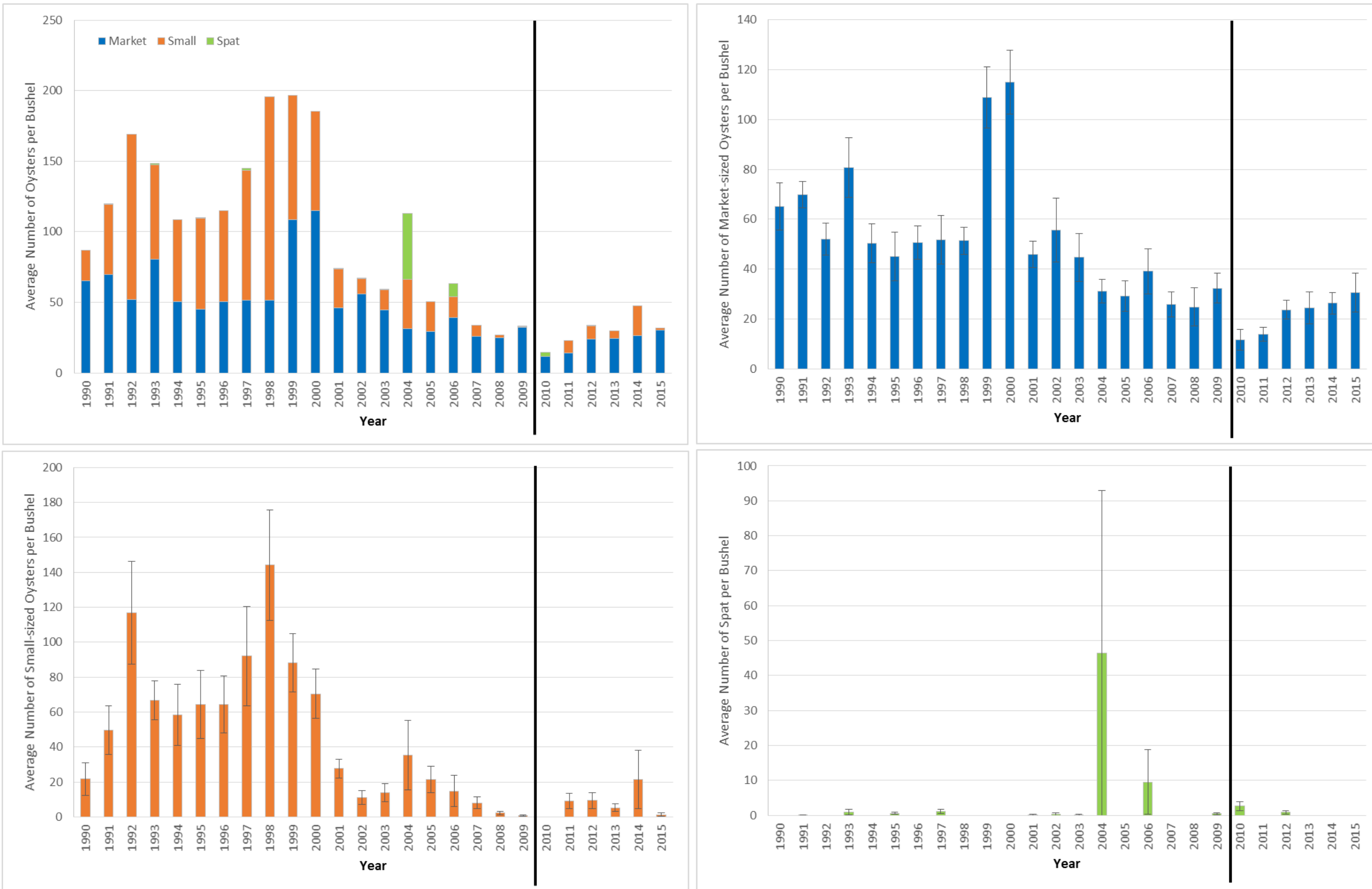


Figure A.46-3. Average number of live oysters per bushel of material by size class in the Upper Chester River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

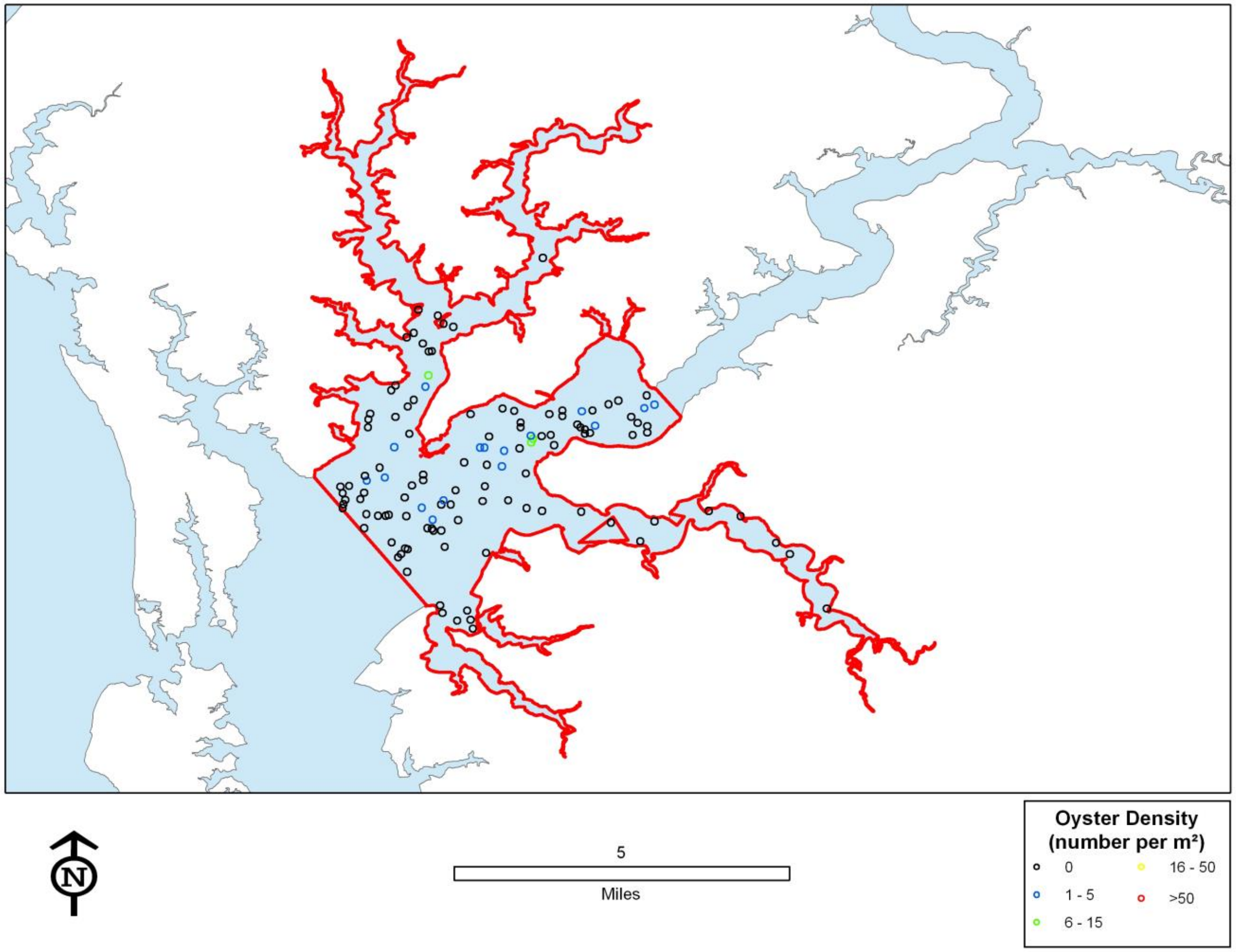


Figure A.46-4. Map of 2012 oyster density in the Upper Chester River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

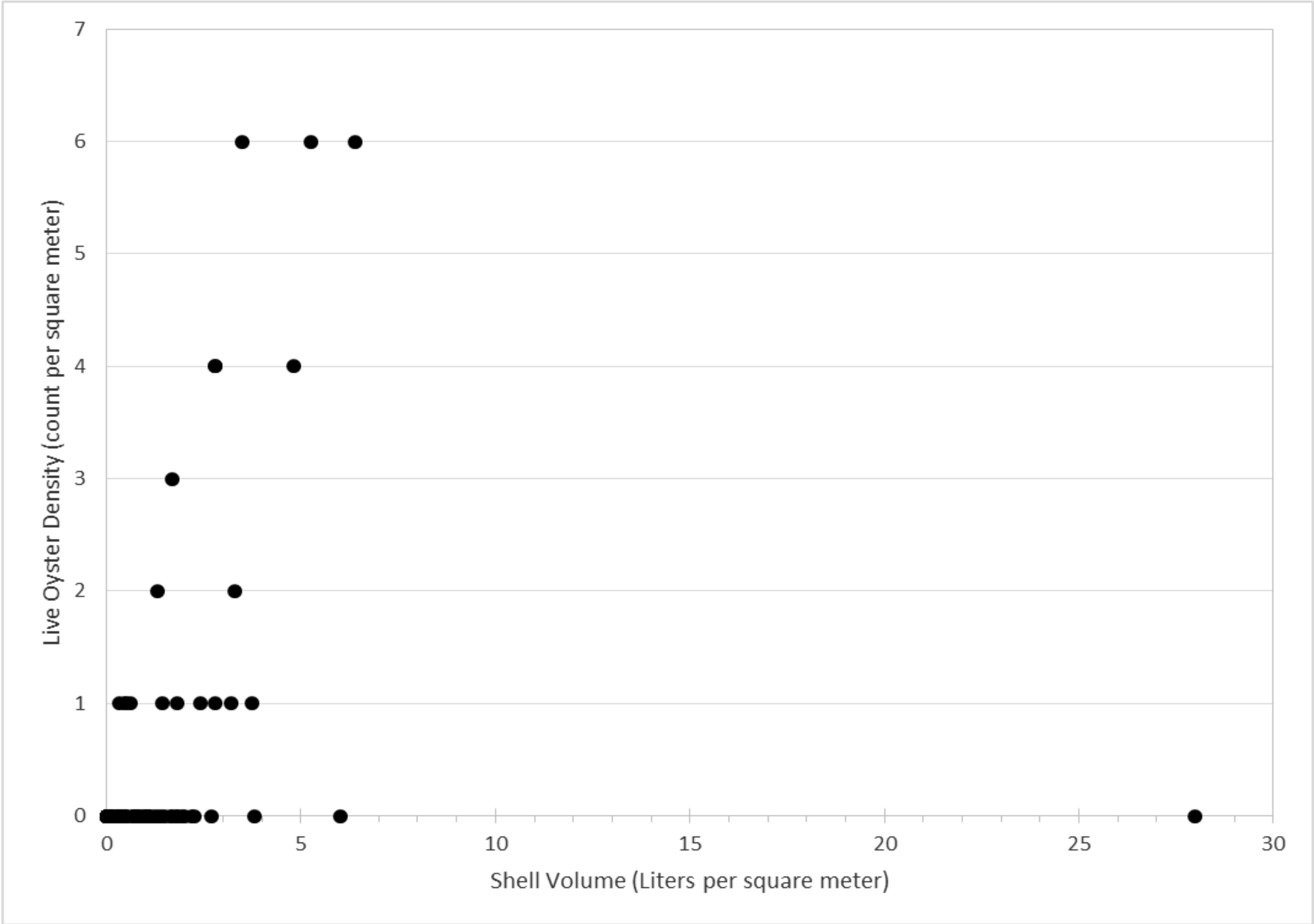


Figure A.46-5. 2012 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Upper Chester River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

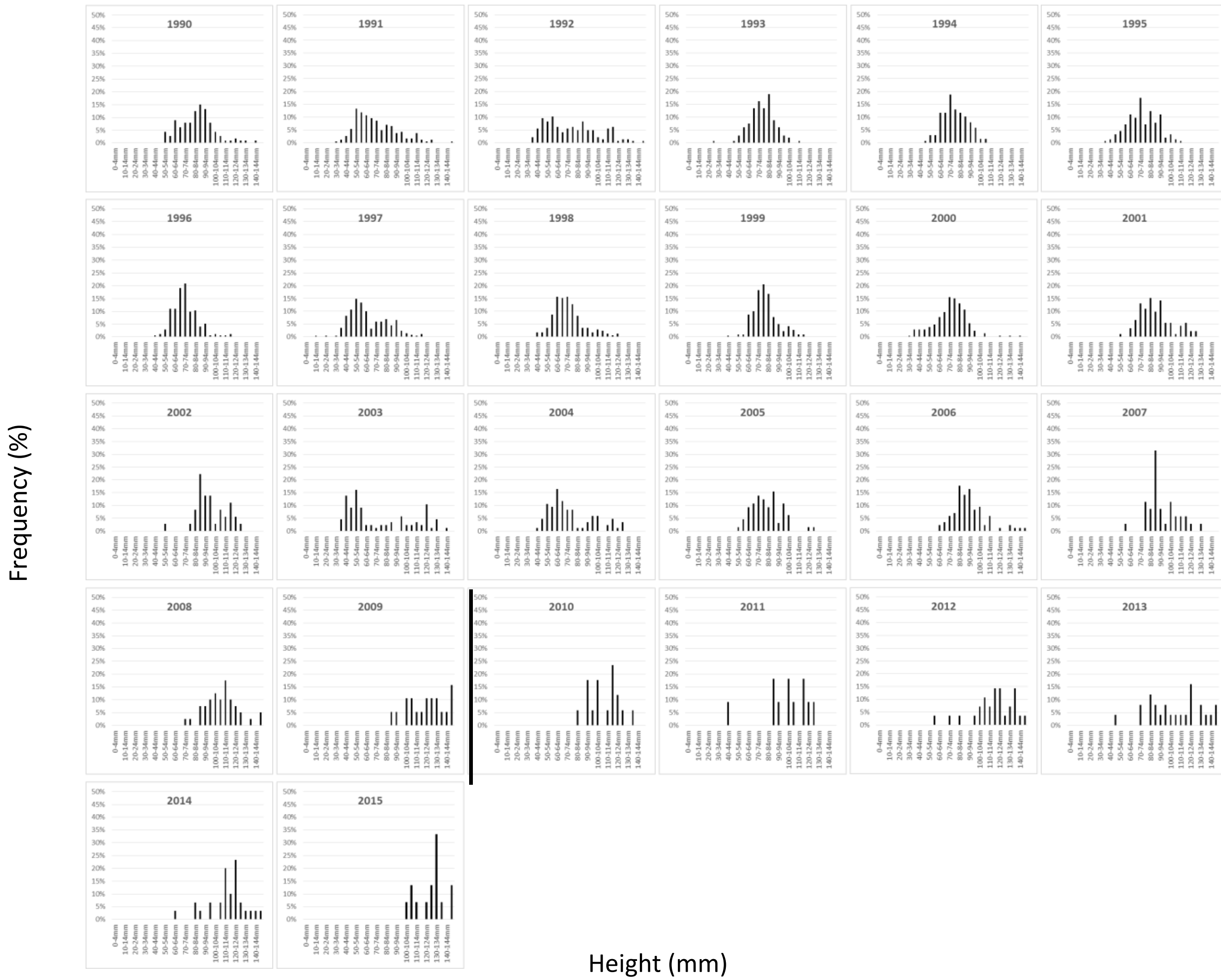


Figure A.46-6. Oyster shell height frequencies of live oysters per bushel of material from 1990 to 2015 in the Upper Chester River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Old Field bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

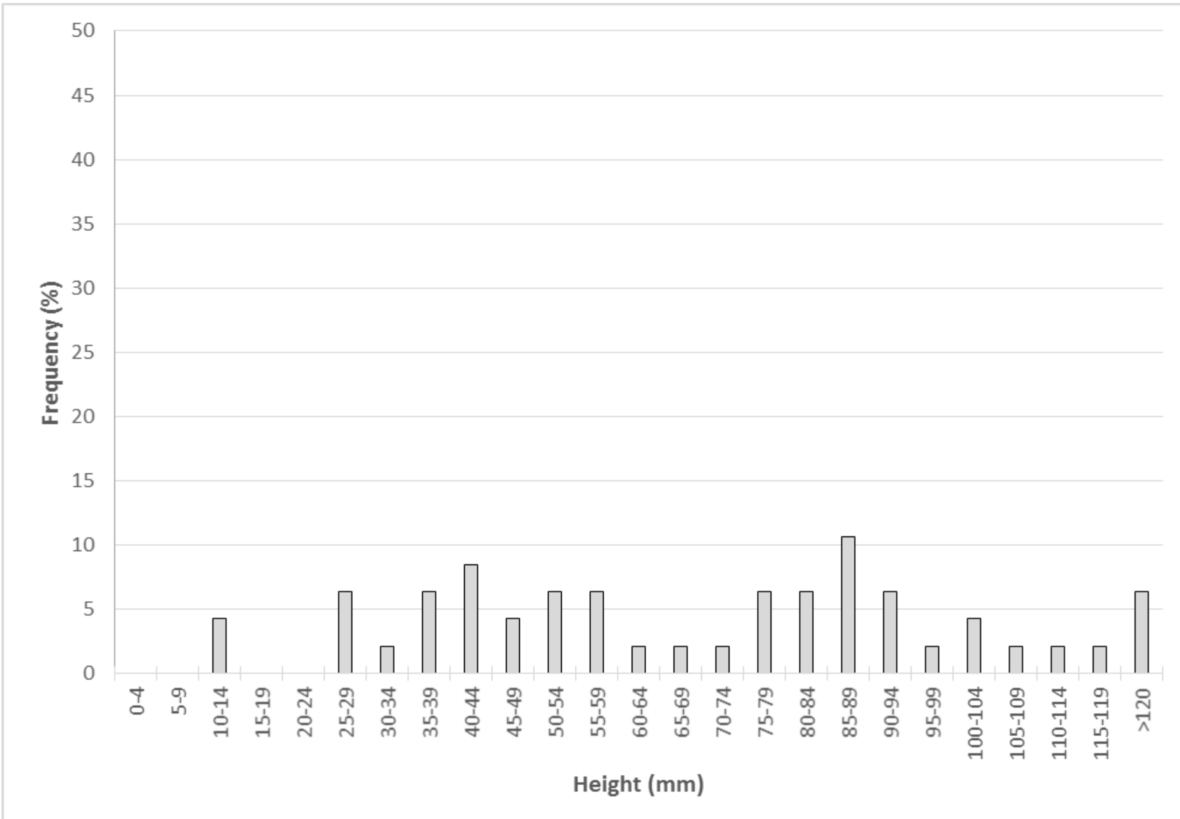


Figure A.46-7. Shell height frequencies of live oysters in the Upper Chester River Sanctuary in 2012. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

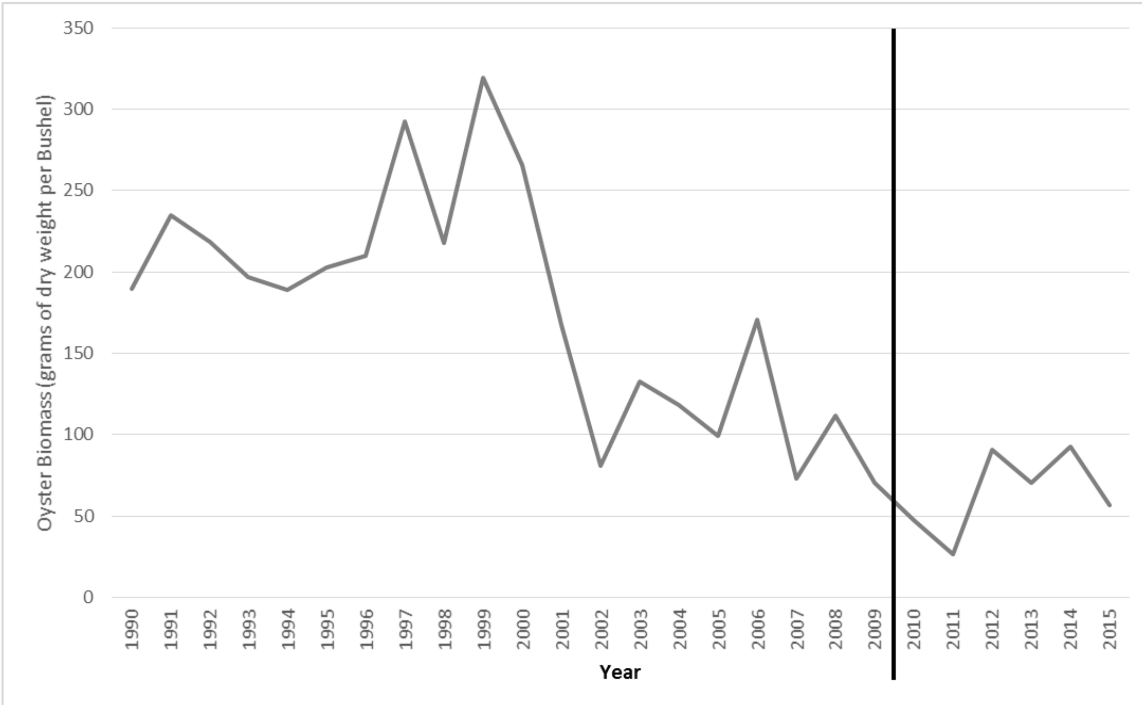


Figure A.46-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Upper Chester River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Old Field bar. Black line indicates the date the sanctuary was established.

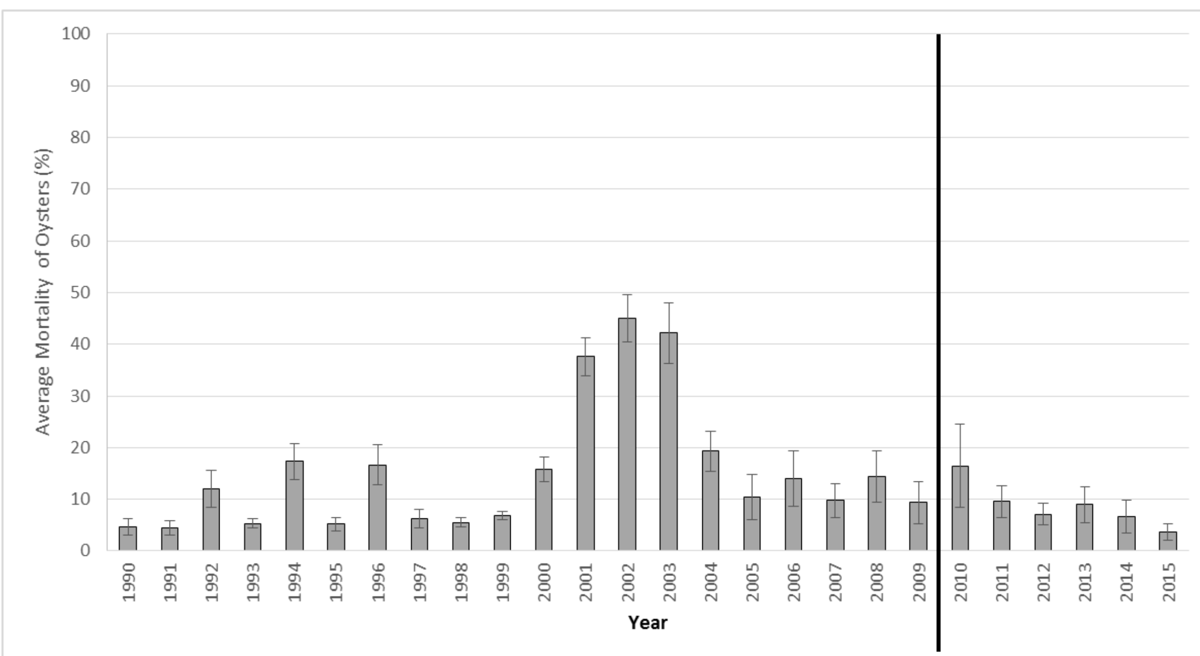


Figure A.46-9. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Upper Chester River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

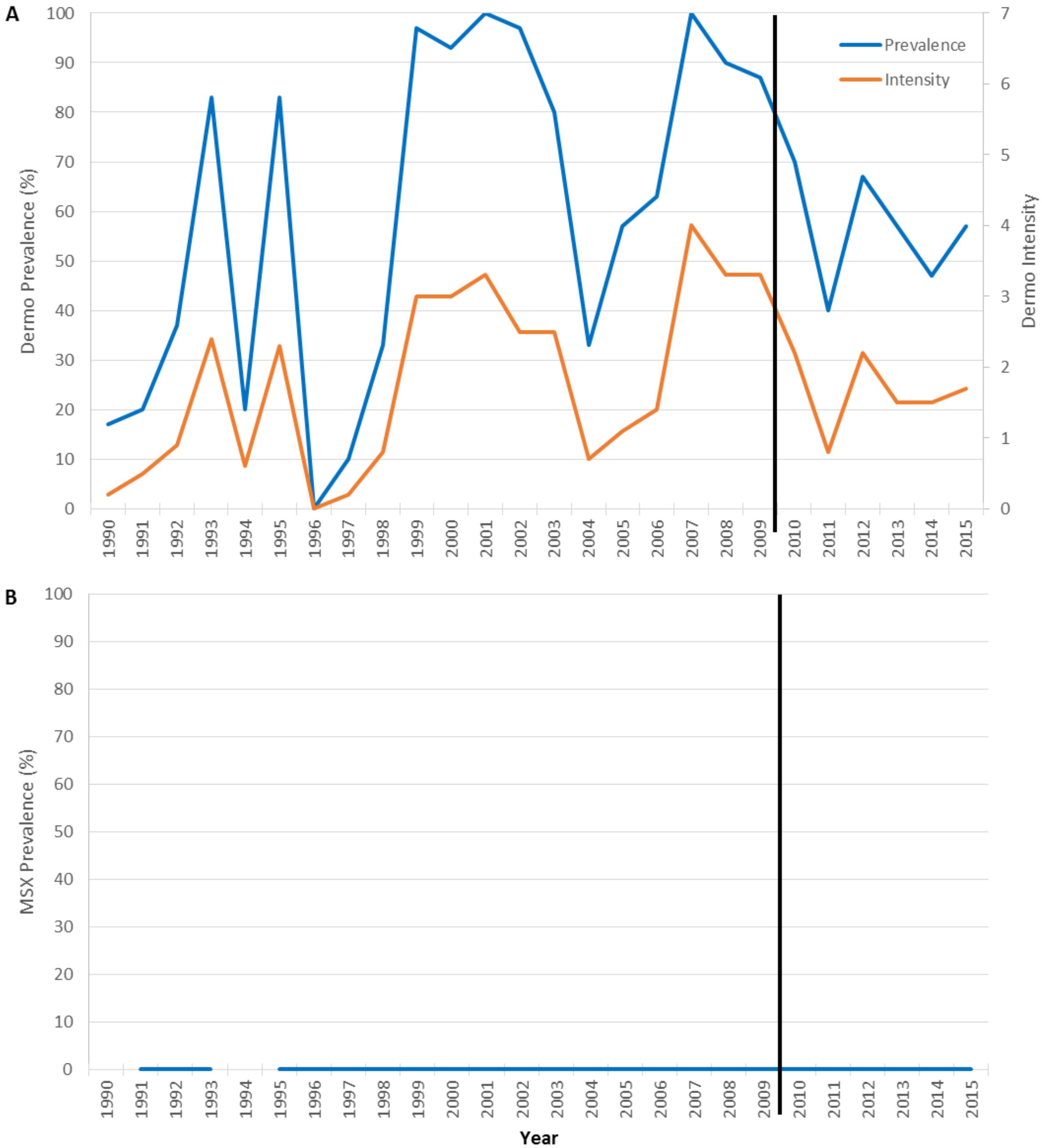


Figure A.46-10. Oyster disease prevalence and intensity from 1990 to 2015 in the Upper Chester River Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Old Field bar.

Harvest

The sanctuary straddles two NOAA Code areas (331 and 231), but does not encompass either NOAA code in its entirety. Because harvest from these NOAA Code areas may have come from places other than the areas that eventually became the sanctuary, seafood dealer reports from these areas cannot be used to assess harvest in this area. In the 2009-2010 harvest season, commercial waterman reported a harvest of 712 bushels from the area that is now the sanctuary.

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program recorded monthly water quality data at station XHH4916 (39.0818, -76.1392) located at the mouth of the Corsica River (Figure A.46-11). Water quality was generally favorable for oysters except for a period of low salinity in 2011.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

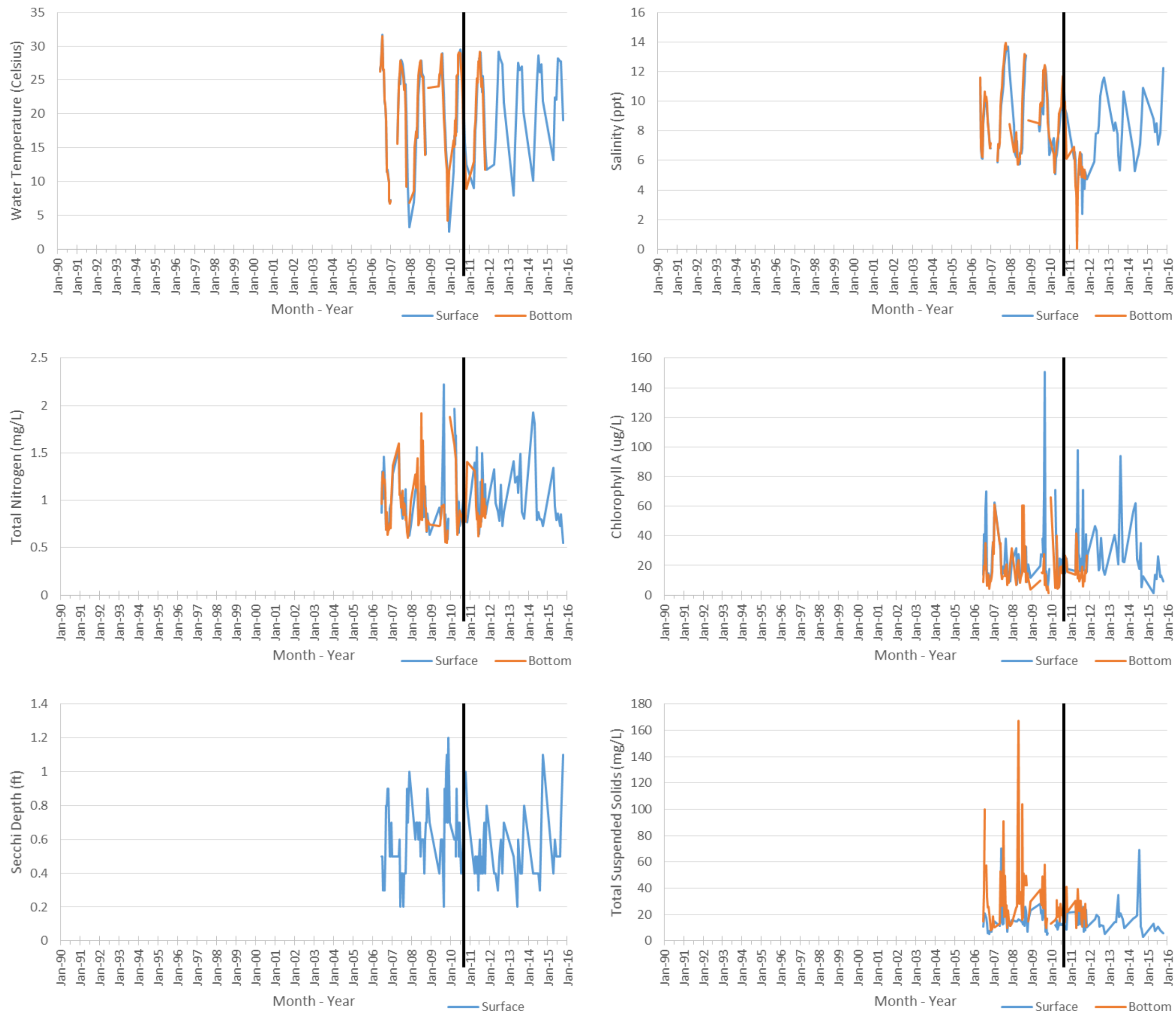


Figure A.46-11. Water quality data collected at Station XHH4916 in Upper Chester River in the Corrisa River. Black line denotes the date the sanctuary was established.

Section A.47: Upper Choptank River Sanctuary

The Upper Choptank River Sanctuary is located along the southern shore of the Choptank River, a low salinity (less than 12 ppt) region (Figure A.47-1). The sanctuary was created in 2010 and encompasses 5,898 acres of which 1,675 (28.4%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 9 historic oyster bars within the sanctuary[106]. States Bank Sanctuary (82 acres), established in 2005, is now encompassed by the Upper Choptank River Sanctuary. Due to high fecal coliform counts and the potential for bacterial contamination of shellfish, Maryland Department of the Environment has classified a portion of the sanctuary as restricted, meaning no shellfish harvest is permitted. In addition, some of the sanctuary is classified as conditionally closed, meaning that shellfish cannot be harvested for three days following a rainfall event of one inch or greater over 24 hours.

After the sanctuary was established, harvest was allowed on two areas within the sanctuary during the 2010-2011 oyster harvest season, which ended on 3/31/2011. These were the Black Buoy (140 acres) and Bolingbroke Sand (266 acres) harvest reserves. Harvest reserves were created in 2001 and closed for a time to provide ecological benefits until there was an increase in the number of harvestable oysters. After the 2010-2011 harvest season, these two reserves were eliminated and re-classified as part of the sanctuary.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.47-2). Of the 3,111 acres surveyed within the sanctuary, 1,248 acres (40%) were classified as oyster reef. Between 2007 and 2010, Maryland Geological Survey and NOAA Chesapeake Bay Office conducted a side scan sonar survey of the area. Of the 3305 acres surveyed, 651 acres (20%) were classified as oyster reef. Based on the area examined by both surveys, there appears to be a substantial loss of oyster habitat since the Bay Bottom Survey.

Restoration and Replenishment Activities

This area has received both replenishment and restoration planting activities since 1990 (Table A.47-1). The majority of the planting occurred on public fishery bottom prior to the establishment of the sanctuary. Hatchery spat-on-shell plantings occurred on the States Bank Sanctuary in 2005 and from 2007 to 2009 prior to the expansion of the sanctuary. In 2010, the Bolingbroke Sand harvest reserve was planted.

[106] See chart 21 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

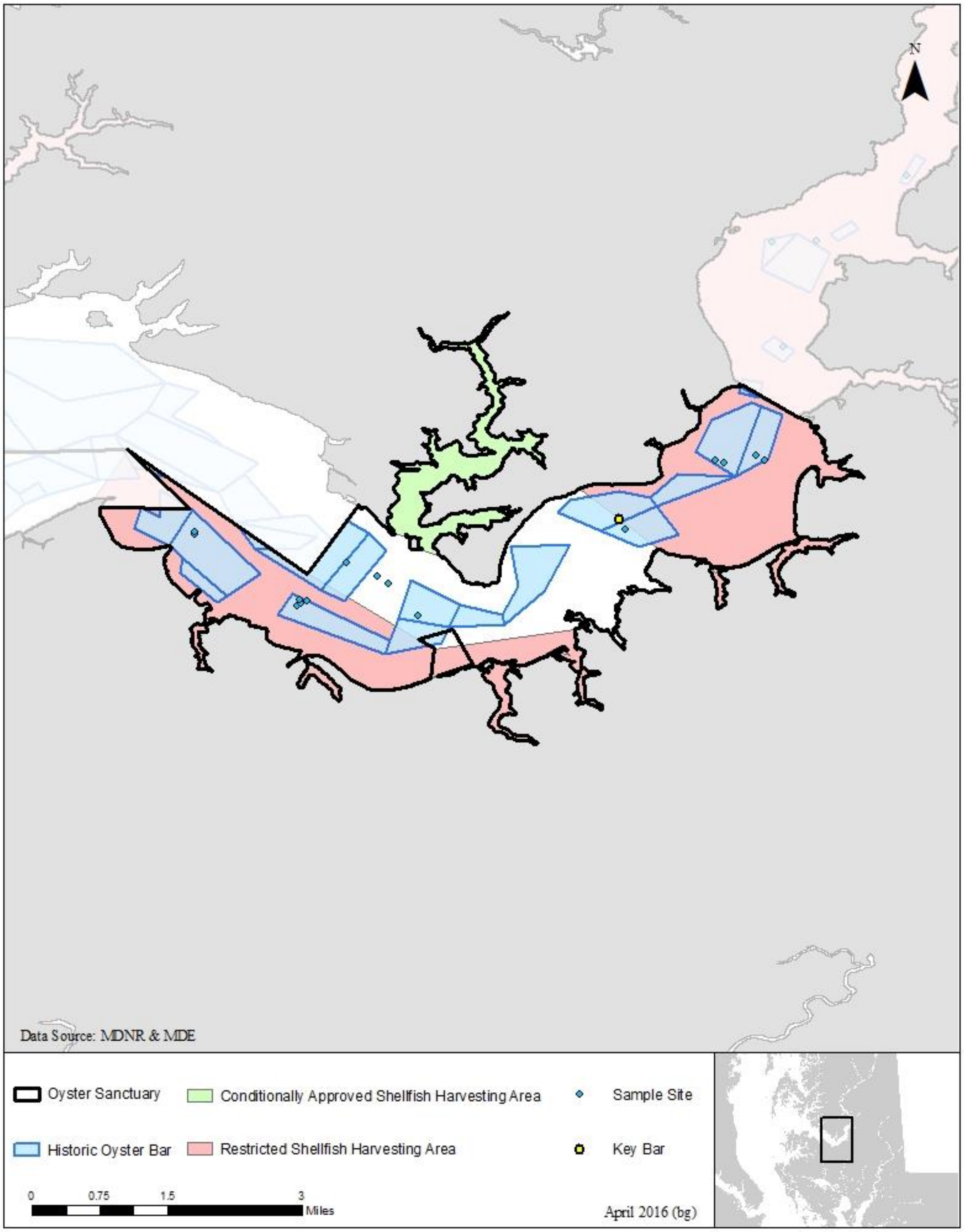
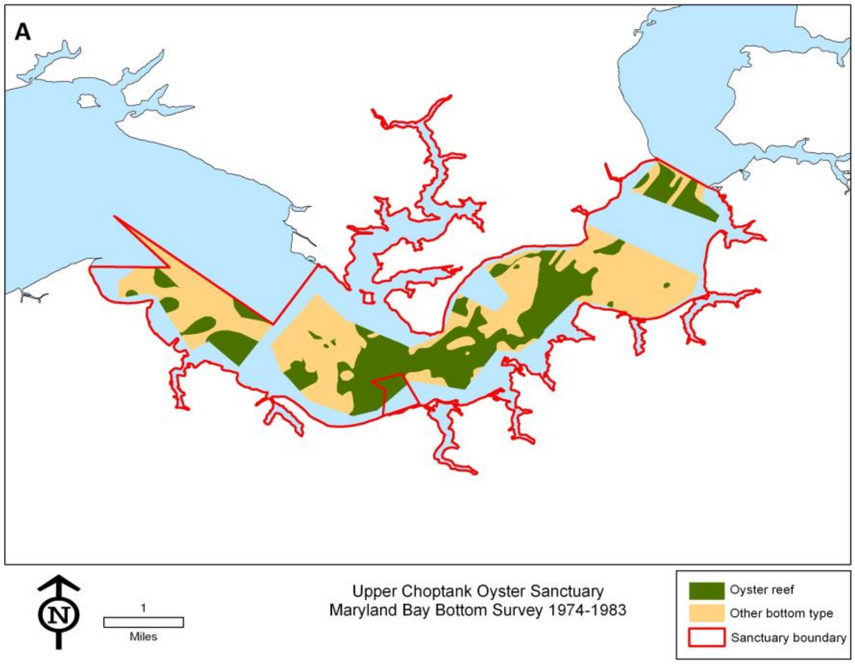


Figure A.47 -1. Upper Choptank River Sanctuary.



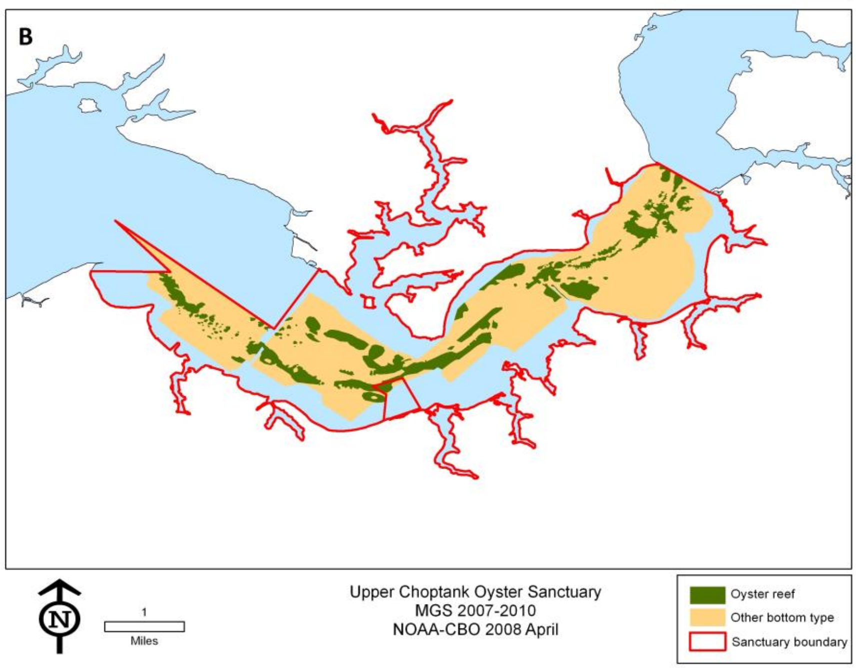


Figure A.47 -2. Upper Choptank River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from Maryland Geological Survey and NOAA Chesapeake Bay Office in 2007-2010. Tan and green colored areas depict areas examined during the surveys.

Table A.47-1. Replenishment and restoration planting activities occurring since 1990 in the area now established as the Upper Choptank River Sanctuary in 2010. S = planting activity occurring in a sanctuary. R = planting activity occurring in a harvest reserve. ND = No Data

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Wild Seed	27.78	16.51	-
1991	Wild Seed	120.64	62.92	-
1992	Fresh Shell	3.47	20.06	-
1992	Wild Seed	211.96	103.69	-
1993	Fresh Shell	1.09	7.95	-
1993	Wild Seed	71.35	11.34	-
1994	Wild Seed	37.73	20.31	-
1995	Wild Seed	22.72	16.45	-
1996	Wild Seed	8.15	19.37	-
1997	Wild Seed	39.09	45.10	-
1997	Hatchery Spat-on-Shell	ND	-	2.5
1997	Dredged Shell	1.62	41.55	-
1998	Dredged Shell	10.31	133.19	-
1998	Wild Seed	73.14	67.30	-
1998	Hatchery Spat-on-Shell	10	-	4.77
1999	Wild Seed	4.37	5.61	-
2000	Wild Seed	16.34	23.22	-
2001	Hatchery Spat-on-Shell	3.87	1.50	-
2001	Hatchery Spat-on-Shell	ND	-	18.92
2001	Wild Seed	9.51	11.28	-
2001	Dredged Shell	12	57.53	
2002	Hatchery Spat-on-Shell	20		14.93
2002	Dredged Shell	90.62	699	-
2003	Dredged Shell	111.25	800.75	-
2003	Hatchery Spat-on-Shell	139.25	-	79.90
2003	Gabion Stone	ND	149.03	
2004	Hatchery Spat-on-Shell	34.74	-	17.10
2004	Dredged Shell	43	381.98	-
2005 (S)	Hatchery Spat-on-Shell	13.56	-	11.37
2005	Hatchery Spat-on-Shell	35.10	-	34.15
2006	Hatchery Spat-on-Shell	97.27	-	91.20
2006	Wild Seed	10.62	ND	-
2007 (S)	Hatchery Spat-on-Shell	9.65	-	7.90
2007	Hatchery Spat-on-Shell	24.86	-	31.39
2008 (S)	Hatchery Spat-on-Shell	15.49	-	25.61
2008	Hatchery Spat-on-Shell	55.31	-	104.17

2009 (S)	Hatchery Spat-on-Shell	11.05	-	32.52
2009	Hatchery Spat-on-Shell	80.37	-	108.81
2010 (R)	Hatchery Spat-on-Shell	10.47	-	6.94
2010 (S)	Hatchery Spat-on-Shell	49.19	-	81.14
2011 (S)	Hatchery Spat-on-Shell	46.30	-	64.77

Oyster Population Characteristics

The Fall Survey has sampled five to eleven oyster bars in this area since 1990 with an average of eight oyster bars sampled annually. The average number of live oysters per bushel (market, small, and spat) decreased slightly after sanctuary creation (Table A.47-2; Figure A.47-3). The slightly higher oyster counts prior to the establishment of the sanctuary may be due to the many wild and hatchery seed plantings that occurred during that time period. The average number of small-sized oysters per bushel has decreased since sanctuary establishment, whereas the average number of market-sized oysters per bushel increased steadily from 2010 to 2014.

Table A.47-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Upper Choptank Sanctuary in 2010. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 165	6 / 53
Number of Live Oysters per Bushel	89 ± 11	74 ± 6
Number of Live Small-Sized Oysters per Bushel	45 ± 8	17 ± 3
Number of Live Market-Sized Oysters per Bushel	39 ± 3	55 ± 6
Live Oyster Biomass (g Dry Weight per Bushel)	134 ± 18.5	181 ± 20.9
Mortality (%)	17.6 ± 3.2	6.1 ± 1.0

A patent tong population survey was conducted in 2015 (Figures A.247-4). The average density of live oysters was 6.91 ± 2.12 oysters m^{-2} (mean ± standard error, n=143). The density of small-sized oysters was less than the density of market-sized oysters (1.08 ± 0.62 and 5.83 ± 1.91 oysters m^{-2}, respectively). Fifty-two percent of the samples contained no live oysters or boxes. There was no clear relationship between oyster density and shell volume, suggesting that something other than surface shell is controlling oyster density (Figure A.47-5).

Paynter et al. noted densities as high as 186 oysters m^{-2} one year after planting hatchery spat-on-shell and as low as 0 oysters m^{-2} six years after planting.[107,108,109,110,111]

[107] Paynter, K.T. 2007. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program: 1997-2006. 87 pp.
[108] Paynter, K.T. 2011. 2008 Sanctuary Assessment. Report to the U.S. Army Corps of Engineers, Baltimore District. 67 pp. http://www.nab.usace.army.mil/Portals/63/docs/Environmental/Oysters/2008SanctuaryAssessment.pdf
[109] Lane, H., A. Michaelis, and K.T. Paynter. 2011. Oyster Restoration Monitoring 2010. Report to the Oyster Recovery partnership. 87 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2010%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

Oyster Size Structure

Oysters collected by the Fall Survey in this area at Oyster Shell Point bar have been measured since 1990 (Figure A.47-6). Oysters collected during the 2015 patent tong population survey were also measured (Figure A.47-7). In recent years the size distribution has been shifting toward larger oysters, with few spat and small oysters.

Monitoring hatchery seed plantings Paynter et al. found average shell heights to range from 41 mm two years after planting to 110 mm five years after planting.

Biomass

Since 1990 biomass of oysters from Oyster Shell Point bar has been calculated based on Fall Survey samples (Table A.47-2; Figure A.47-8). Average biomass shows an increasing trend since 2005, after the impacts of high disease-caused mortality in 2002 and 2003. The average annual biomass from 2010 to 2015 is greater than the biomass prior to the area's becoming a sanctuary. This increase is both due to the increasing number and size of large oysters.

Recruitment (Spatfall)

Based on Fall Survey data, high spat counts were observed before the establishment of the sanctuary, and lower spat counts after sanctuary creation (Figure A.47-3). Most of the high spat counts were from samples taken on hatchery seed plantings. Excluding these samples, spatfall has ranged from 0 to 29 spat per bushel (Figure A.47-9). Since 2012 spatfall has been consistent but low.

Mortality

Based on Fall Survey box counts, the average mortality after sanctuary establishment was lower than the average mortality before sanctuary creation (Table A.47-2; Figure A.47-10). Mortality ranged from 0% to 54%, with the highest mortality seen in 2003 during the bay-wide disease epizootic.

Disease

[110] Paynter, K., H. Lane, and A. Michaelis. 2012. Paynter Lab Annual Summary 2011. Report to the Oyster Recovery Partnership. 129 pp. http://www.life.umd.edu/biology/paynterlab/labpub/Paynter%20Lab%20ORP%20Annual%20Report%202011_Revised3-12-13.pdf

[111] Paynter, K., H. Lane, and A. Michaelis. 2013. Paynter Lab Annual Monitoring and Research Summary 2012. Report to the Oyster Recovery Partnership. 110 pp. http://www.life.umd.edu/biology/paynterlab/labpub/2012%20Paynter%20Lab%20Annual%20Report%20to%20the%20ORP.pdf

From 1990 to 2015, dermo prevalence has ranged from 0% to 100% (Figure A.47-11) and has been greater than 80% in only 5 of the 26 years since oysters have been analyzed for disease. Dermo intensity ranged from 0 to 3.9, with highest dermo intensities in 1992 and 2001. Intensity did not reach lethal levels (values greater than5 on a 0 to7 scale). MSX was observed only in 1992 and 2002.

Paynter et al. found dermo prevalence on hatchery plantings ranging from 0% to 100%.

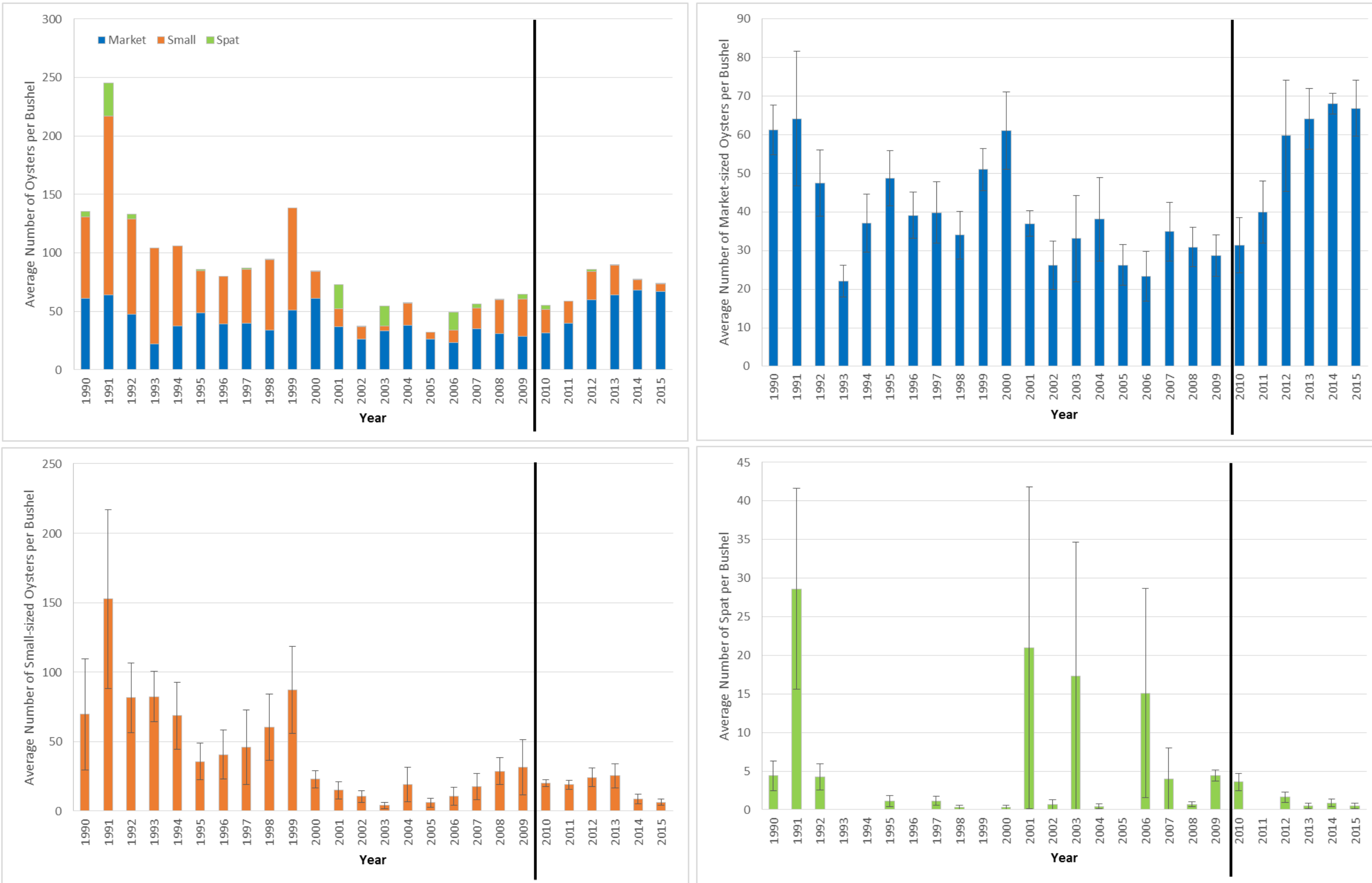


Figure A.47-3. Average number of live oysters per bushel of material by size class in the in Upper Choptank River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

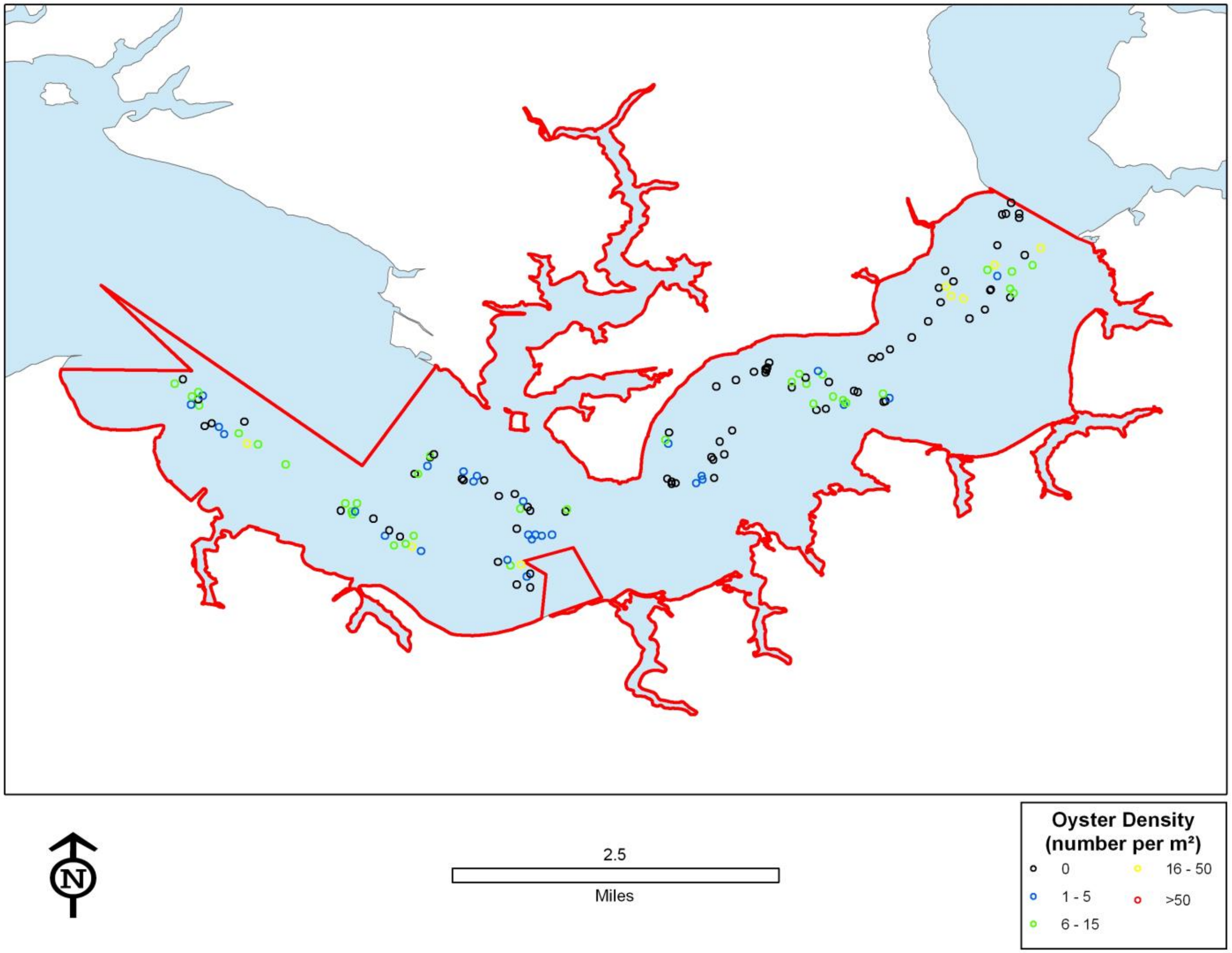


Figure A.47-4. Map of 2015 oyster density in the in Upper Choptank River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

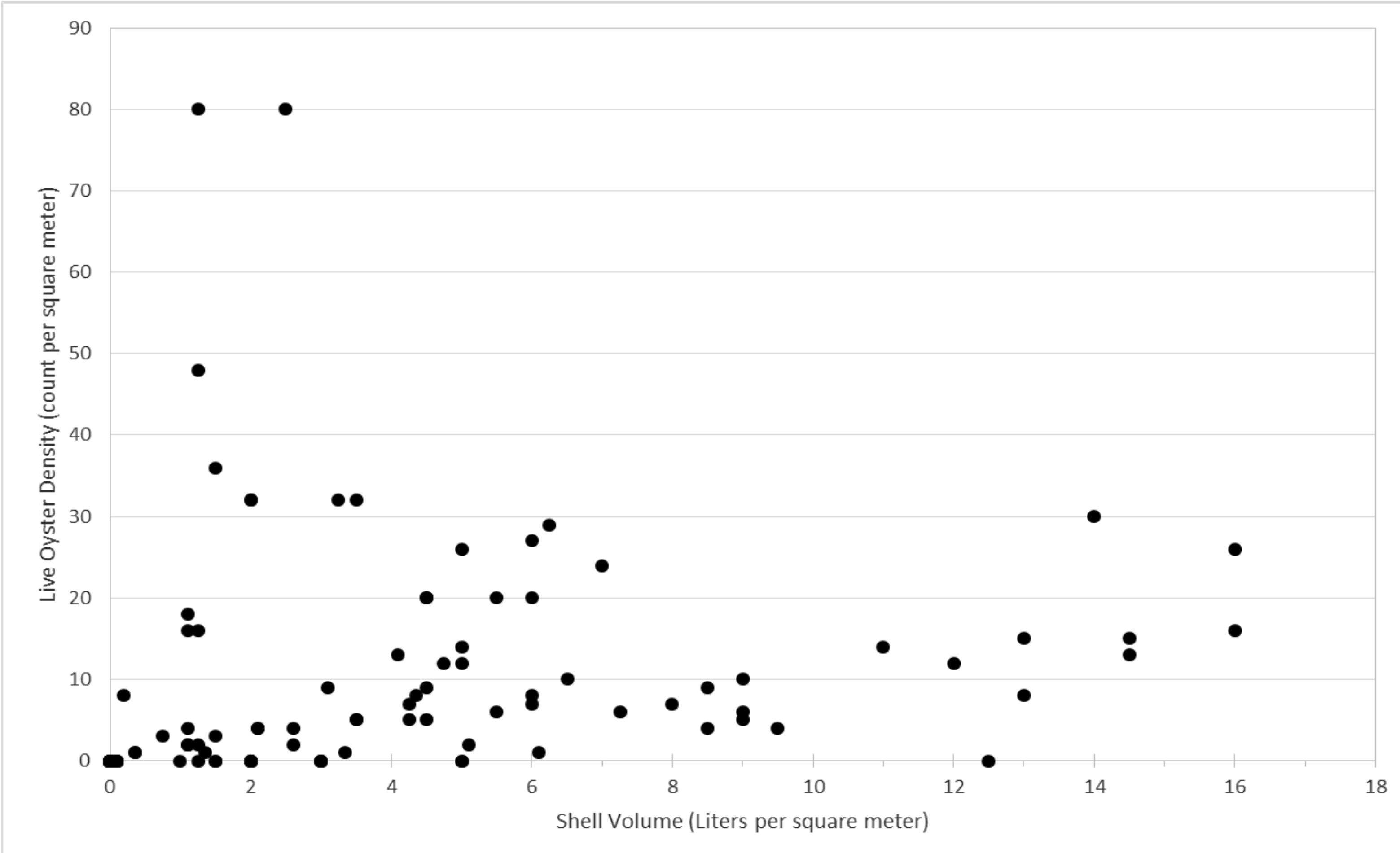


Figure A.47-5. 2015 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Upper Choptank River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

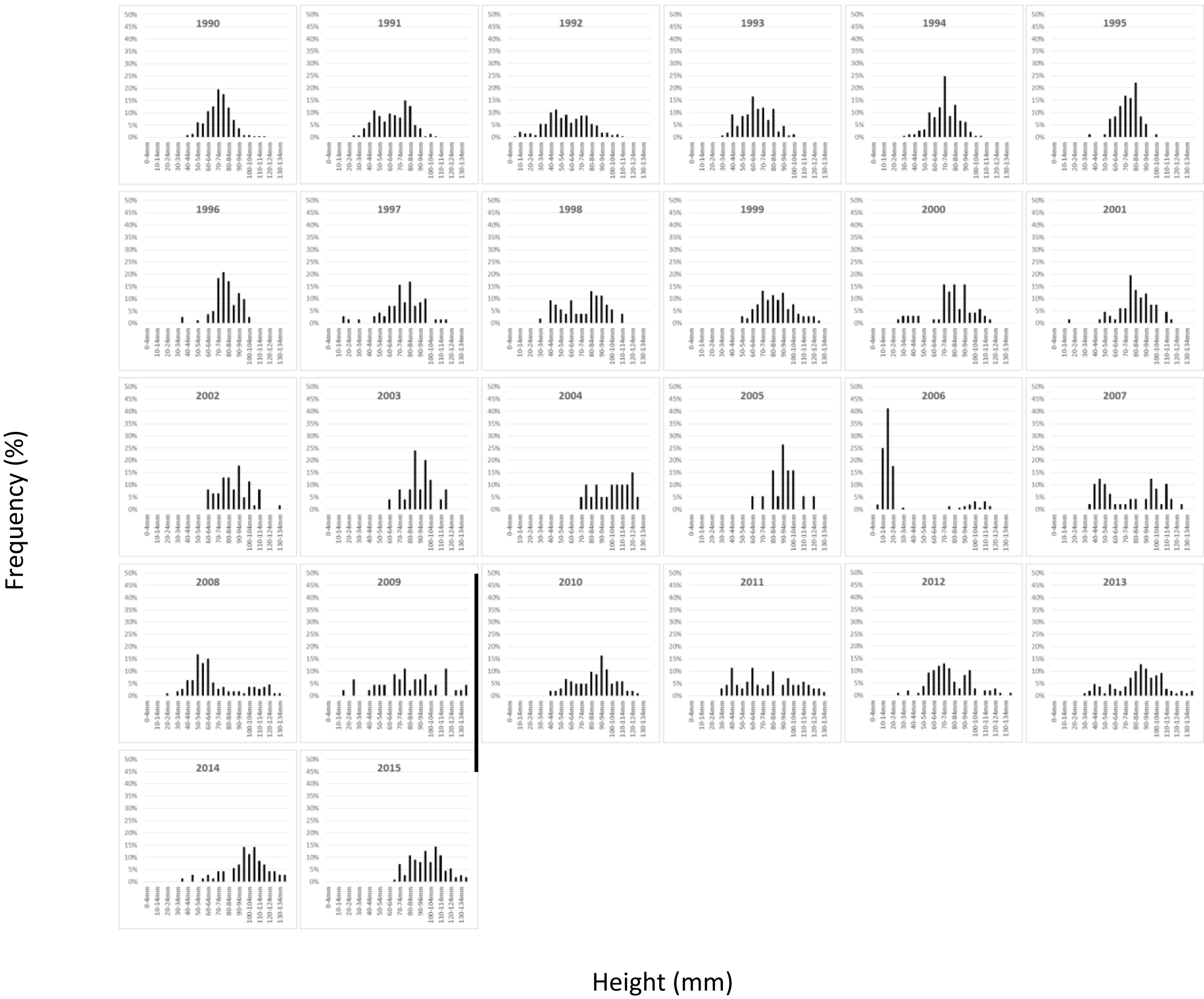


Figure A.47-6. Shell height frequencies of live oysters in the Upper Choptank River Sanctuary from 1990 to 2015. Data from Maryland's Annual Fall Oyster Dredge Survey on Oyster Shell Point bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

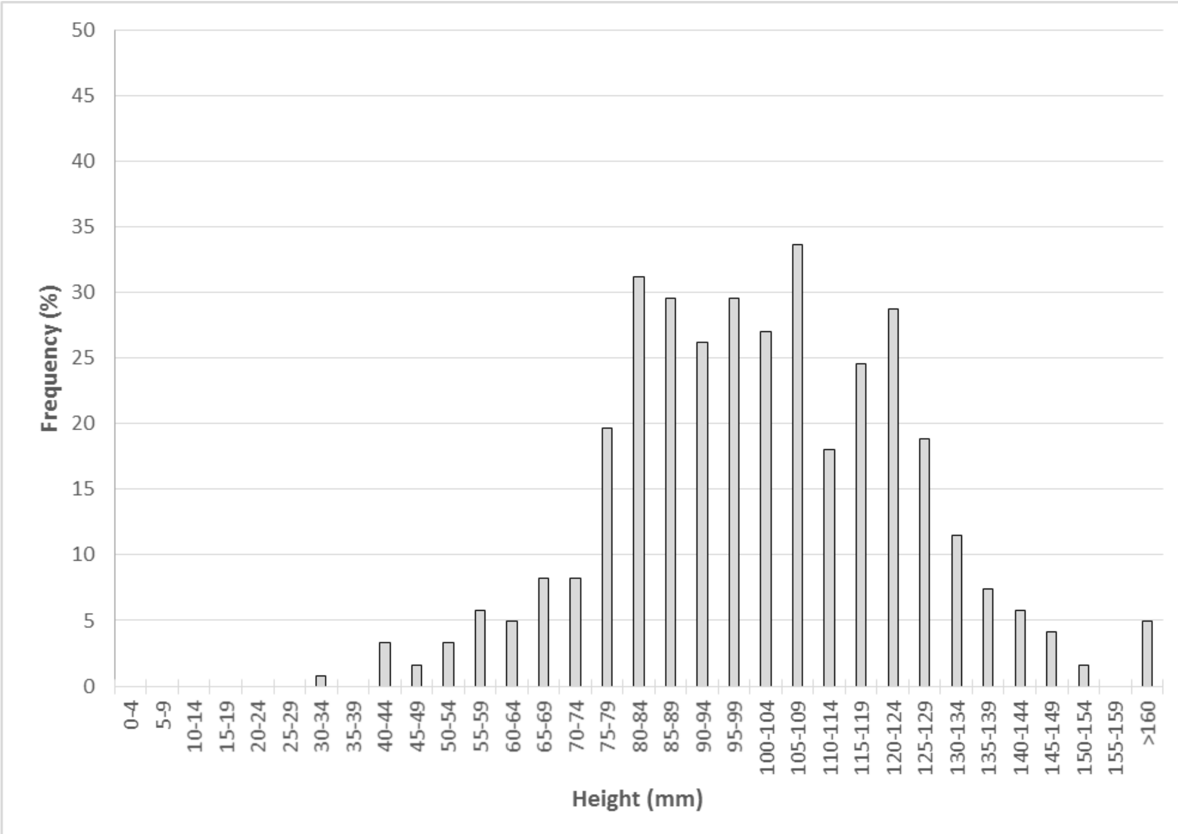


Figure A.47-7. Shell height frequencies of live oysters in the Upper Choptank River Sanctuary in 2015. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

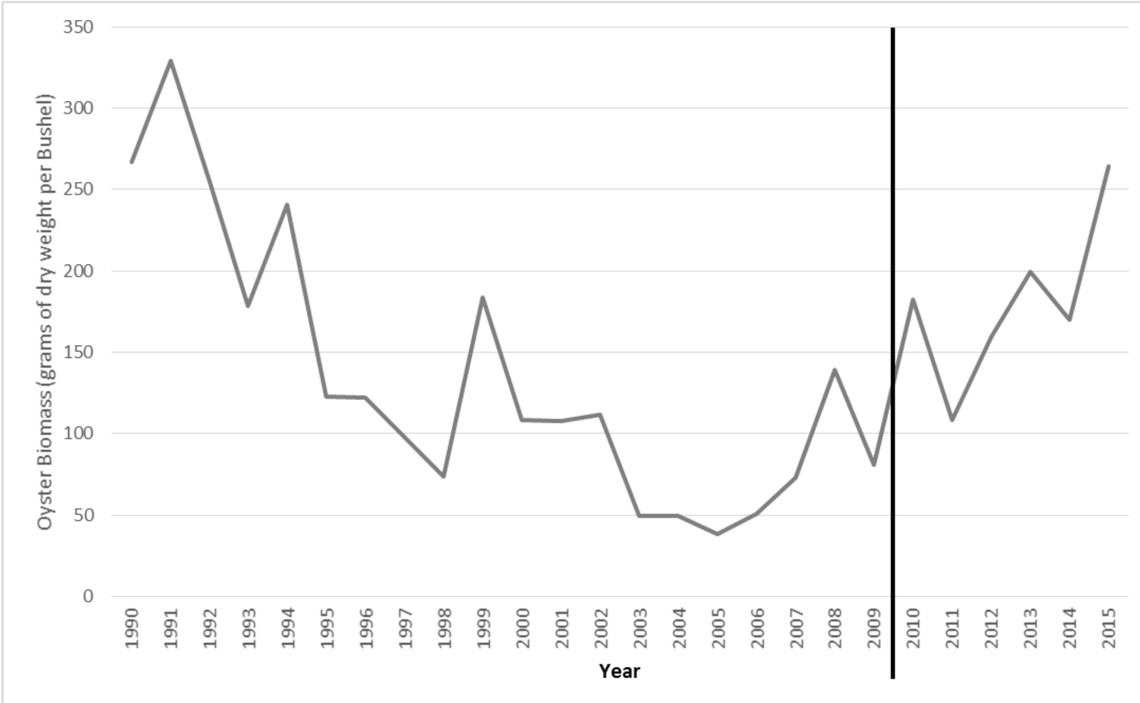


Figure A.47-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Upper Choptank River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Oyster Shell Point bar. Black line indicates the date the sanctuary was established.

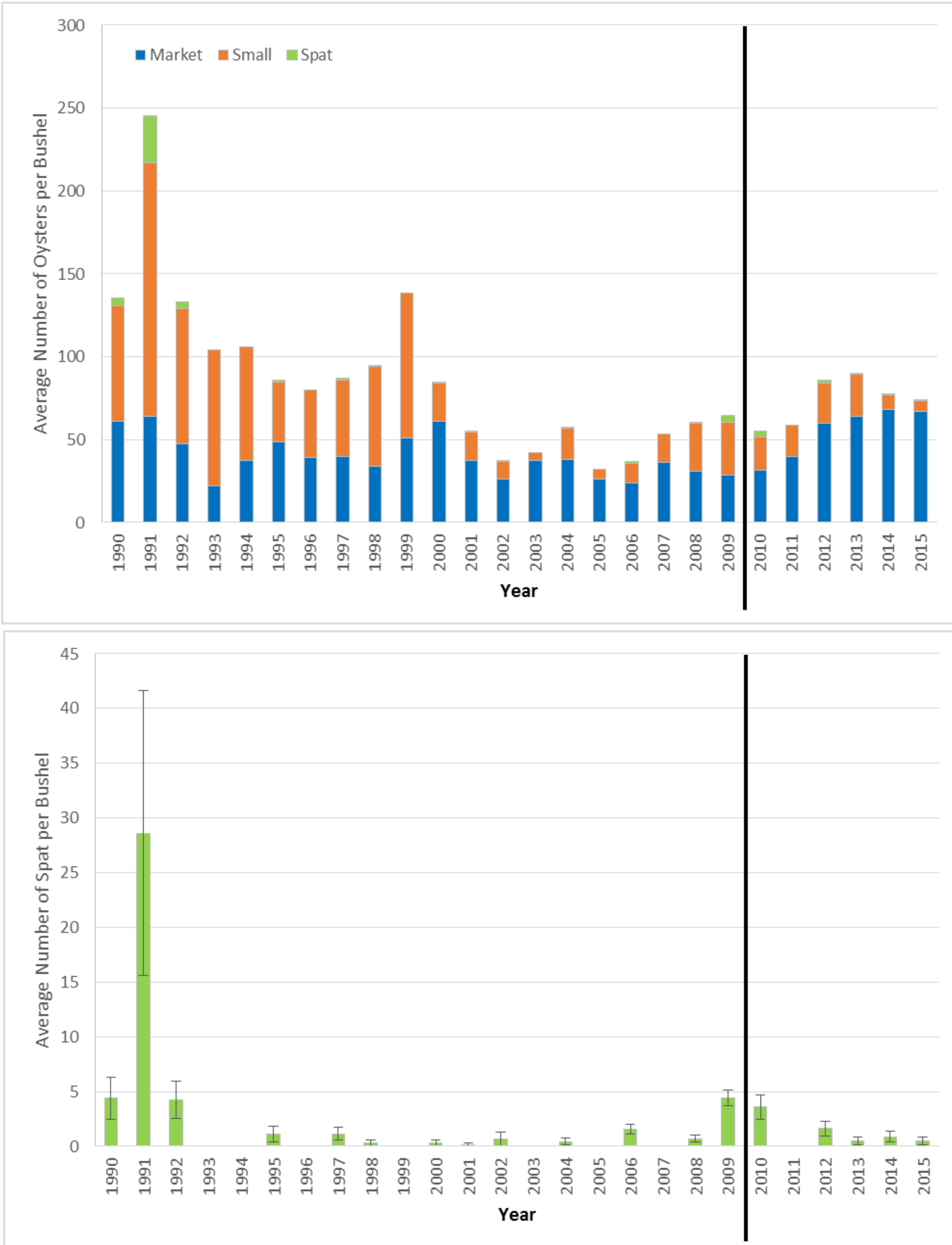


Figure A.47-9. Average number of live oysters per bushel of material by size class in the in Upper Choptank River Sanctuary excluding samples taken on the hatchery seed plantings. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

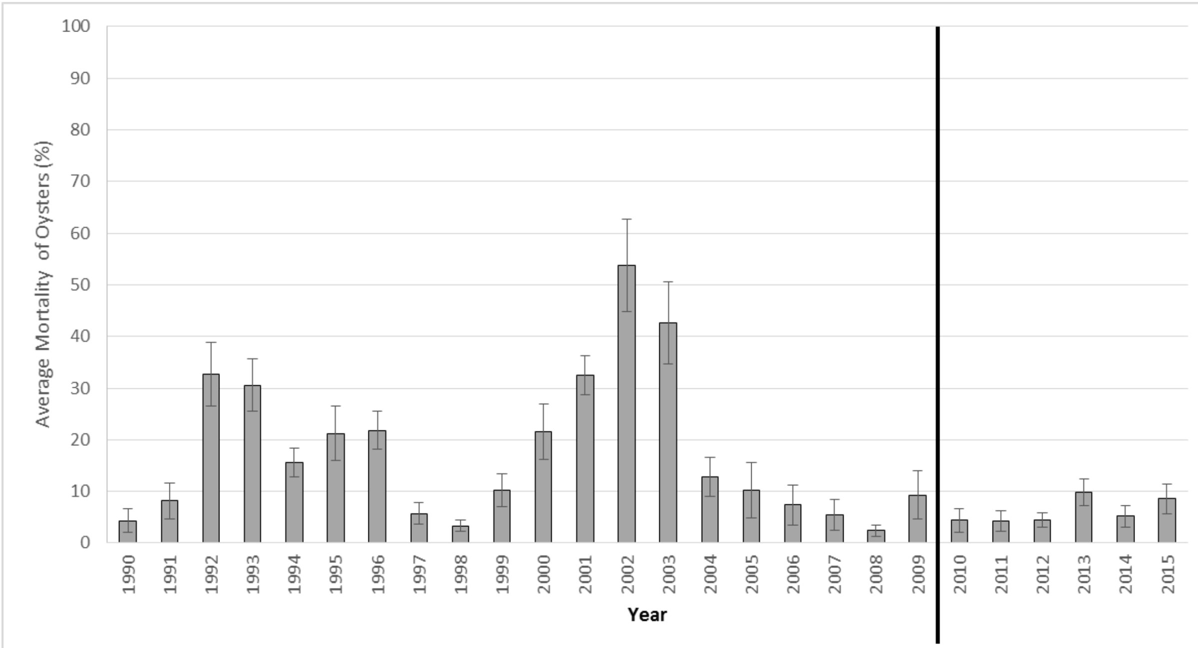


Figure A.47-10. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Upper Choptank River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

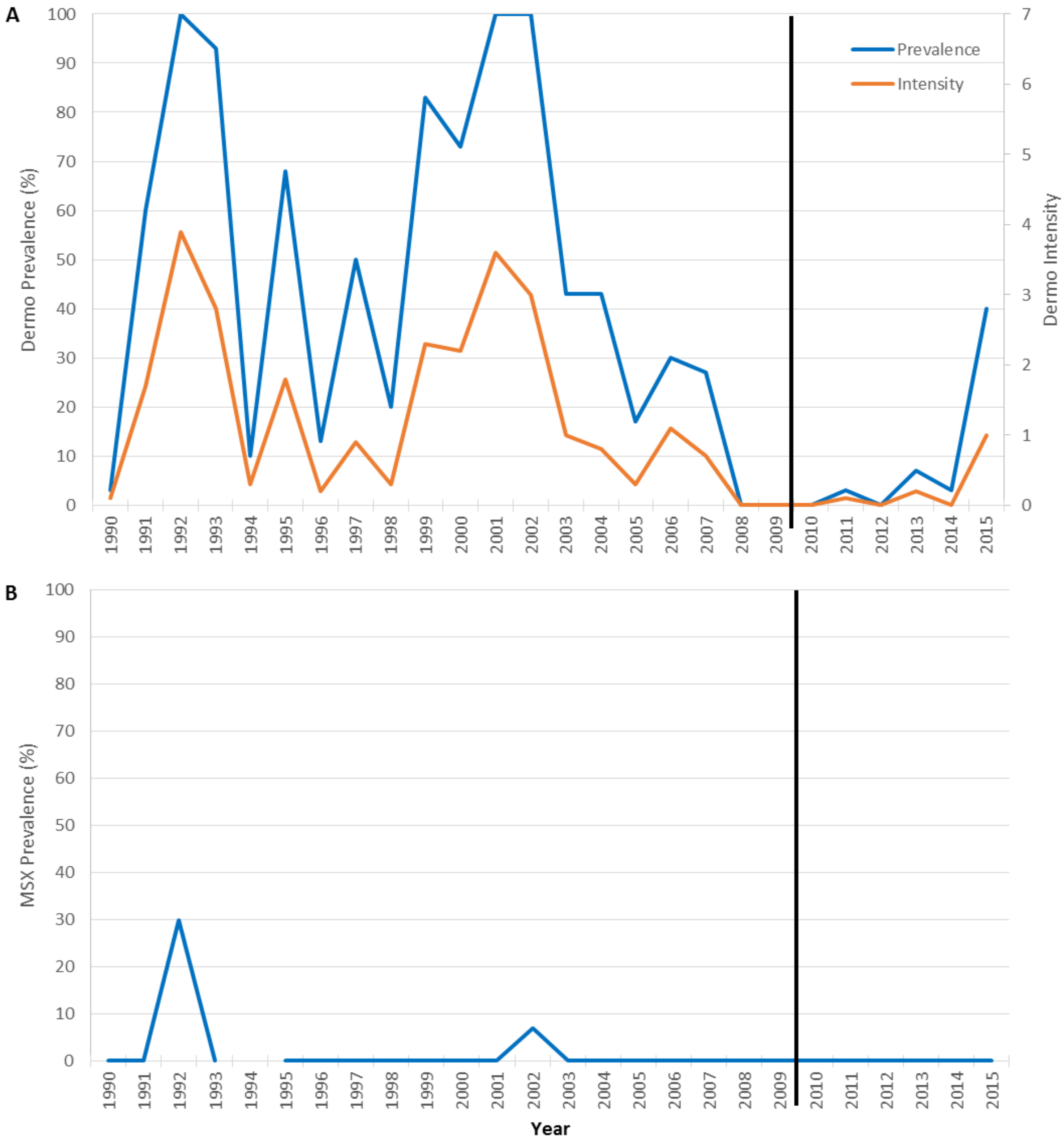


Figure A.47-11. Oyster disease prevalence and intensity from 1990 to 2015 in the Upper Choptank River Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Oyster Shell Point bar.

Harvest

The sanctuary encompasses 42% of the 14,142 acres in NOAA Code 337. Because harvest from NOAA code 337 is likely to have come from places outside the area that became the sanctuary, seafood dealer reports for this NOAA code cannot be used to assess harvest in this area. In the 2009-2010 harvest season, commercial waterman reported a harvest of 19.5 bushels on oyster bars now located within the sanctuary.

Environmental Conditions and Ecosystem Services

Maryland's Eyes on the Bay Program monitors monthly water quality at station ET5.2 (38.5807, -76.0587) in this area (Figure A.47-12). Water quality was generally suitable for oysters except for occasional periods of low salinity.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

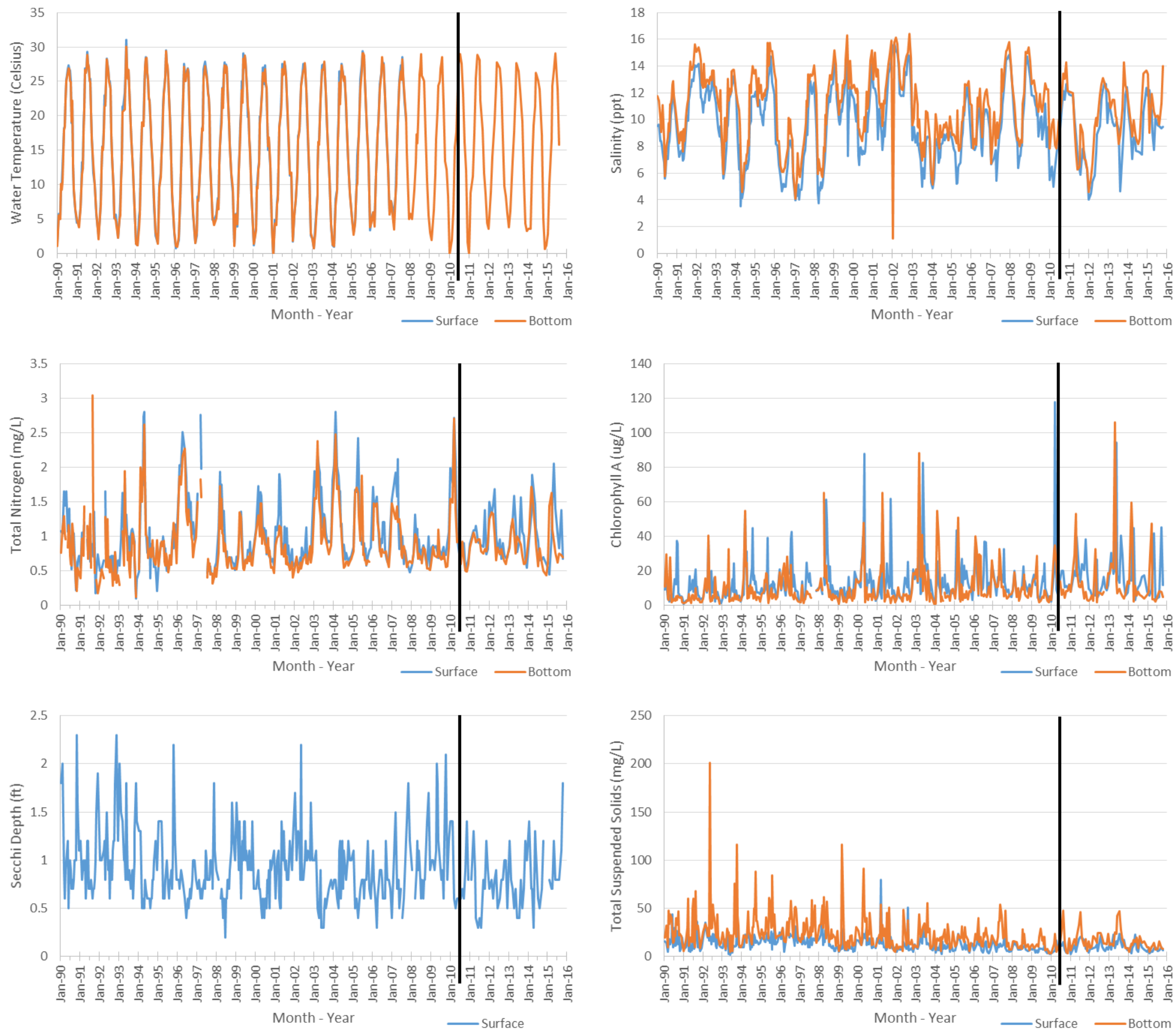


Figure A.47-12. Water quality data collected at Station ET5.2 in Upper Choptank River. Black line denotes the date the sanctuary was established.

Section A.48: Upper Patuxent River Sanctuary

The Upper Patuxent River Sanctuary is located in the Patuxent River, a low salinity (less than 12 ppt) region (Figure A.48-1). Originally there was a small sanctuary in the area (Trent Hall, 9 acres, created 2003). The sanctuary was expanded in 2010 to encompass 14,461 acres of which 2,228 (15%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 29 historic oyster bars within the sanctuary[112]. Due to high fecal coliform counts and the potential for bacterial contamination of shellfish, Maryland Department of the Environment has classified a portion of the sanctuary as restricted, meaning no shellfish harvest is permitted. In addition, some of the sanctuary is classified as conditionally closed, meaning that shellfish cannot be harvested for three days following a rainfall event of one inch or greater over 24 hours.

After the sanctuary was established, harvest was allowed in two areas within the sanctuary during the 2010-2011 oyster harvest season. These were the Broad Neck (224 acres, established 2001) and Holland Point (33 acres, established 2008) harvest reserves. Harvest reserves were closed for a time to provide ecological benefits until the the number of harvestable oysters increased. After the 2010-2011 harvest season, these two reserves were eliminated and re-classified as part of the sanctuary.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.48-2). Of the 6,560 acres were surveyed within the sanctuary, 3,654 acres (56%) were classified as oyster reef habitat. In 2011, Maryland Geological Survey conducted a bottom side scan sonar survey of the area. Of the 5,840 acres surveyed, 581 acres (10%) were classified as oyster reef habitat (10%), suggesting a decline in oyster habitat since the Bay Bottom Survey.

Restoration and Replenishment Activities

This area has received both replenishment and restoration efforts since 1990 (Table A.48-1). Two restoration plantings occurred in 2009 and 2010 on the Trent Hall Sanctuary, which was encompassed by the larger Upper Patuxent River Sanctuary in 2010. The remaining planting activities occurred on public fishery areas prior to the area’s becoming a sanctuary in 2010. The U.S. Army Corps of Engineers and Chesapeake Bay Foundation were involved in the two plantings on this sanctuary.

[112] See chart 22 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

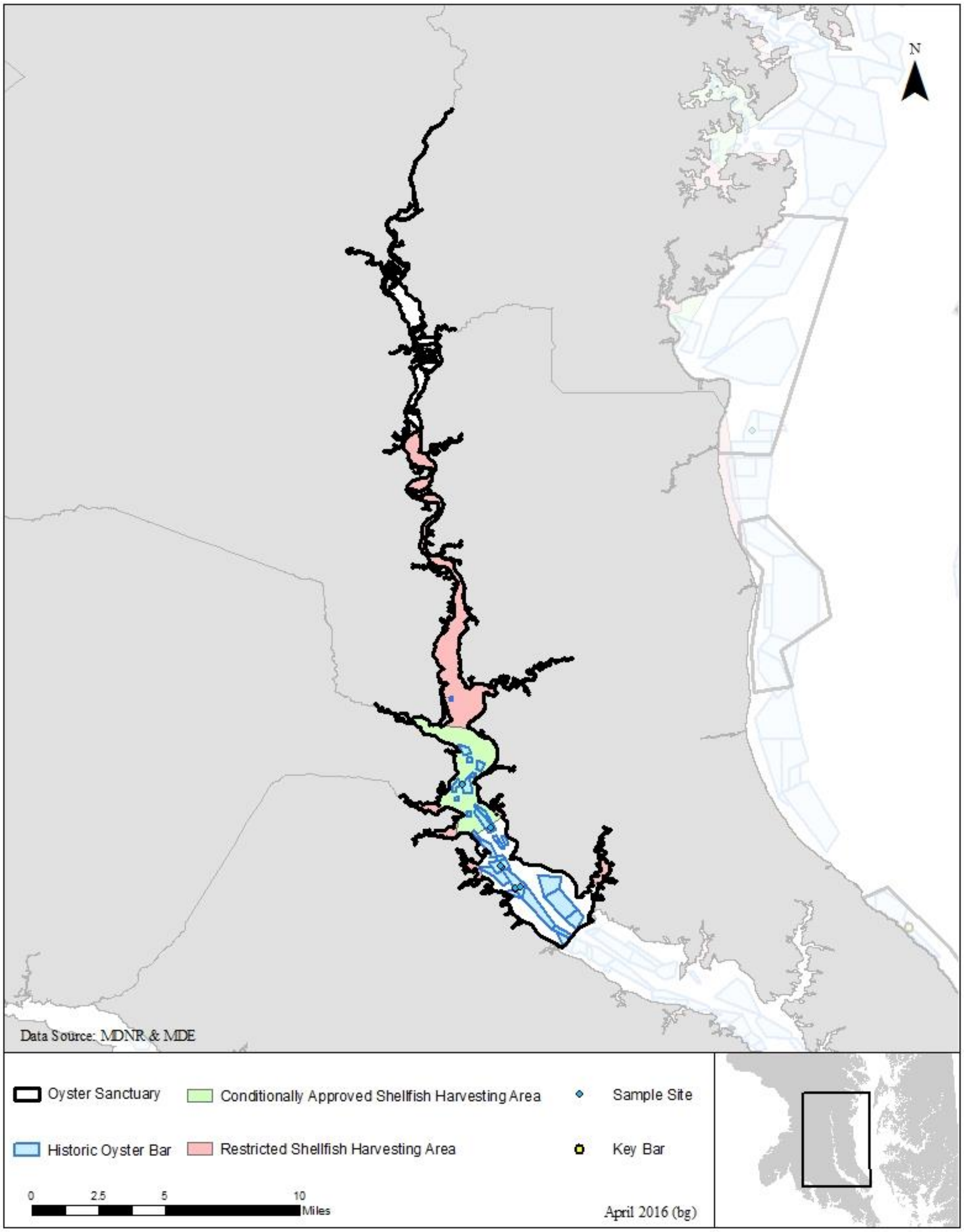


Figure A.48 -1. Upper Patuxent River Sanctuary.

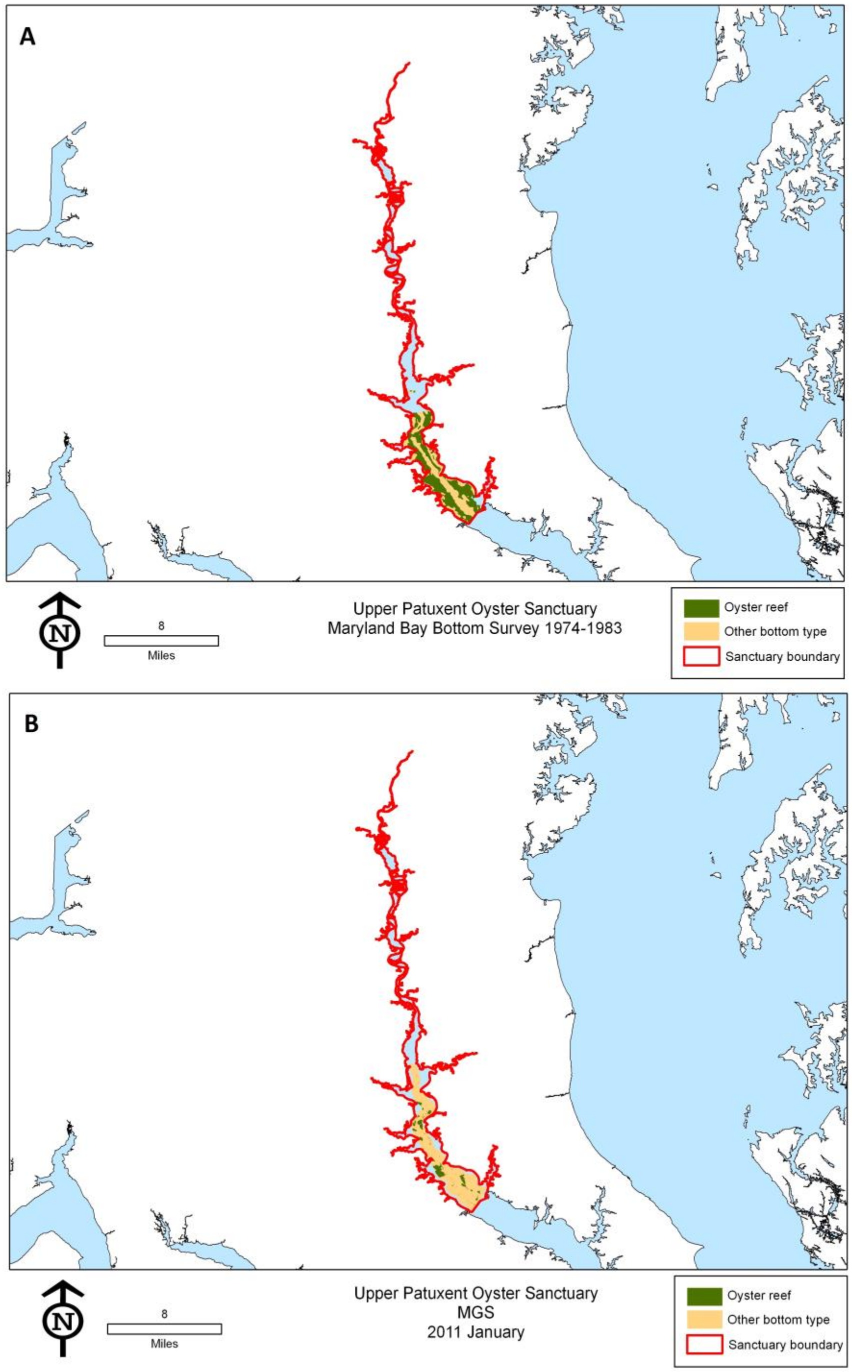


Figure A.48 -2. Upper Patuxent River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from Maryland Geological Survey in 2011. Tan and green colored areas depict areas examined during the surveys.

Table A.48-1. Replenishment and restoration planting activities occurring since 1990 in area established as the Upper Patuxent River Sanctuary in 2010. ND = No Data. S = planting activity occurring in a sanctuary

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Wild Seed	26.98	31.09	-
1991	Wild Seed	17.83	11.36	-
1992	Wild Seed	8.35	5.55	-
1995	Fresh Shell	1.79	8.70	-
1997	Dredged Shell	1.62	41.55	-
1997	Hatchery Spat-on-Shell	ND	-	2.00
1998	Wild Seed	9.68	6.94	-
1999	Dredged Shell	13.37	60.12	-
1999	Hatchery Spat-on-Shell	ND	-	2.63
2001	Hatchery Spat-on-Shell	11.32	-	6.4
2002	Dredged Shell	20.00	146.98	-
2002	Hatchery Spat-on-Shell	30.00	-	18.08
2003	Dredged Shell	5.78	31.68	-
2003	Hatchery Spat-on-Shell	7.60	-	6.75
2003	Shell Bags	10		100 bags
2004	Hatchery Spat-on-Shell	36.97	-	15.23
2006	Hatchery Spat-on-Shell	4.46	-	29.00
2007	Hatchery Spat-on-Shell	3.62	-	4.93
2008	Hatchery Spat-on-Shell	14.18	-	19.39
2009	Hatchery Spat-on-Shell	7.52	-	17.97
2009 (S)	Hatchery Spat-on-Shell	16.12	-	16.89
2010 (S)	Hatchery Spat-on-Shell	5.52	-	10.48

Oyster Population Characteristics

The Fall Survey has sampled four to seven oyster bars in this area since 1990 with an average of five oyster bars sampled annually. The average number of live oysters per bushel (market, small, and spat) was similar before and after sanctuary establishment (Table A.48-2; Figure A.48-3). However, two of the Fall Survey samples (in 2006 and 2009) were taken on the hatchery spat-on-shell plantings. Removing the plantings from the analysis shows an increase in the number of live oysters after sanctuary creation (54 ± 5 prior and 72 ± 11 after). The average number of small-sized oysters per bushel was similar before and after sanctuary creation, whereas the average number of market-sized oysters per bushel increased after sanctuary creation. The three years with the greatest average number of market-sized oysters (ranging from 52 to 75 oysters per bushel) occurred after sanctuary creation.

Table A.48-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Upper Patuxent River Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 115	6 / 30
Number of Live Oysters per Bushel	63 ± 9	72 ± 11
Number of Live Small-Sized Oysters per Bushel	27 ± 4	28 ± 8
Number of Live Market-Sized Oysters per Bushel	25 ± 2	43 ± 11
Live Oyster Biomass (g Dry Weight per Bushel)	ND	ND
Mortality (%)	23.8 ± 4.5	8.8 ± 1.3

A patent tong population survey was conducted in 2012 (Figure A.48-4). The average density of live oysters was 0.91± 0.24 oysters m^{-2} (mean ± standard error, n = 138). The density of small-sized oysters was greater than the density of market-sized oysters (0.57 ± 0.14 m^{-2} and 0.34 ± 0.12 m^{-2}, respectively). Eighty-three percent of the samples collected contained no live oysters or boxes. Live oyster density generally increased with volume of shell (Figure A.48.5).

Oyster Size Structure

Oysters collected from the sanctuary during the fall survey were not measured. Shell heights were measured during the patent tong population survey, however (Figure A.48-6). The size distribution shows oyster heights ranging from 20 to greater than120 mm.

Paynter found an average hatchery spat-on-shell shell height of 84 mm 3 years after planting[113].

Biomass

The Fall Survey has not measured oyster biomass on oyster bars in this area since 1990.

[113] Paynter, K.T. 2007. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program: 1997-2006. 87 pp.

Recruitment (Spatfall)

Based on Fall Survey data and excluding the two samples taken on hatchery seed plantings, spatfall ranged from 0 to 9 (Figure A.47-7). The average number of spat per bushel is 1 both before and after the area was established as a sanctuary.

Mortality

Based on Fall Survey box counts, the average mortality after sanctuary establishment was lower than the average mortality before sanctuary establishment (Table A.48-2; Figure A.48-8). Mortality ranged from 3% to 70% throughout the time series.

Disease

The Fall Survey has not measured oyster disease levels on oyster bars in this area since 1990.

In 2005, Paynter found a dermo prevalence of 93% on a hatchery planting[114].

[114] Paynter, K.T. 2007. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program: 1997-2006. 87 pp.

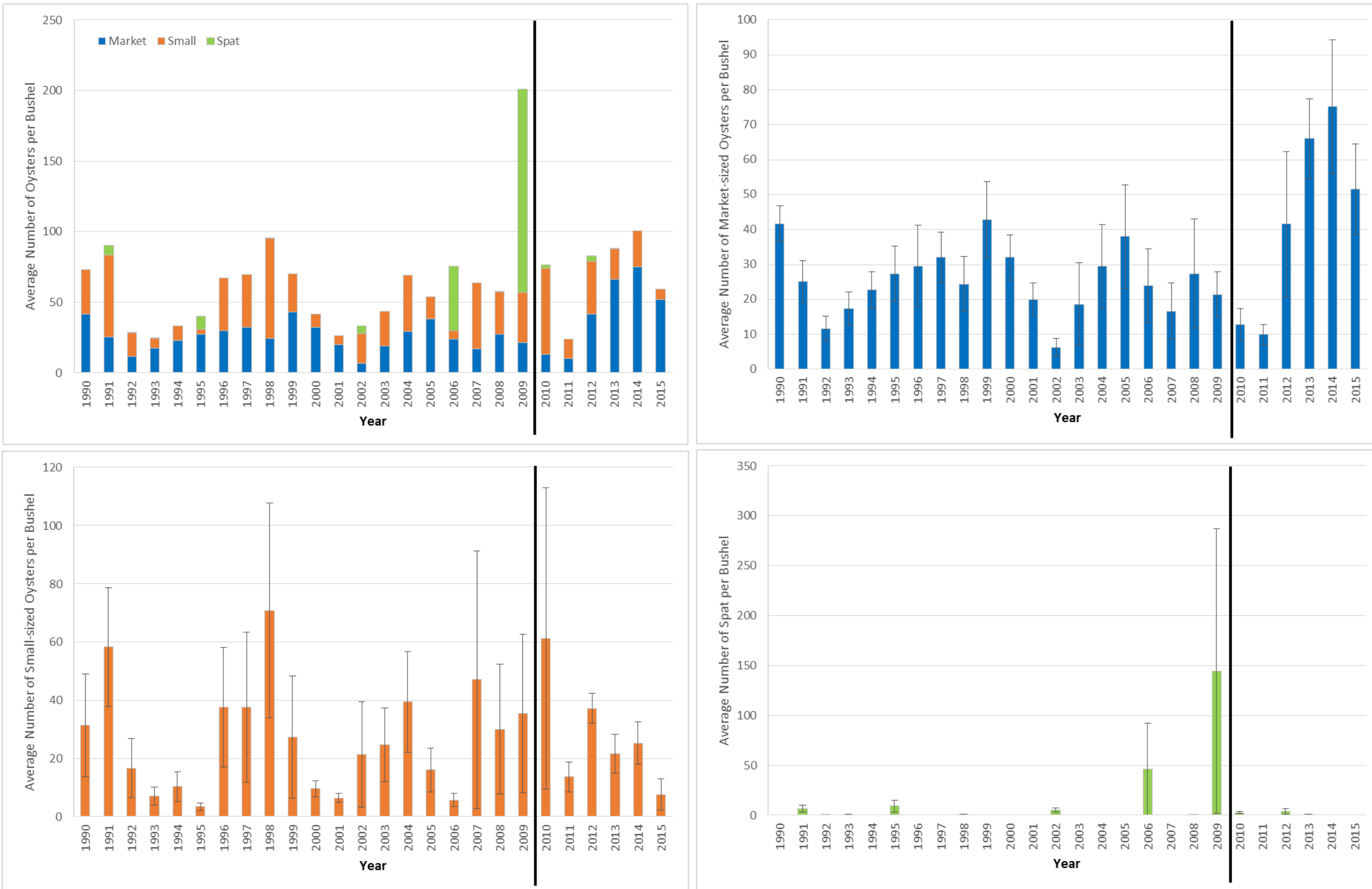


Figure A.48-3. Average number of live oysters per bushel of material by size class in the Upper Patuxent River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

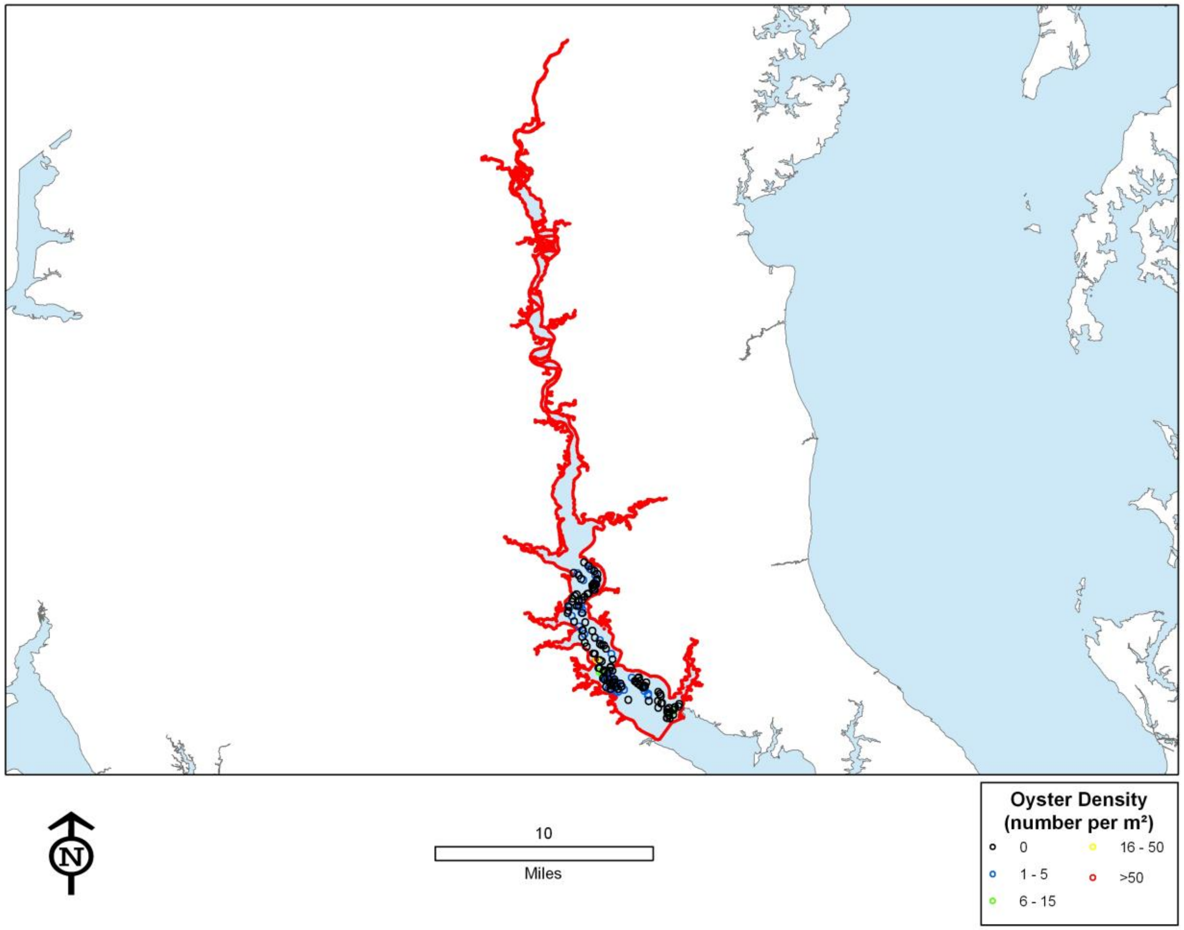


Figure A.48-4. Map of 2012 oyster density in the Upper Patuxent River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

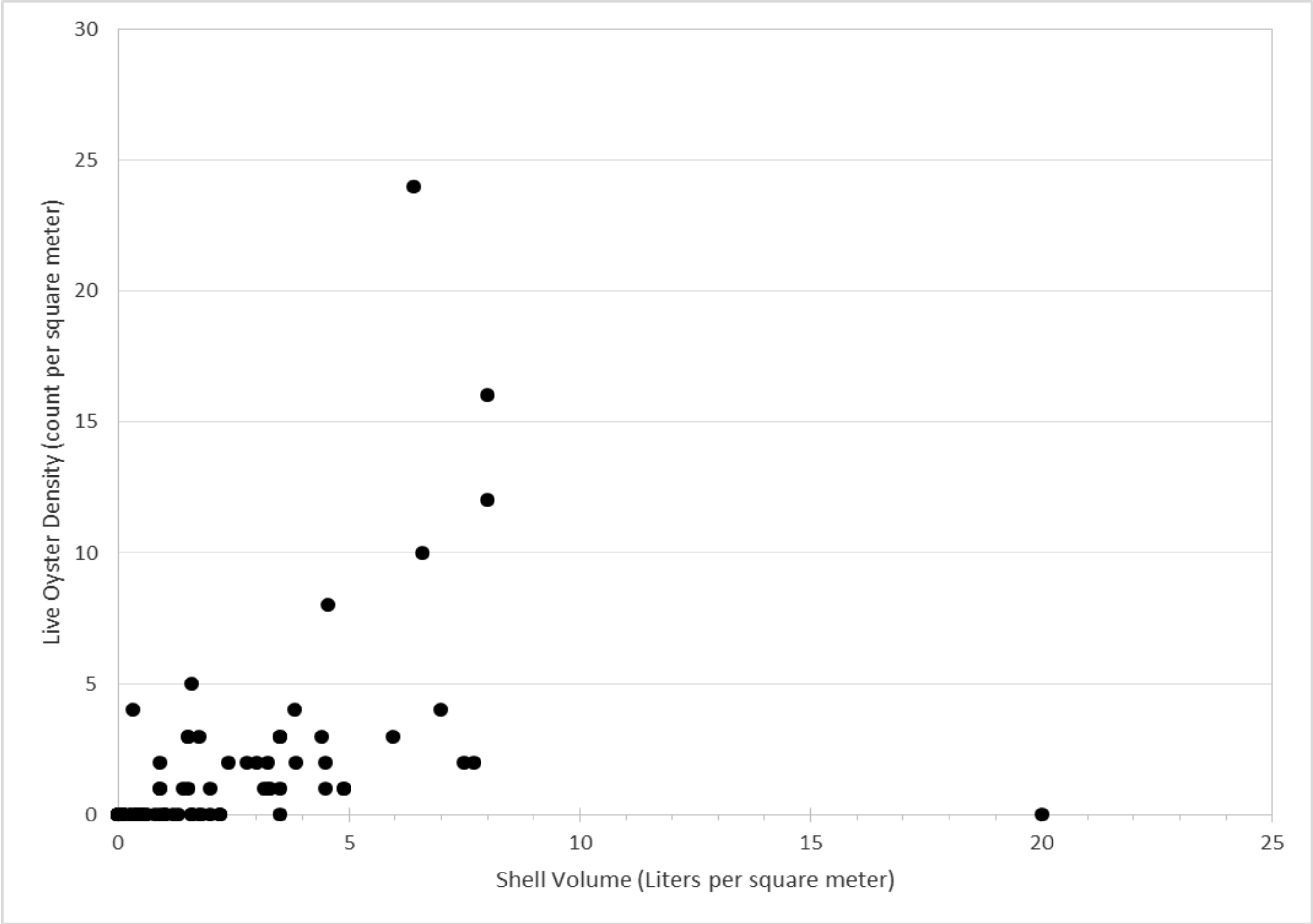


Figure A.48-5. 2014 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Upper Patuxent River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

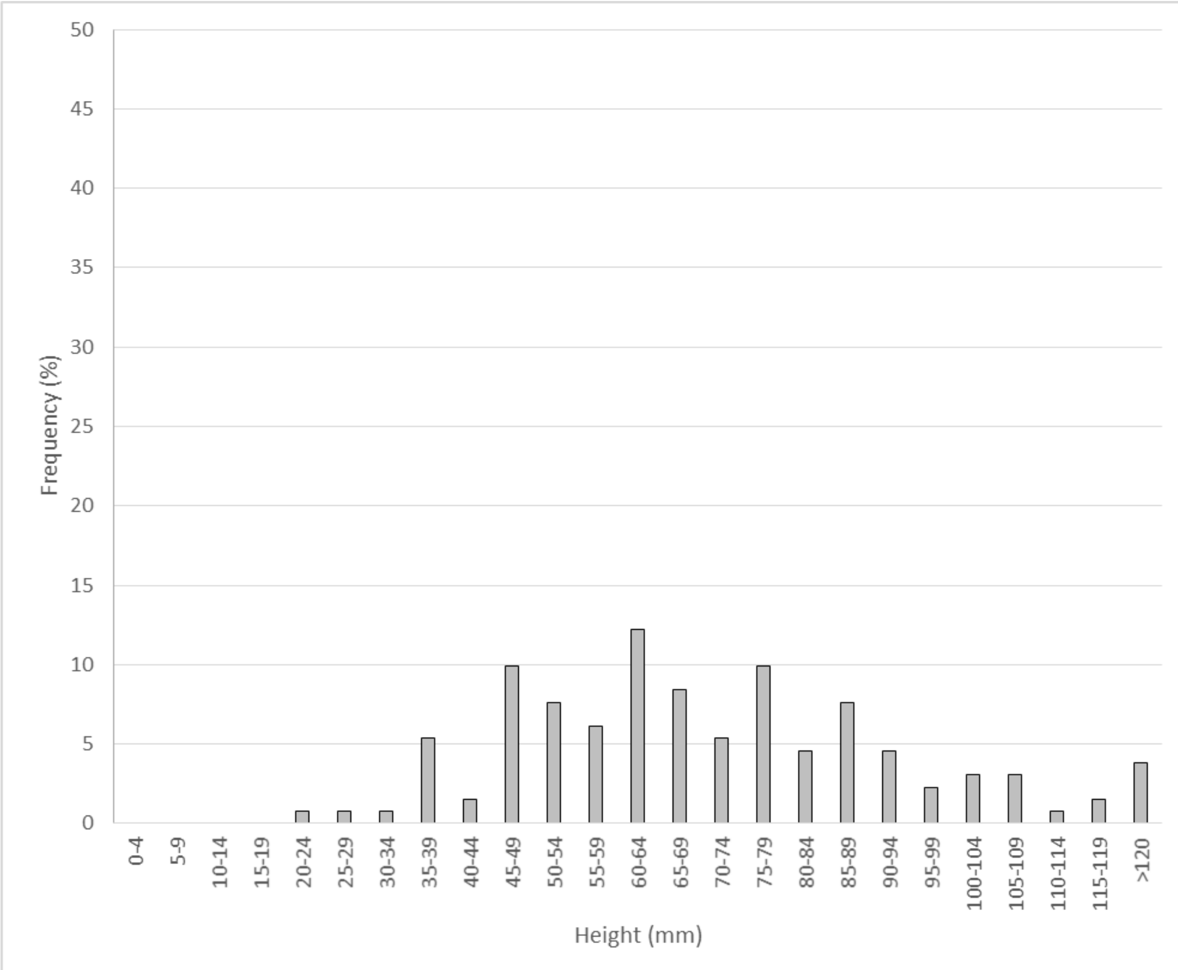


Figure A.48-6. Shell height frequencies of live oysters in the Upper Patuxent River Sanctuary in 2012. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

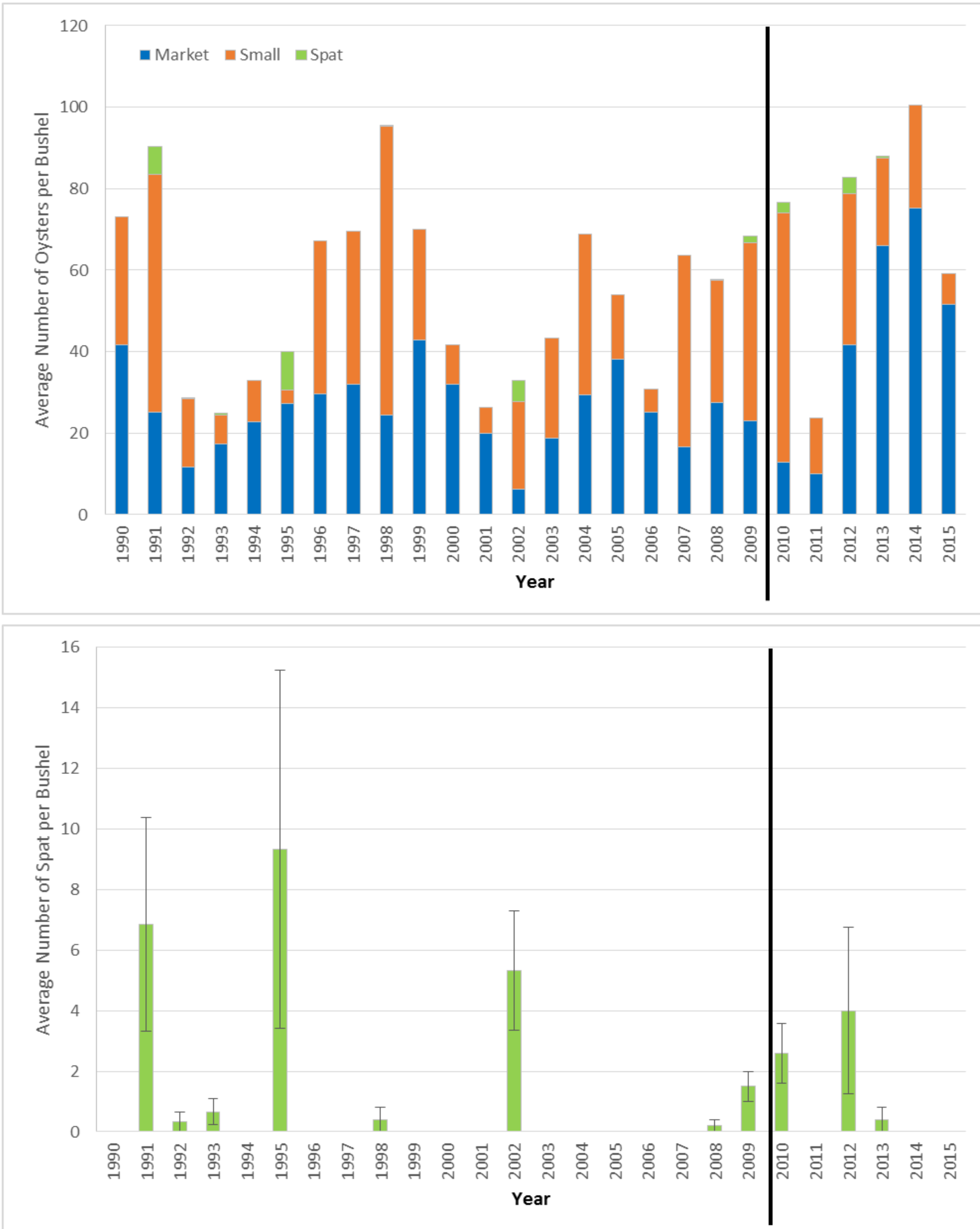


Figure A.48-7. Average number of live oysters per bushel of material by size class in the Upper Patuxent River Sanctuary excluding samples taken on hatchery seed plantings. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

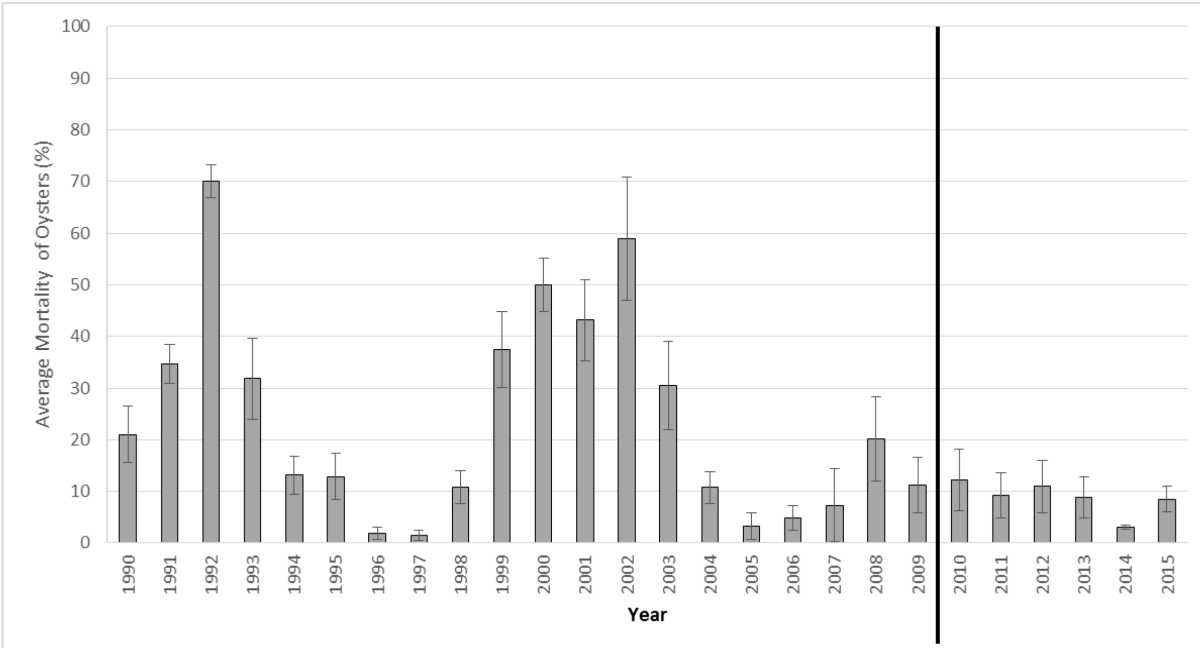


Figure A.48-8. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Upper Patuxent River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

Harvest

The sanctuary encompasses 76% of the 18,905 acres in NOAA Code 368. Harvest reported by seafood dealers prior to the establishment of the sanctuary peaked in the 1990-1991 season at 9,279 bushels (Figure A.48-9). The average harvest per season from 1990 to 2009 was 675 bushels. Watermen reported only 22 bushels harvested in 2009-2010 on bars now located within the sanctuary boundary, suggesting little harvest was coming from this area prior to sanctuary establishment.

After the 2009-2010 season, 76% of the NOAA Code area was a sanctuary where harvest is prohibited. In the 2015-2016 season, between 5,728 bushels were harvested in NOAA Code 368 outside the sanctuary. Based on seafood dealer reports, this is the second highest harvest since the 1990-1991 season.

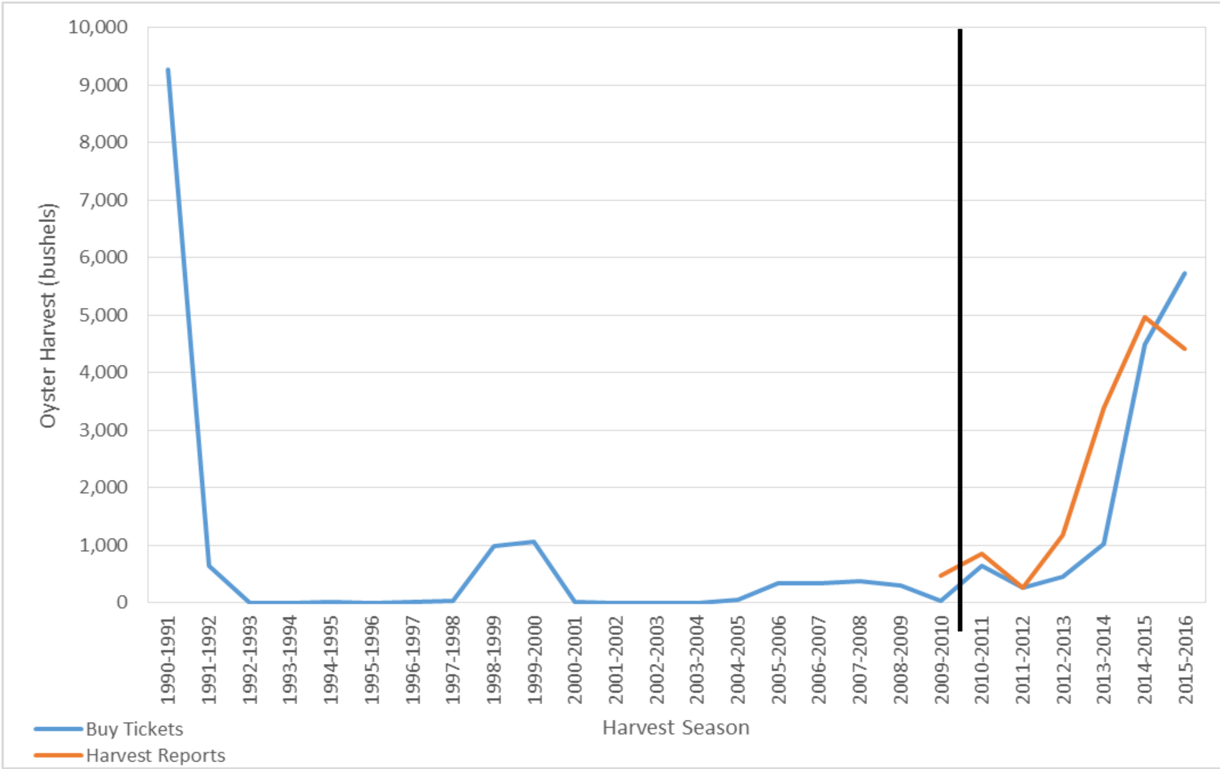


Figure A.48-9. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in NOAA Code 368 (Upper Patuxent River). In 2010, 76% of NOAA Code became an oyster sanctuary (denoted by the black line) where harvest is prohibited.

Environmental Conditions and Ecosystem Services

Maryland's Eyes on the Bay Program monitors monthly water quality at station RET1.1 (38.13794, -75.81411) in this area (Figure A.48-10). Salinity, water temperature and secchi depth minimum and maximum ranges have remained similar over the 25-year period. Water quality was suitable for oysters except for occasional periods of low salinity.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

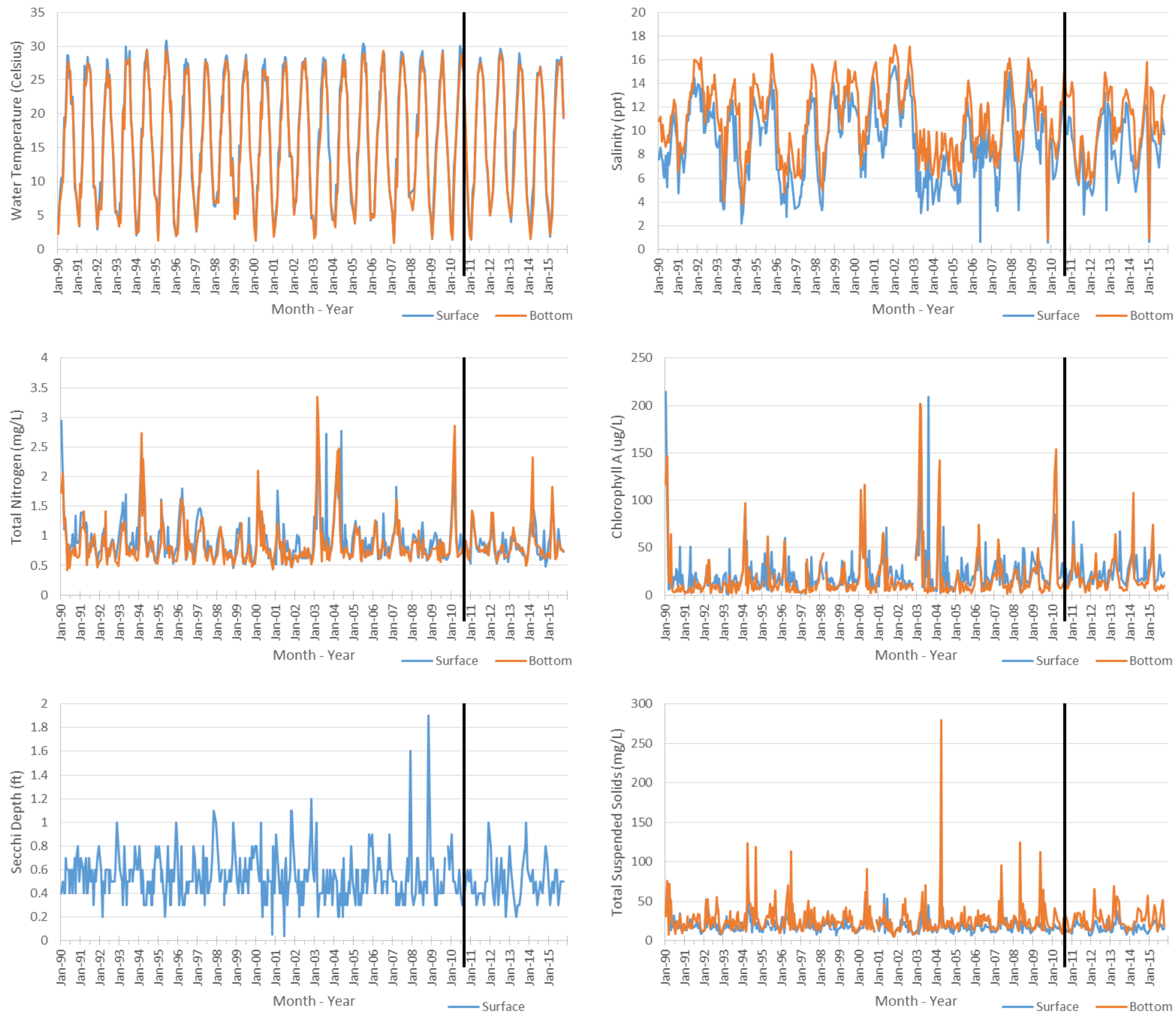


Figure A.48-10. Water quality data collected at Station RET1.1 in Upper Patuxent River. Black line denotes the date the sanctuary was established.

Section A.49: Webster Sanctuary

The Webster Sanctuary is located in the lower eastern portion of Maryland's Chesapeake Bay, a high salinity (greater than 14 ppt) region (Figure A.49-1). The sanctuary is located at the mouth of the Wicomico River. It was created in 1997 and encompasses 554 acres, none of which is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). The sanctuary was an old aquaculture lease that is located adjacent to the Monie Bay National Estuarine Research Reserve and the Deal Island facility Wildlife Management Area.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.49-2). Of the 224 acres surveyed within the sanctuary, 36 acres (16%) were classified as oyster reef habitat. There has not been any updated bottom mapping of this area using side scan sonar.

Restoration and Replenishment Activities

No replenishment or restoration efforts have taken place in this area since 1990.

Oyster Population Characteristics

The Fall Survey has not sampled any oyster bars within this area since 1990, nor has a patent tong survey been conducted there by the Department.

Harvest

No oyster harvest has been reported from this area prior to it becoming a sanctuary in 1997.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

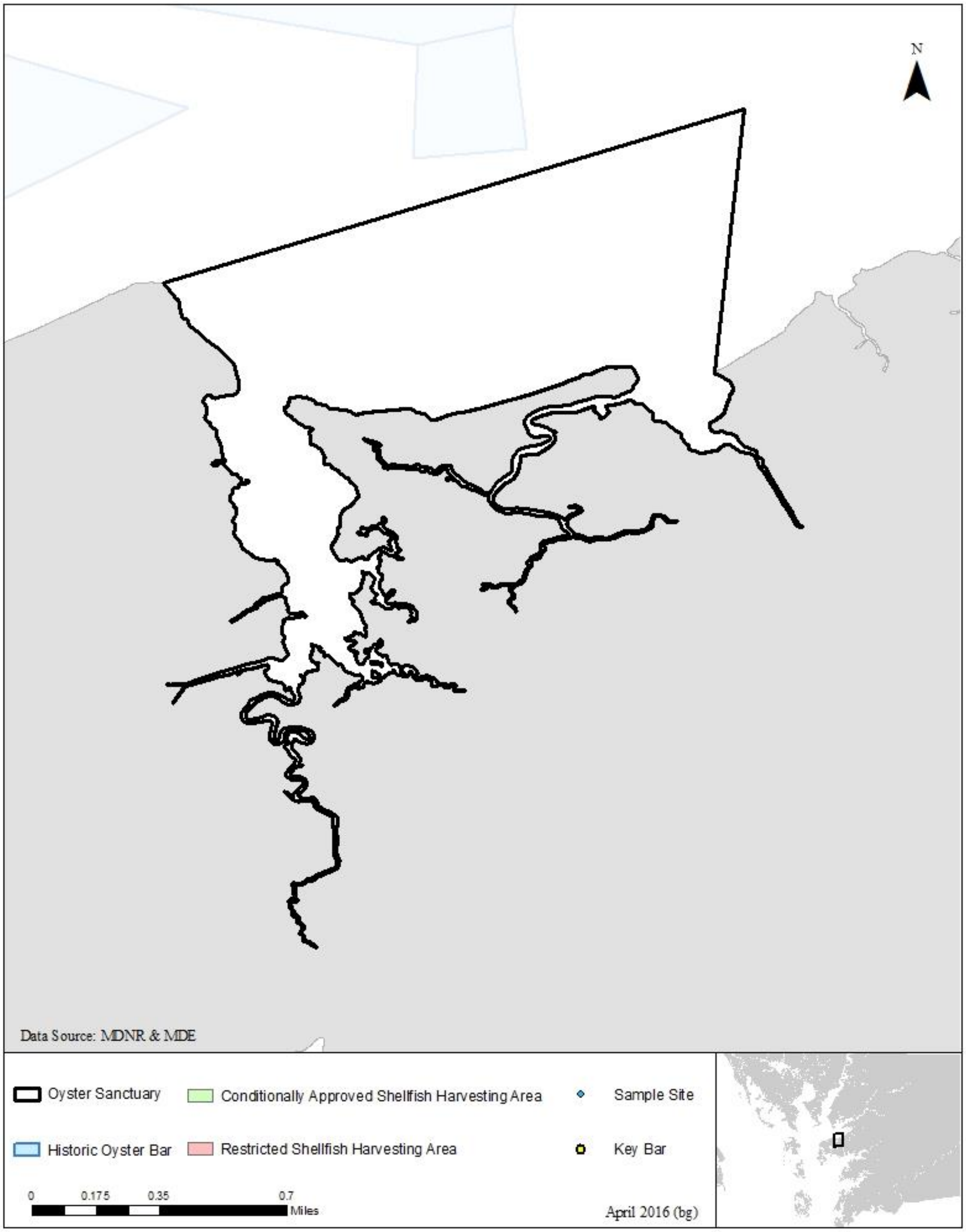


Figure A.49 -1. Webster Sanctuary.

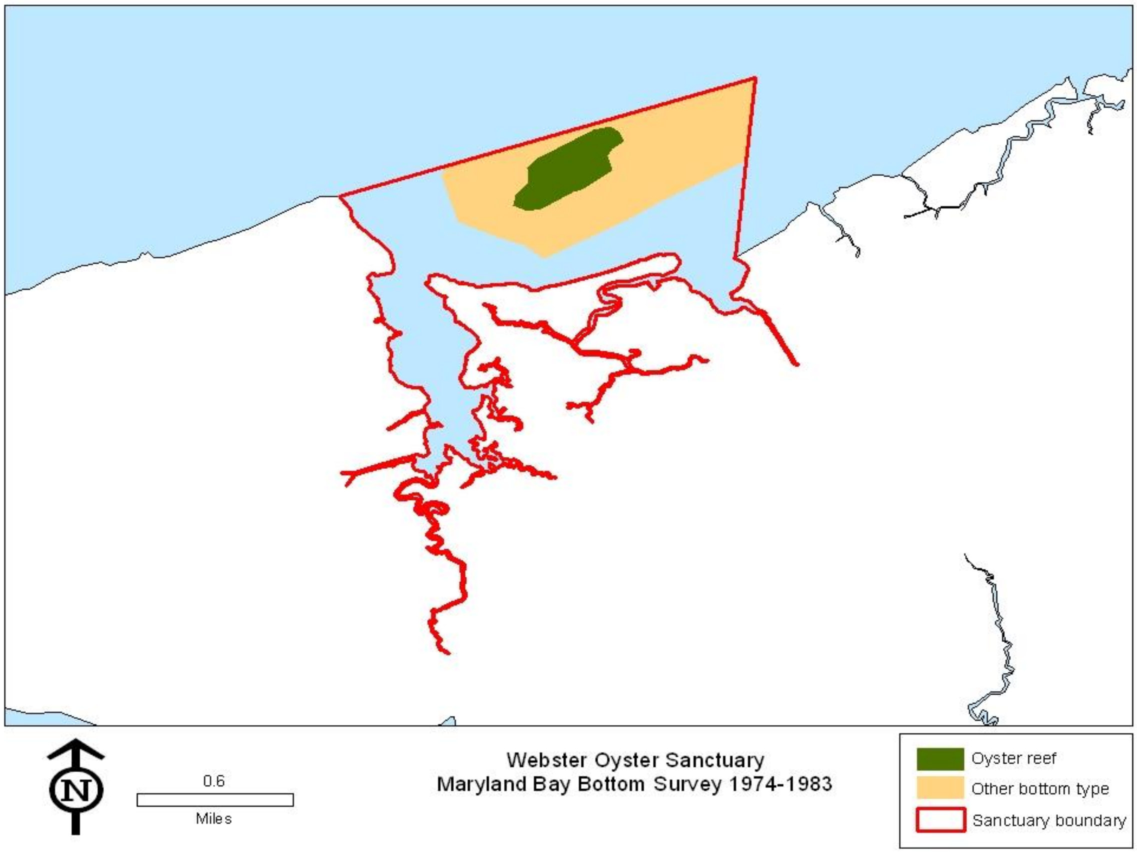


Figure A.49 -2. Webster Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict areas examined during the surveys.

Section A.50: Wicomico River Sanctuary

The Wicomico River Sanctuary is located in Maryland's western shore, a low salinity (less than 12 ppt) region, and near the Potomac River (Figure A.50-1). The sanctuary was created in 2010 and encompasses 450 acres of which 272 (61%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are portions of three historic oyster bars within the sanctuary. Blackstone bar is located almost entirely within the sanctuary (96%), but two others are only partially within the sanctuary (Bluff Point, 35%; White Point, 7%).

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.50-2). Of the 386 acres surveyed within the sanctuary, 348 acres (90%) were classified as oyster reef habitat. No additional bottom mapping of the sanctuary has occurred using side scan sonar.

Restoration and Replenishment Activities

No replenishment or restoration efforts have occurred in this area since 1990.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 102 cages and planted approximately 30,000 oysters.

Oyster Population Characteristics

The Fall Survey has collected one sample in this area in 2015. No live or dead oysters were found in the sample.

No patent tong population surveys by the Department have been conducted in the sanctuary.

Harvest

The sanctuary makes up a small portion (4%) of NOAA Code 274, which encompasses 11,953 acres. Because harvest from NOAA Code 2004 is likely to have come from places other than the area that became the sanctuary, seafood dealer reports cannot be used to assess harvest in this area. Commercial watermen reported a catch of 6 bushels in the 2009-2010 season on the bars which are now within the sanctuary.

Environmental Conditions and Ecosystem Services

We are unaware of any studies explicitly examining environmental conditions (e.g. continuous water quality monitoring) or oyster ecosystem services in this area.

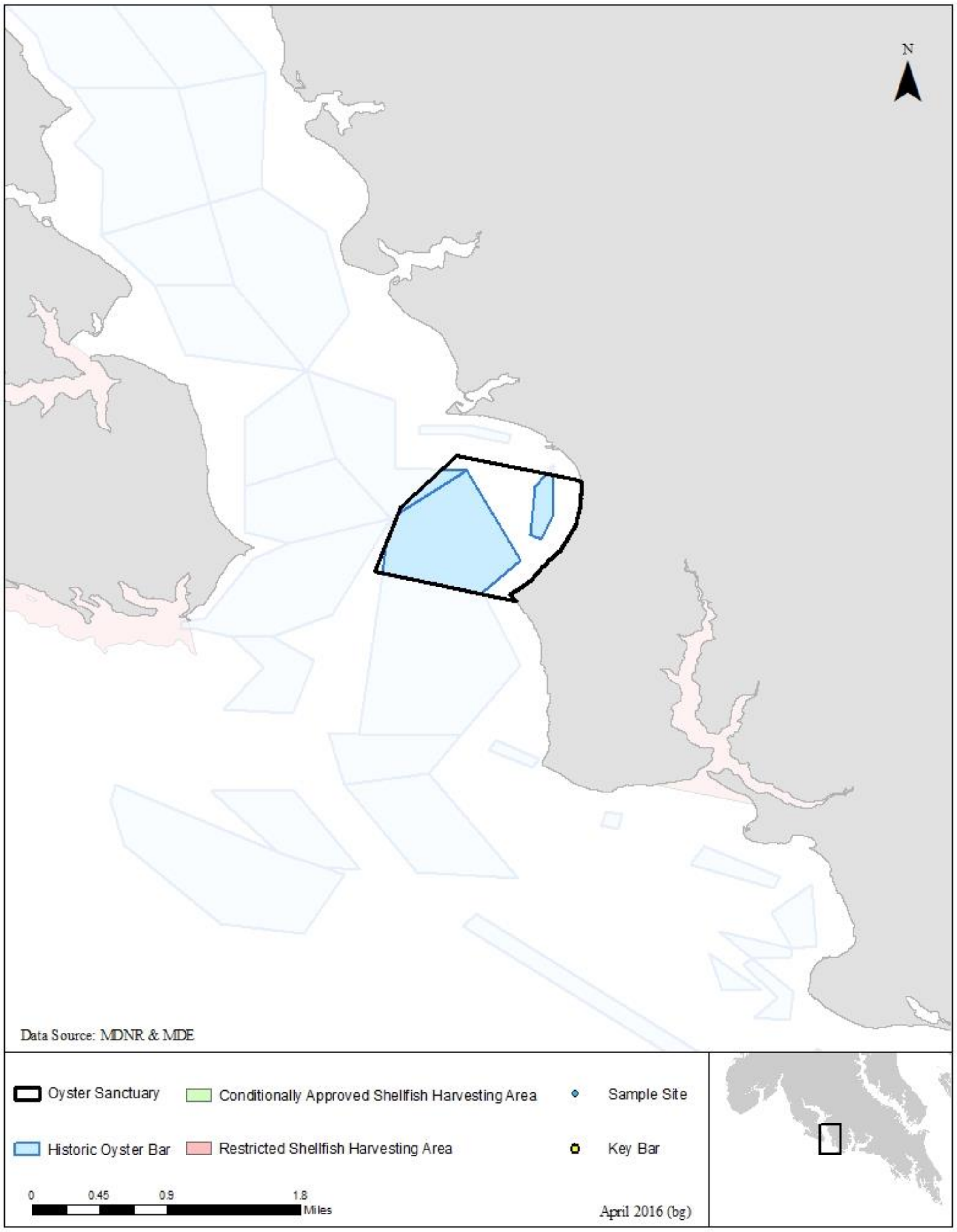


Figure A.50-1. Wicomico River Sanctuary.

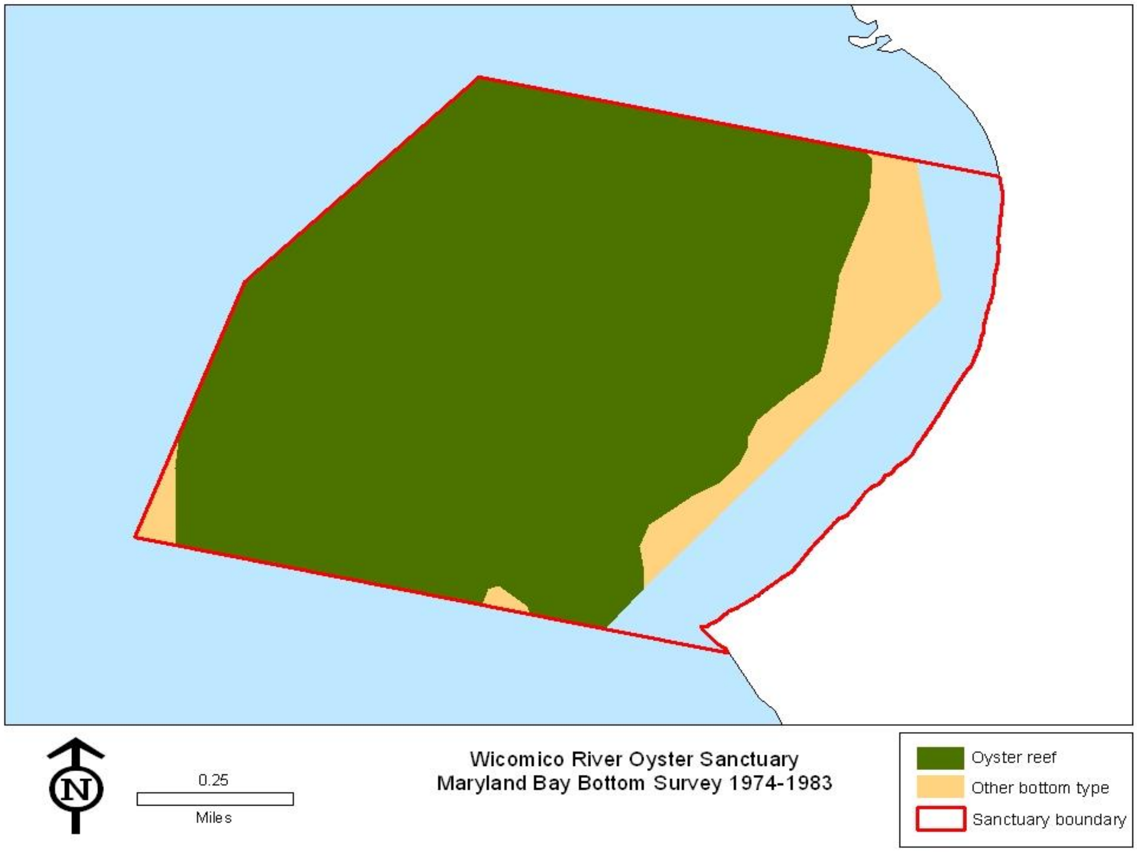


Figure A.50 -2. Wicomico River Sanctuary bottom types. Data from Maryland Bay Bottom Survey from 1974-1983. Tan and green colored areas depict areas examined during the surveys.

Section A.51: Wye River Sanctuary

The Wye River Sanctuary is located in Eastern Bay, a low salinity (less than 12 ppt) region (Figure A.51-1). The sanctuary was created in 2010 and encompasses 3,510 acres of which 1,100 (31%) is historic oyster bottom (as charted in the Yates Oyster Survey from 1906 to 1912 plus its amendments). There are 23 historic oyster bars within the sanctuary[115]. Due to high fecal coliform counts and the potential for bacterial contamination of shellfish, Maryland Department of the Environment has classified a portion of the sanctuary as restricted, meaning no shellfish harvest is permitted.

Bottom Habitat Characteristics

The area that is now the sanctuary was surveyed during the Bay Bottom Survey (1974 to 1983) to determine its bottom type (Figure A.51-2). Of the 840 acres surveyed within the sanctuary, 525 acres (63%) were classified as oyster reef habitat. In 2011, NOAA Chesapeake Bay Office conducted a side scan sonar survey of the area. Of the 1,979 acres surveyed, 285 acres (14%) were classified as oyster reef habitat. In the area covered by both surveys, there appears to be a substantial loss of habitat since the Bay Bottom Survey.

Restoration and Replenishment Activities

Prior to sanctuary creation, wild seed and fresh shell were planted to enhance the public fishery (Table A.51-1). No restoration efforts have occurred since the sanctuary was established in 2010.

Marylanders Grow Oysters, a public outreach program, plants oysters at one site in the sanctuary. In 2016, growers tended 100 cages and planted approximately 30,000 oysters.

Table A.51-1. Replenishment planting activities occurring since 1990 in the area now established as the Wye Sanctuary in 2010.

Year	Planting Substrate Type	Area Planted (acres)	Thousands of Bushels Planted	Millions of Spat Planted
1990	Wild Seed	23.8	11.23	-
1998	Wild Seed	12.9	8.81	-
2001	Fresh Shell	10.9	62.75	-

[115] See chart 12 for bar names and locations in the State of Maryland Shellfish Closure Areas Book http://dnr.maryland.gov/fisheries/Pages/oysters/index.aspx

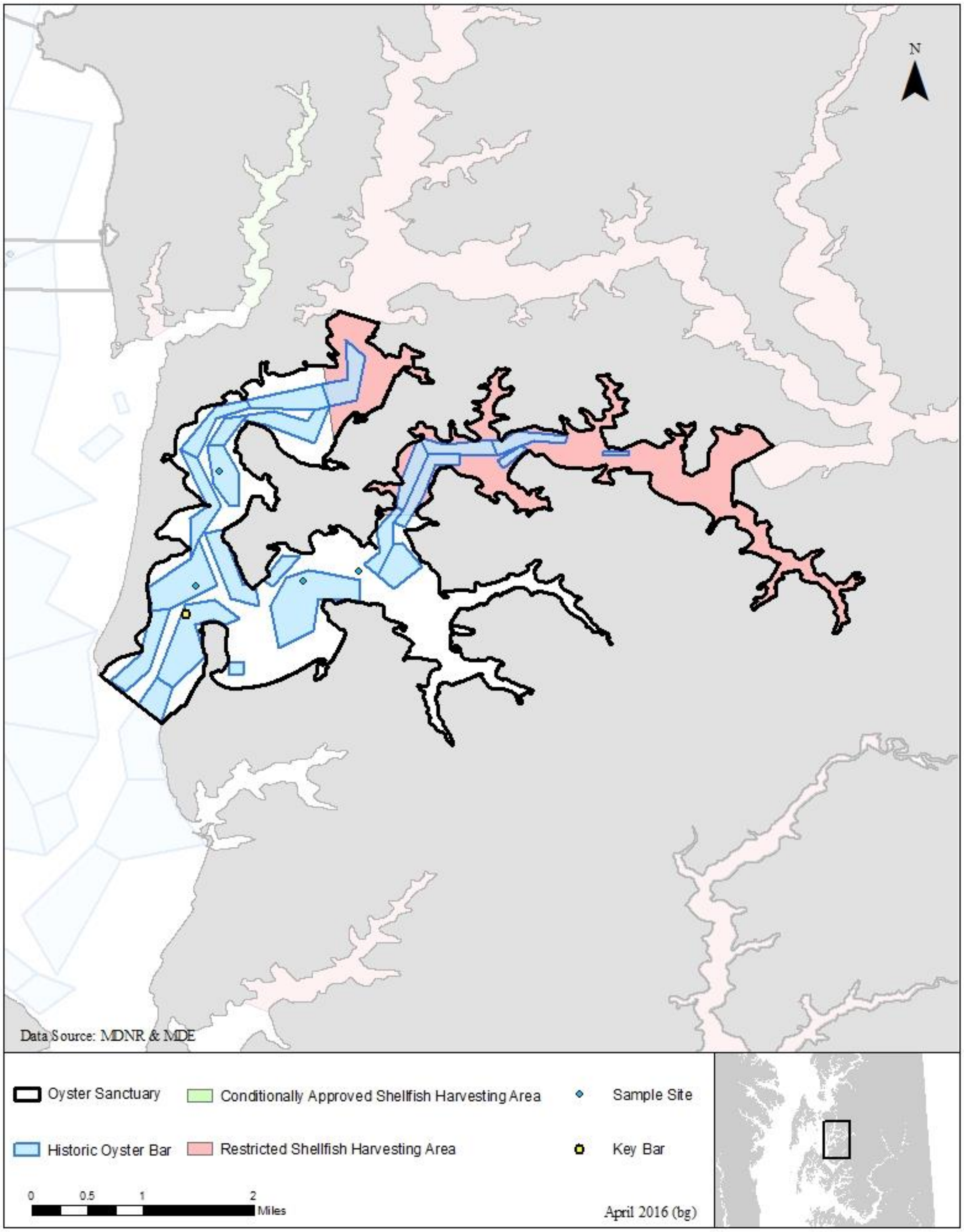


Figure A.51 -1. Wye River Sanctuary.

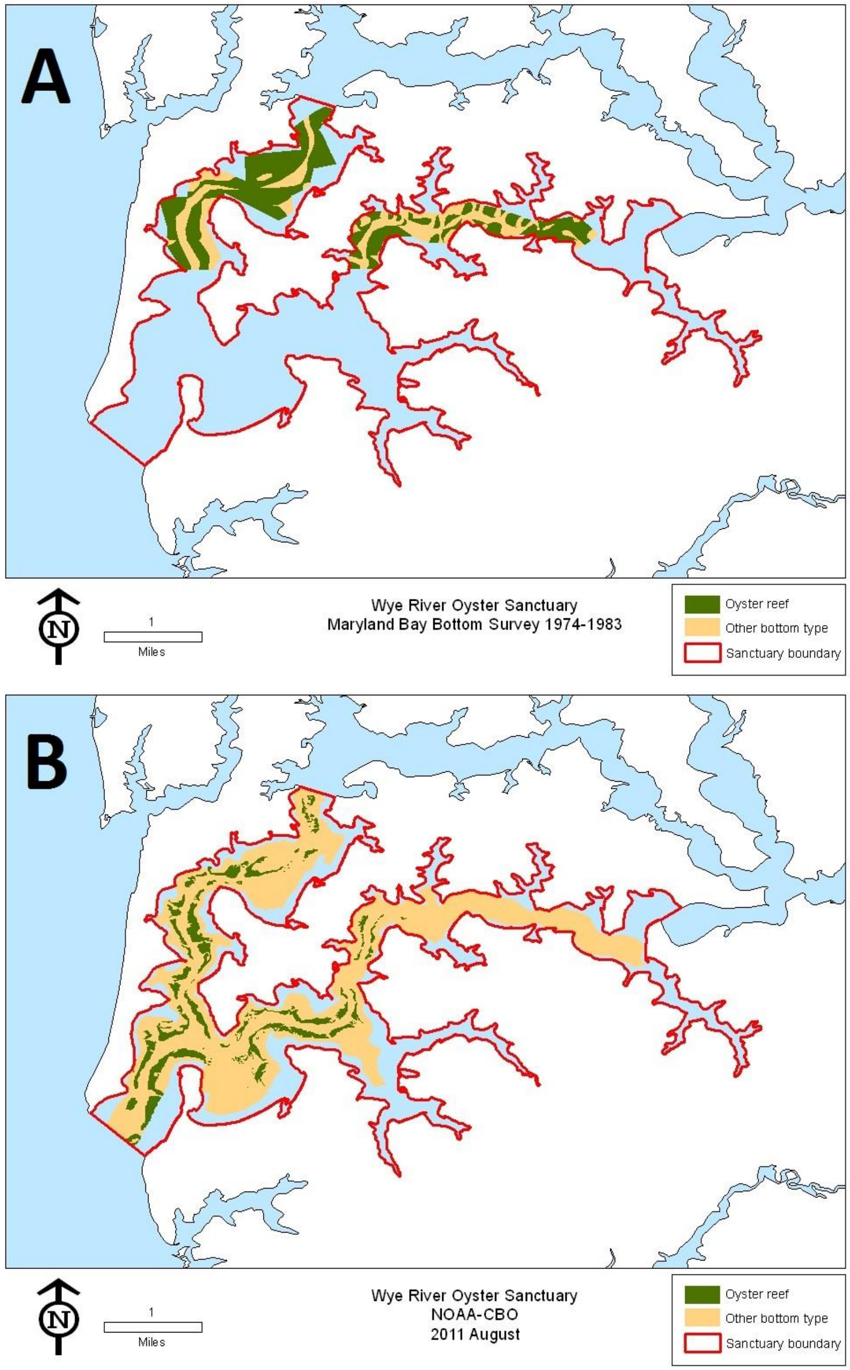


Figure A.51 -2. Wye River Sanctuary bottom types. (A) Data from Maryland Bay Bottom Survey from 1974-1983. (B) Data from NOAA Chesapeake Bay Office in 2011. Tan and green colored areas depict areas examined during the surveys.

Oyster Population Characteristics

The Fall Survey has sampled three to six oyster bars in this area since 1990 with an average of four oyster bars sampled annually. The average number of live oysters per bushel (market, small, and spat) decreased after sanctuary establishment (Table A.51-2; Figure A.51-3). However, the greater number of oysters from 1990 to 2009 was mostly driven by one large spat set in 1997. The number of live oysters per bushel has increased steadily since 2010. The average number of small-sized oysters per bushel decreased after sanctuary establishment. The average number of market-sized oysters was similar before and after sanctuary establishment, but has increased steadily since 2011.

Table A.51-2. Oyster population characteristics based on the Fall Survey before and after the establishment of the Wye River Sanctuary in 2010. ND = No Data. Values are given as mean ± standard error.

	1990-2009	**2010-2015**
Number of Years Sampled / Number of Samples	20 / 83	6 / 30
Number of Live Oysters per Bushel	87 ± 25	46 ± 9
Number of Live Small-Sized Oysters per Bushel	34 ± 14	11 ± 4
Number of Live Market-Sized Oysters per Bushel	31 ± 6	31 ± 10
Live Oyster Biomass (g Dry Weight per Bushel)	106 ± 19.5	117 ± 47
Mortality (%)	20.1 ± 4.4	2.3 ± 0.9

A patent tong population survey was conducted in 2014 (Figures A.51-4). The average density of live oysters was 2.28± 0.29 oysters m^{-2} (mean ± standard error, number = 149). The density of small-sized oysters was 1.69 ± 0.24 m^{-2} was greater than the density of market-sized oysters (0.56 ± 0.11 m^{-2}), contrary to the Fall Survey findings for that year. Forty-eight percent of the samples contained no live oysters or boxes. Oyster density increased with shell volume (Figure A.51.5).

Oyster Size Structure

The Fall Survey has measured oyster shell heights in this area at Bruffs Island bar since 1990 (Figure A.51-6). Oysters collected during the patent tong survey were also measured (Figure A.51-7). There has been an increase in the number of large oysters since the establishment of the sanctuary. The patent tong survey shows a peak at 55-59 mm, whereas the fall survey data for the same year show a peak at 80 to 84 mm. The patent tong survey was conducted in the spring, whereas the Fall Survey was conducted in the fall. The difference in shell height could be accounted for by the extra growing season experienced by the oysters sampled by the Fall Survey.

Biomass

Biomass has been calculated for Fall Survey samples from Bruffs Island bar since 1990 (Table A.51-2; Figure A.51-8). Average biomass has shown an increasing trend since 2008, with the second highest biomass of 322 grams dry weight per bushel occurring in 2015. This increase is both due to the increasing number and size of oysters in the population. The highest biomass, 325 grams dry weight per bushel, occurred in 1999 and was due to the large spat fall in 1997, resulting in a large number of small and market-sized oysters that year

Recruitment (Spatfall)

Based on Fall Survey data, spatfall has ranged from 0 to 391 spat per bushel (Figure A.51-3). The highest spat counts since 1990 occurred in 1997, a year of high spatfall throughout the bay. If the 1997 spatfall is excluded, the average number of spat per bushel is the same before and after the sanctuary was established (4 ±1 spat per bushel). No spat were found during the 2014 patent tong survey, which is not unexpected given that the survey was conducted in the spring before reproduction season.

Mortality

Based on Fall Survey box counts, the average mortality after sanctuary establishment was lower than before sanctuary establishment (Figure A.51-9). Mortality ranged from 1% to a peak of 55%, with the highest value occurring in 1992.

Disease

From 1990 to 2015, dermo prevalence has ranged from 17% to 100% with intensities ranging from 0.2 to 3.8 (Figure A.51-10). From 1999 to 2002, dermo intensity was consistently high although it never reached lethal levels (greater than 5 on a 0 to 7 scale). MSX was only found in three years: 2001, 2002, and 2009, with prevalence ranging from 0% to 17%.

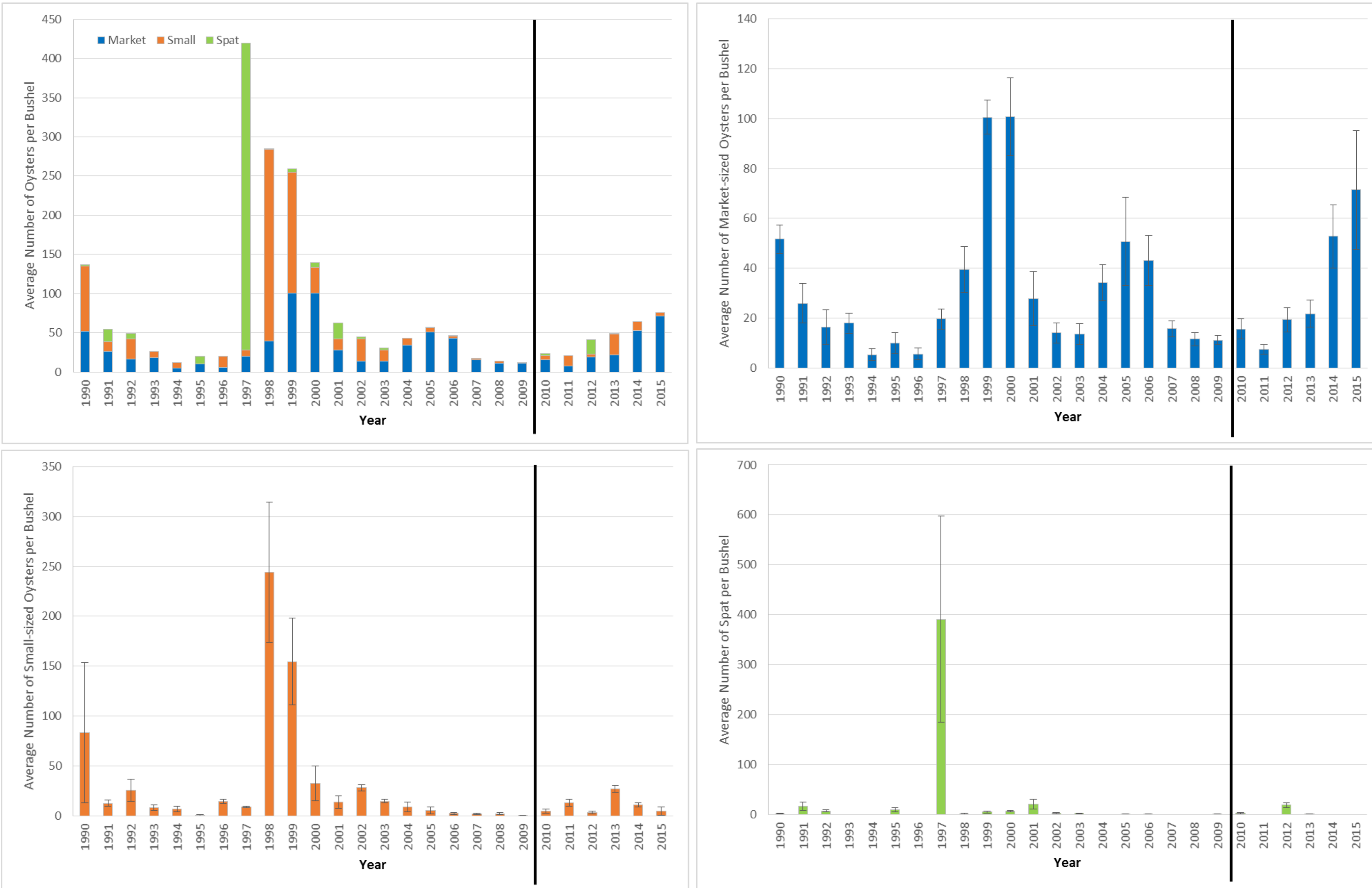


Figure A.51-3. Average number of live oysters per bushel of material by size class in the Wye River Sanctuary. The black line denotes the year the sanctuary was established. Error bars represent ± 1 standard error. Data from Maryland's Annual Fall Oyster Dredge Survey. Note differing Y-axis scales.

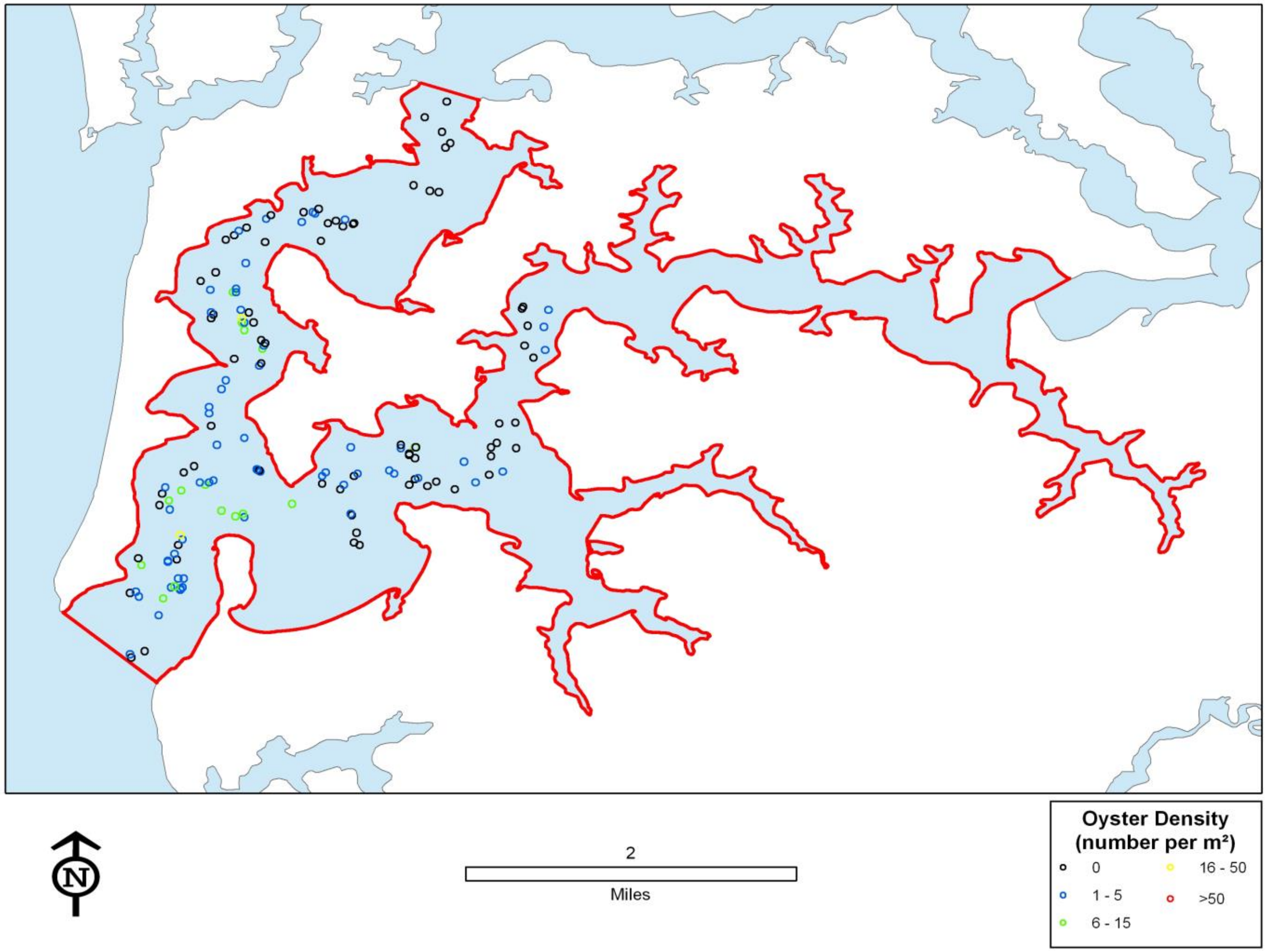


Figure A.51-4. Map of the 2014 oyster density in the Wye River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

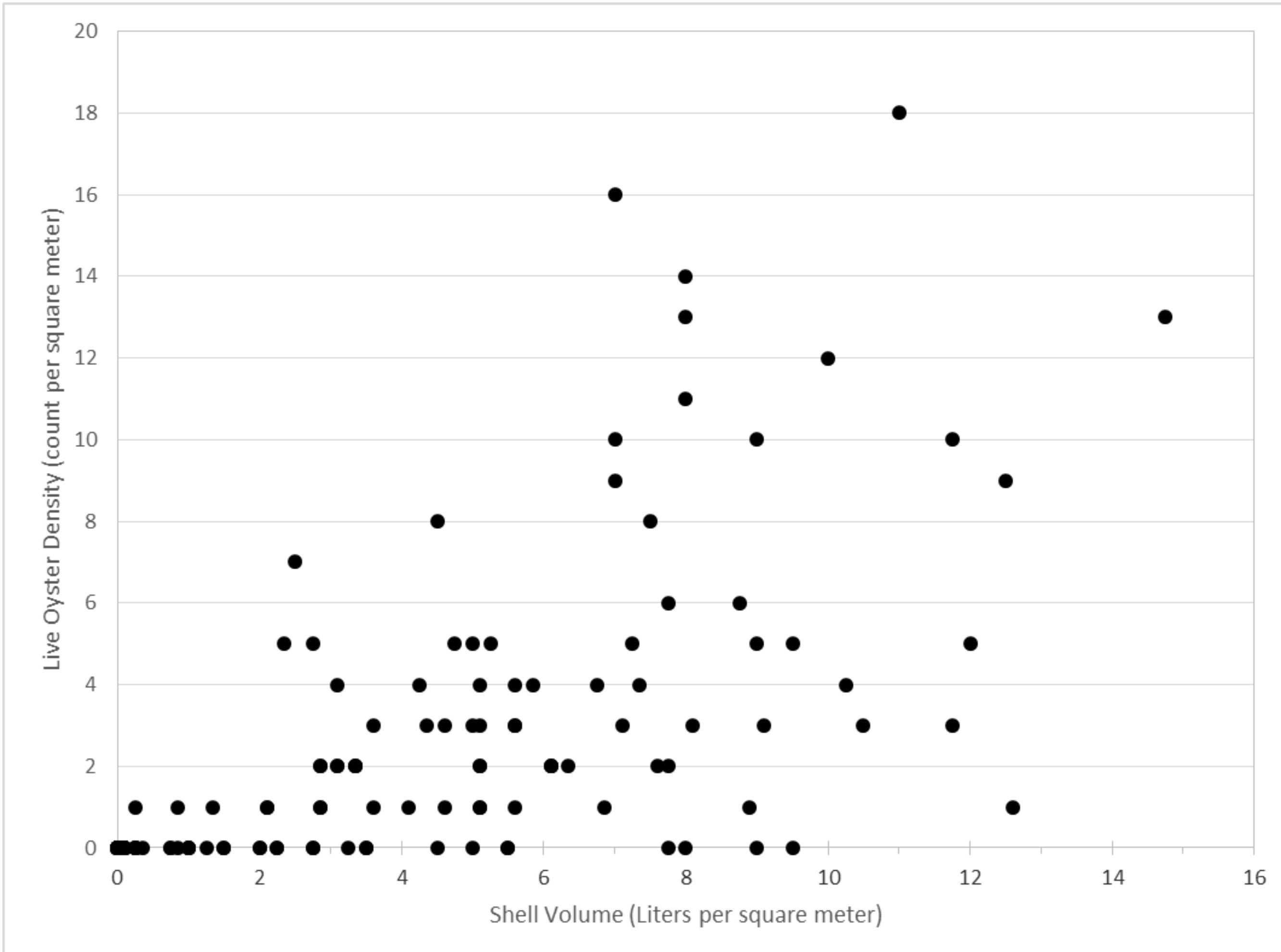


Figure A.51-5. 2014 live oyster density vs. shell volume (liters of live oysters, boxes, and surface shell) in the Wye River Sanctuary. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

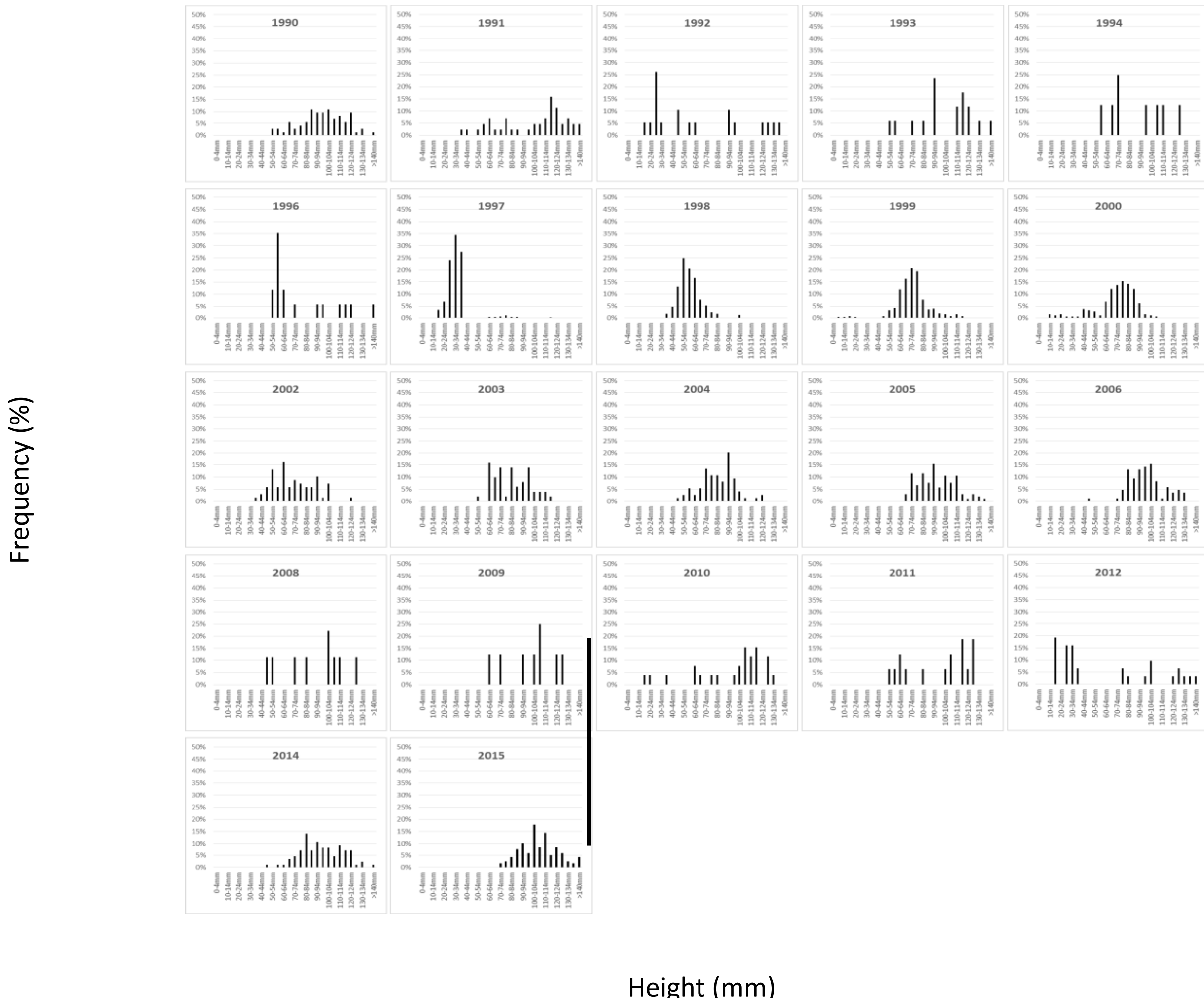


Figure A.51-6. Shell height frequencies of live oysters in the Wye River Sanctuary from 1990 to 2015. Data from Maryland's Annual Fall Oyster Dredge Survey on Bruffs Island bar. The black line denotes the year the sanctuary was established. Oyster sizes less than 37mm were not recorded by the Fall Survey at any sampling location in 2002 and 2003.

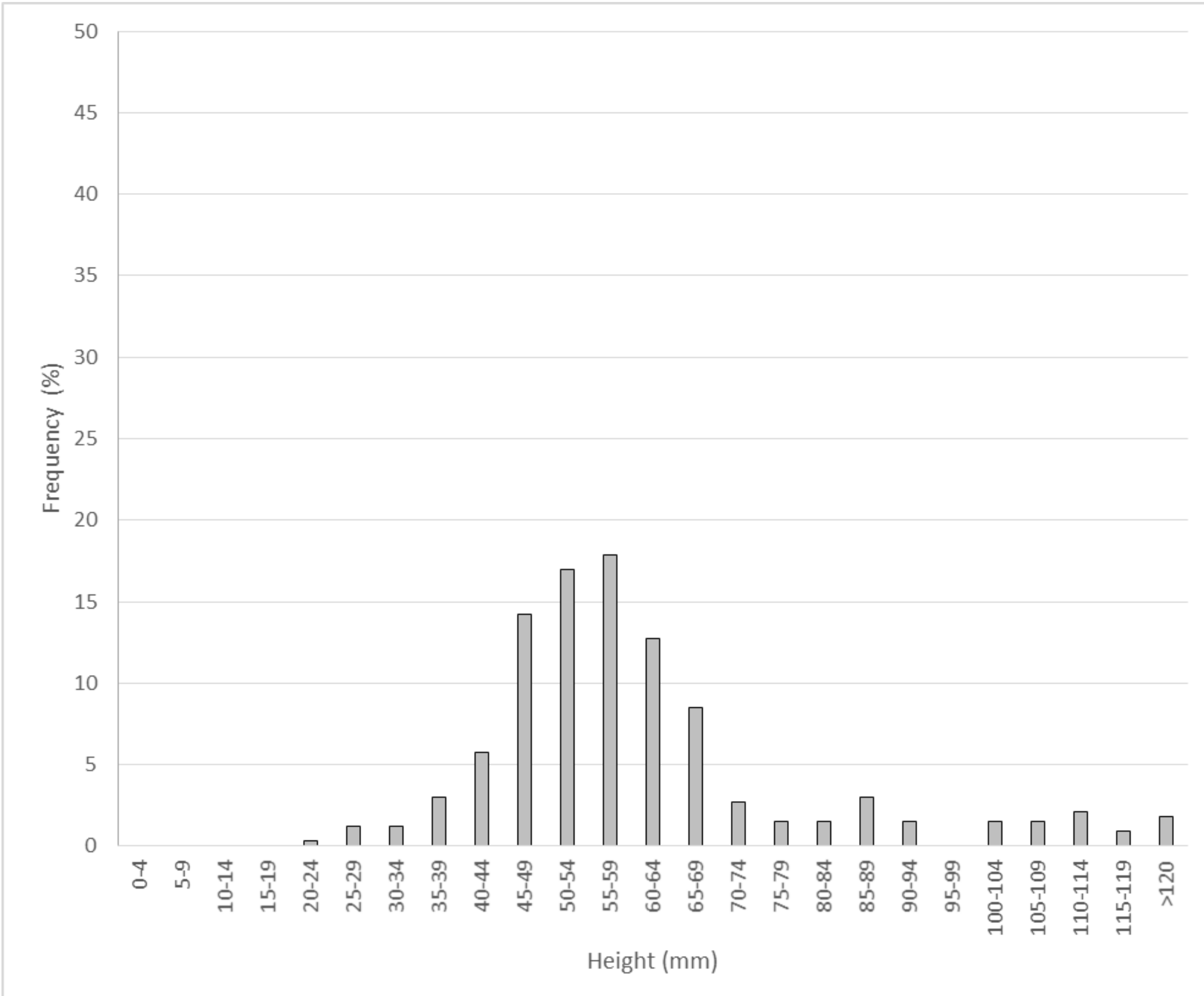


Figure A.51-7. Shell height frequencies of live oysters in the in the Wye River Sanctuary in 2014. Data from Maryland Department of Natural Resources Patent Tong Population Survey.

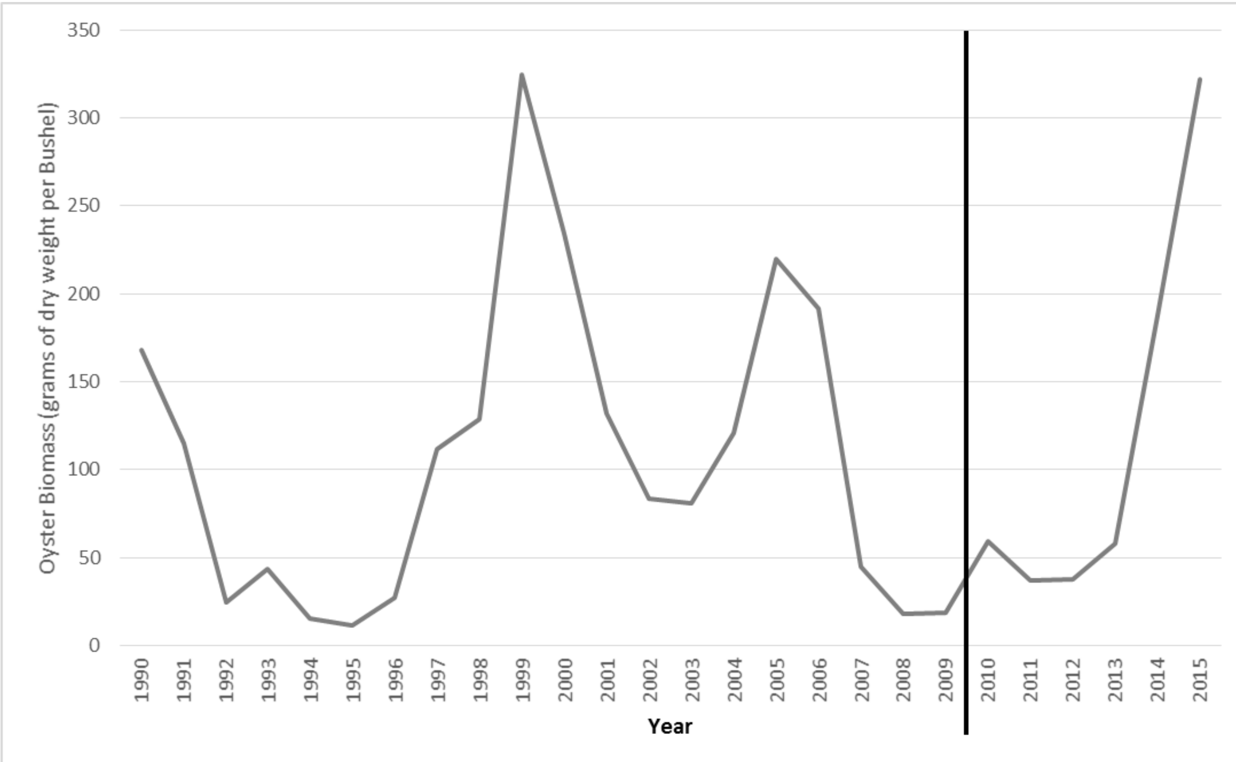


Figure A.51-8. Oyster biomass (grams of dry weight per bushel of material) from 1990 to 2015 in the Wye River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey on Bruffs Island bar. Black line indicates the date the sanctuary was established.

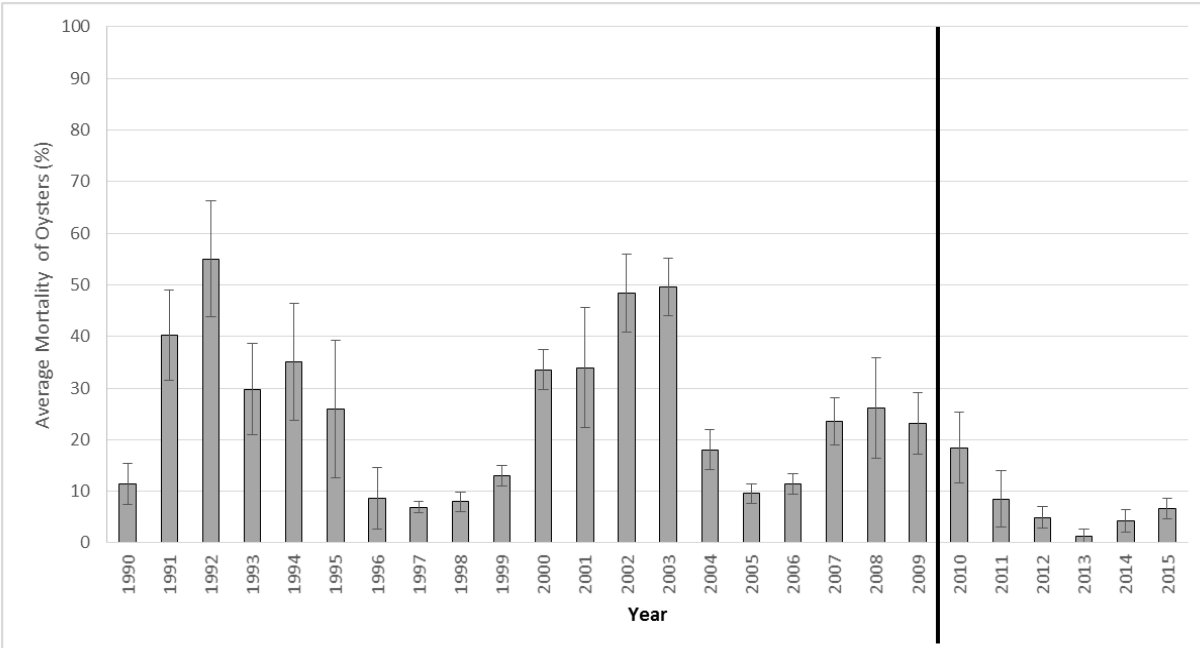


Figure A.51-9. Average mortality of market-sized and small-sized oysters from 1990 to 2015 in Wye River Sanctuary. Data from Maryland's Annual Fall Oyster Dredge Survey. Black line denotes the date the sanctuary was established. Error bars represent ± 1 standard error.

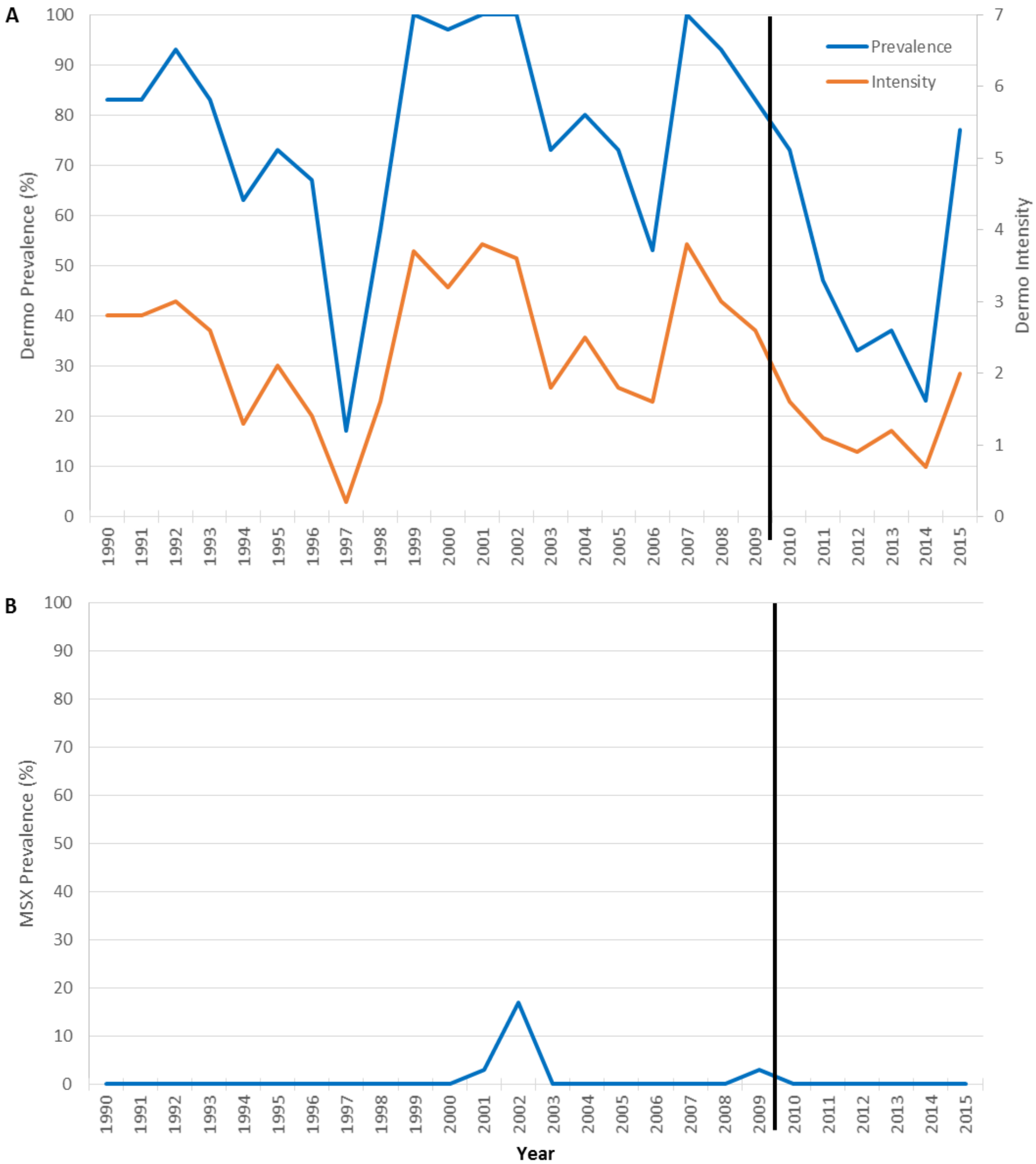


Figure A.51-10. Oyster disease prevalence and intensity from 1990 to 2015 in the Wye River Sanctuary. (A) Dermo prevalence and intensity (B) MSX prevalence (intensity is not examined). Data from Maryland's Annual Fall Oyster Dredge Survey on Bruffs Island bar.

Harvest

The Wye River Sanctuary encompasses 54% of the 6,493 acres in NOAA Code 099, however all oysters bars are located in the sanctuary with the exception of one (90% of the historic oyster bottom within NOAA Code 099 is located in the sanctuary). Harvest reported by seafood dealers prior to the establishment of the sanctuary peaked in the 2000-2001 season at 11,605 bushels (Figure A.51-11). The average harvest per season from 1990 to 2009 was 1,380 bushels. In the 2009-2010 harvest season, commercial waterman reported a catch of 177 bushels in the Wye River.

After the establishment of the sanctuary in 2010, only 10% of charted oyster bottom in the Wye River was available for harvest. After the sanctuary was created, harvest ranged between 0 to 82 bushels annually all taken from one bar, with 75% of its area outside the sanctuary.

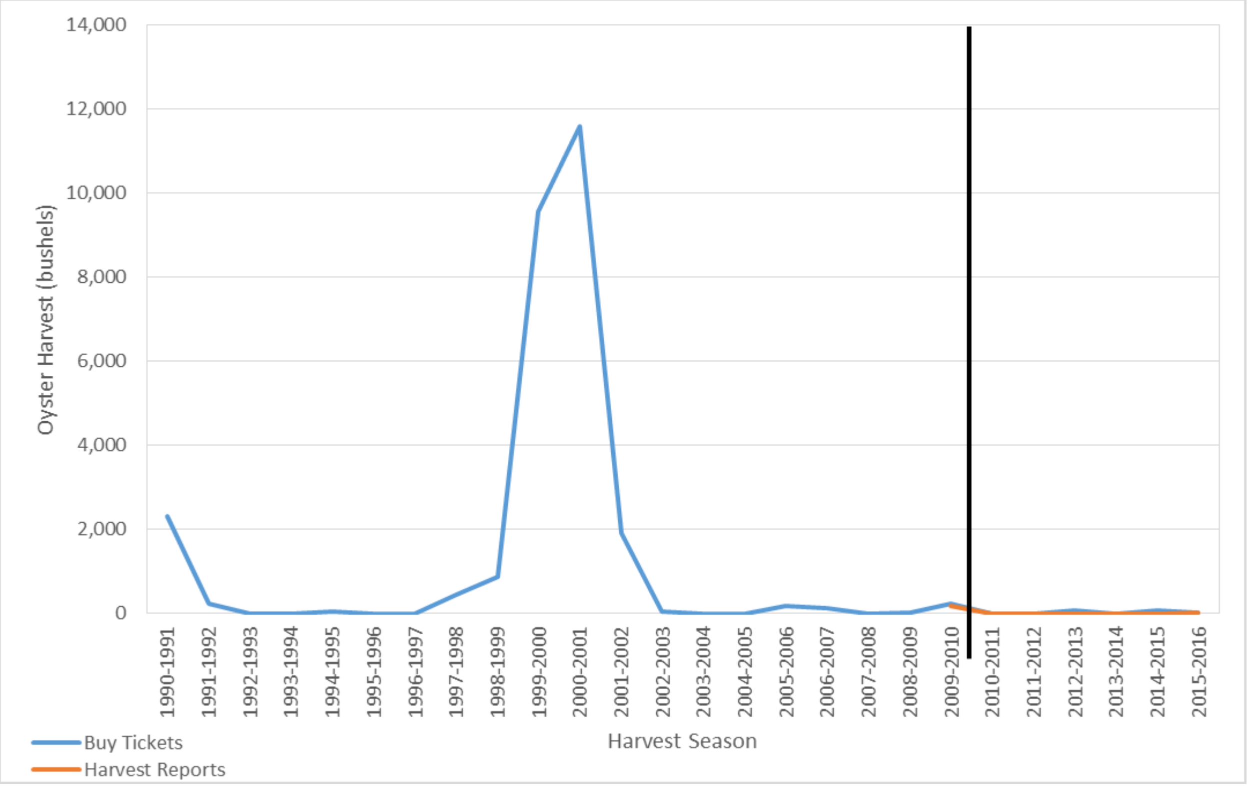


Figure A.51-11. Oyster harvest reported from seafood dealer buy tickets (1990-2016) and harvester reports (2009-2016) in the Wye River. In 2010, 54% of the Wye River became an oyster sanctuary (denoted by the black line).

Environmental Conditions and Ecosystem Services

The Chesapeake Bay Program Water Quality Data Hub recorded monthly water quality at station XGG2084 (38.867, -76.1929) on Mills bar in this area (Figure A.45-12). Surface chlorophyll a, salinity, secchi depth, total nitrogen, total suspended solids, and water temperature were measured from 2004 to 2006. Water quality was suitable for oysters during this time period.

We are unaware of any studies explicitly examining oyster ecosystem services in this area.

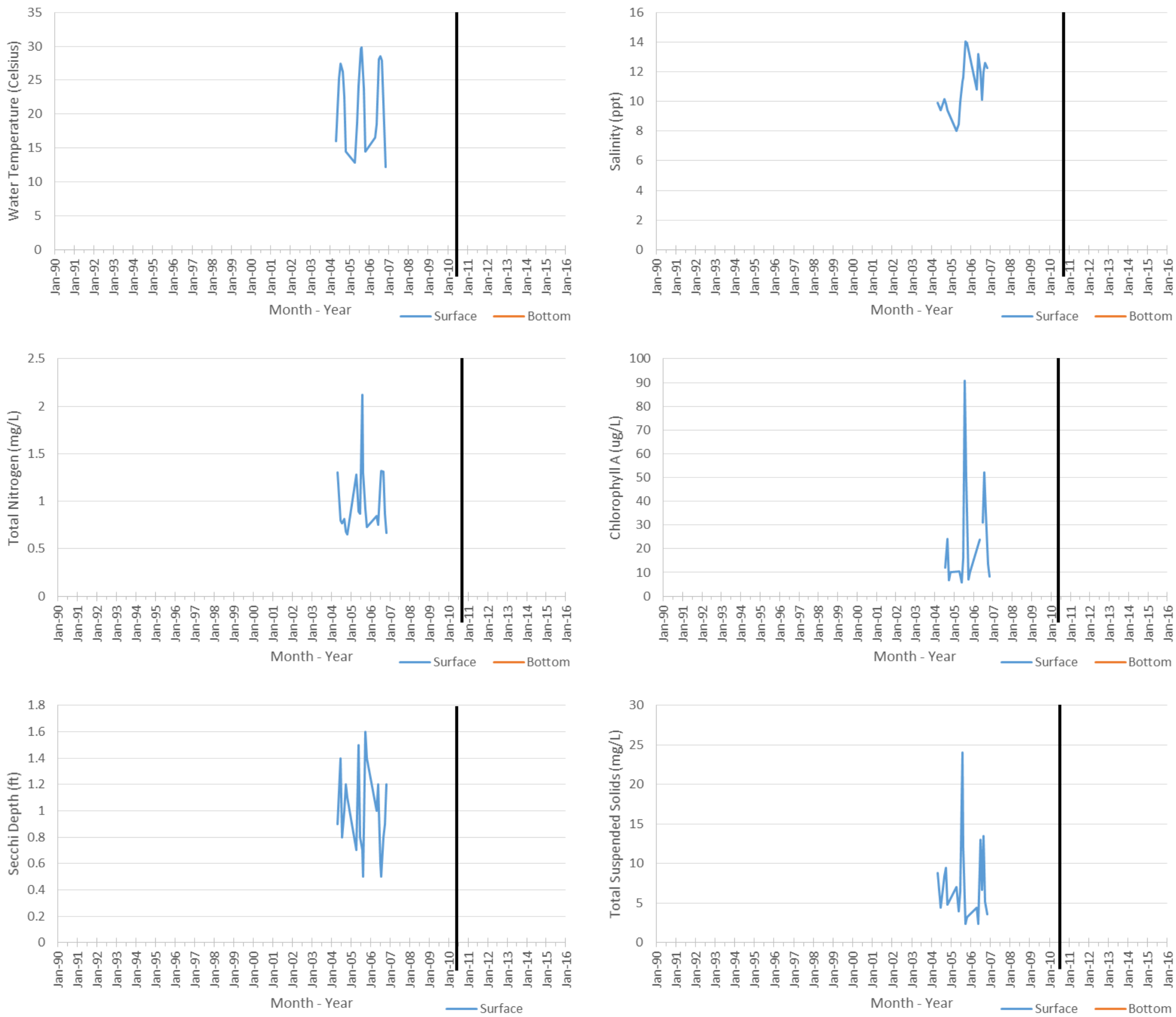


Figure A.45-12. Water quality data collected at Station XGG2084 from 2004 to 2006 within the area now established as Wye River Sanctuary. Black line denotes the date the sanctuary was established. Data from the Chesapeake Bay Program Data Hub.