APPENDIX A

OYSTER DEMOGRAPHIC MODEL

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Note to Readers of Appendix A

Appendix A describes an oyster demographic model (ODM) developed to predict oyster population dynamics for 10 years after the start of the proposed action and each alternative evaluated in the Draft PEIS. The ODM projects changes in oyster abundance by simulating the effects of management actions on three rates that determine the size of an oyster population, which biologists call vital rates. The three vital rates considered in the ODM are (1) the rate at which larval oysters are produced and successfully reach the spat life-stage (i.e., recruitment), (2) the rate of growth of individual oysters, and (3) the rate at which oysters die (i.e., mortality). In natural systems, these rates vary with environmental conditions and the characteristics of particular species of oyster and interact in ways that are difficult to envision without conducting complex calculations. The ODM is a Monte Carlo simulation that predicts the range of outcomes that might occur as a result of variation in the factors that influence those outcomes. The ODM was intended to serve as a tool for integrating data about vital rates collected from wild oysters in the Bay and from laboratory studies with additional information about their interactions with the environment and the outcomes of management actions (e.g., harvest and stocking) to project the size of the oyster population. Output from a larval transport model served as an input to the ODM to account for sources and dispersal of oyster larvae throughout existing habitat. The ODM also provides an estimate of the uncertainty in outcomes caused by variability in vital rates. This source of uncertainty was estimated by conducting many simulations (i.e., 1,000) in which vital rates were selected randomly from the range of values measured in previous studies. Mann and Powell (2007) emphasized that oysters in Chesapeake Bay cannot be considered a single population. The Bay's metapopulation actually comprises numerous exporting source populations and importing sink populations that interact in very complex ways that vary from year to year. The ODM was intended to be an assessment tool that could account for that complexity.

The ODM was reviewed by the Oyster Advisory Panel (OAP) throughout its development. The OAP produced a final review report dated July 12, 2007. The following are some of the most important limitations of ODM identified by the OAP:

- The size of the existing population of Eastern oysters in Chesapeake Bay could not be estimated reliably because no Bay-wide survey designed specifically to estimate abundance has been conducted.
- Insufficient data exist from which to model the rate at which habitat for oysters is being reduced by sedimentation, removal, or biological and physical decay.
- Parameterizations of vital rates for the Eastern oyster are based on data sets that are spatially and temporally limited and may not fully reflect the range of values that occurs in the Bay.
- Vital population rates for the diploid Suminoe oyster have been measured only in contained laboratory research studies, and rates for triploid Suminoe oysters have been documented in a limited number of geographic areas. Bay-wide vital rates for a population of diploid Suminoe oysters in Chesapeake Bay cannot be estimated unless the species is introduced.

The modeling team revised the ODM report and prepared a response to the OAP's review on October 8, 2007. In a final memo entitled "Comments on the ERA/EIS Proposed Approach," dated November 14, 2007, Dr. Brian Rothschild, Chair of the OAP, summarized the OAP's view of appropriate use of the ODM, suggesting that ODM results might be taken at face value with the condition that significant uncertainties are acknowledged as outlined in the OAP's report. That memo also concurred with the modeling team's conclusion that the ODM should not be modified to predict the growth of a population of Suminoe oysters in Chesapeake Bay. Peer reviews and responses are available at http://www.nao.usace.army.mil/OysterEIS/PeerReviews/homepage.asp.

As indicated in the Introduction to these appendices, the OAP was responsible for reviewing the full PEIS prior to its publication. The members of the OAP had their first opportunity to see how ODM results were used in all of the PEIS analyses during their review of a pre-draft version of the PEIS in the summer of 2008. The OAP concluded that PEIS analyses relied too heavily on ODM results, given the substantial uncertainties associated with ODM outcomes. Also, after the ODM documentation report was finalized, the modeling team learned that the data provided to represent growth rates of the Eastern oyster in Virginia waters were erroneous (actual growth rates are higher; R. Mann, VIMS, pers. comm.), which adds an additional source of uncertainty to the ODM projections. Revised analyses of the size of the oyster population completed after the pre-draft report was finalized are documented in Attachment 7 to this appendix. Those analyses estimated a starting population much larger than the one used in the ODM, contributing further to uncertainty in the projections.

In response to the OAP's concerns about the inappropriate use of ODM outcomes, analyses presented in the Environmental Consequences section of the pre-draft PEIS were substantially revised before the Draft PEIS was released to the public. ODM projections presented in this appendix are no longer presented in Environmental Consequences (Section 4 of Draft PEIS), and alternative approaches were used to evaluate the potential effects of the proposed action. ODM outputs are used in Section 4.1 of Draft PEIS to suggest the potential total magnitude of change in the abundance of oysters expected to result from implementing alternatives that involve only the Eastern oyster (Alts. 1, 2, and 3) at the end of the 10-year assessment period, and in Section 4.2 to characterize how the magnitude of those changes may result in different ecological influences among six state/salinity zones defined for analyses in the Ecological Risk Assessment (Appendix B). Although the time frame for issuing the Draft PEIS allowed for new analyses to be included in Section 4 of the PEIS, the available time was insufficient to allow developers to restructure and rerun the ODM in order to revise this appendix.

Supporting data and information used to develop and apply the ODM are documented in attachments to this appendix and were used in various analyses in Section 4.1, including estimating the current size of the oyster population in Chesapeake Bay (Attachment 3); estimating the current amount of oyster habitat and rate of loss of oyster habitat over the past 20 years (Attachment 1), describing alternative restoration strategies (Attachment 5), and estimating the size of the oyster population between 1994 and 2006 (Attachment 2). Calculations of the size of the oyster population between 1994 and 2006 presented in Attachment 2 were subsequently revised. The revised analyses are included in this appendix as Attachment 7. Since the report was finalized, an addendum was added to Attachment 3 that describes how a starting 2004 population size for market-size oysters in Virginia was derived.

A Demographic Model of Oyster Populations in the Chesapeake Bay to Evaluate Proposed Oyster-Restoration Alternatives

4 October 2007

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From the chaos in which I found the business, so far as regards statistical information, I have tried to evolve some facts and figures by which, by showing the importance of the trade, may cause a more careful study to be made of the means to arrest the present depletion of the beds and provide ways for increasing the natural supply of oysters. (Edmonds 1887)

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Preface

This manuscript describes a demographic model for the Eastern oyster (*Crassostrea virginica*) in the Chesapeake Bay that was developed using existing data from many researchers and sources. The authors developed the model structure, parameterized most of the input variables, and implemented the model in the Java™ programming language; however, the model includes several components provided by other scientists. The Maryland Department of Natural Resources (MDNR) estimated the population of oysters at model initiation, identified available substrate that oysters could occupy, and defined oyster restoration scenarios to be projected. We describe MDNR's procedures for developing those components briefly in the text; their detailed documentation of those procedures is presented in appendices to this report. The distribution of spat settlement among bars employed in the demographic model is based on output of a larval-transport model developed by E. North and colleagues at the University of Maryland Center for Environmental Science. Output of the demographic model, in terms of oyster abundance, will serve as input to a model developed by C. Cerco, U.S. Army Corps of Engineers Environmental Laboratory, to predict the potential effects of oyster restoration alternatives on water quality and SAV.

We thank the many researchers who contributed data and expert advice for use in the model. From the Maryland Department of Natural Resources, Fisheries Division: L. Barker provided the abundance and distribution of the oyster population at model initiation; E. Cambell, provided the detailed management scenarios to be modeled for native-oyster restoration; P. Genovese modeled salinity of oyster bars as a function of annual precipitation levels; K. Greenhawk developed the map of the estimated amount habitat that oysters could occupy; P. Jones reviewed the model and developed the report on native-oyster restoration alternatives. C. Judy provided survey data, expert advice, and model review; T. O'Connell provided expert advice and reviewed the model; M. Tarnowski served as a co-author for the mortality-estimation portion of model, and provided survey data, expert advice, and model review. R. Mann and J. Harding, Virginia Institute of Marine Science, provided density and growth data for oysters in the James River. From the University of Maryland Center for Environmental Science, J. Coakley provided height-frequency analysis used to estimate growth in Maryland, R. Newell provided expert opinion on oyster biology and suggestions for modeling Suminoe oyster dynamics, and K. Paynter, provided data used to estimate oyster growth. J. Wesson, Virginia Marine Resources Commission Division of Fisheries Management, provided descriptions of native-oyster restoration alternatives for Virginia, data on available oyster habitat and harvest estimates for the James River. S. Ford, Rutgers University, provided expert advice and review of the mortality estimation methods. We also thank the EIS independent oyster advisory panel consisting of J. Anderson, University of Rhode Island, M. Berrigan, Florida Department of Agriculture and Consumer Services, M. Heral, French Research Institute for Exploitation of the Sea, R. Mann, Virginia Institute of Marine Science, E. Powell, Rutgers University, M. Roman, University of Maryland, and B. Rothschild, Dartmouth University, for reviewing the model.

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1.0 Introduction

The U.S. Army Corps of Engineers, the states of Maryland and Virginia, and several cooperating agencies are evaluating strategies for restoring depleted oyster populations in the Chesapeake Bay. Nine alternative strategies are being considered that include various combinations of restoration of the native Eastern oyster (*Crassostrea virginica*), augmentation of wild populations with aquaculture, and introduction of the non-native Suminoe oyster (*C. ariakensis*; the proposed action). Recent research indicates that Suminoe oysters are resistant to diseases that have been an important cause of the decline in native oyster populations; however, Suminoe oysters could have undesirable effects on the ecosystem. The lead agencies, therefore, are conducting an ecological risk assessment and preparing a programmatic Environmental Impact Statement (EIS) to evaluate the relative risks and benefits of each alternative management strategy. A major component of this assessment has been the development of a demographic model to predict oyster population dynamics for ten years after the start of each alternative restoration approach. The purpose of this document is to describe the structure and parameterization of the oyster demographic model.

An important consideration in modeling population dynamics of oysters is that differences in the physical and chemical characteristics of the water have biologically significant effects on the spatial structure of populations. A suitable model must account for differences in recruitment, growth, and survival rates among oyster bars distributed throughout the estuary. Water current is one characteristic that affects oyster populations. Currents mix water of different temperatures and salinities, and disperse larval oysters. The locations of bars in relation to currents causes some bars to act as sources of larvae that are exported and others to act as sinks that receive large numbers of larvae. Differences in vertical swimming behavior between Eastern and Suminoe oysters (Newell et al. 2005) also interact with current, resulting in different patterns of transport between the two species (North et al. 2006, 2008) and different population distributions. Another hydrologic characteristic that strongly affects oysters is freshwater tributary inflow. Freshwater inflow controls salinity at individual bars, which strongly affects oyster recruitment and survival. Storms that cause freshets can kill oysters in upstream bars by reducing salinity below oysters' physiological tolerance. Tributary inflow and salinity also affect recruitment of spat. Areas of the Bay with high salinity generally exhibit the greatest recruitment (Ulanowiticz et al. 1980; Tarnowski et al. 2003); therefore, recruitment is greater in downstream portions of the Bay located nearer to the ocean and during dry-weather years, when freshwater inflow is reduced. Salinity also affects survival of Eastern oysters via disease prevalence. Dermo disease, caused by the parasite *Perkinsus marinus,* and MSX disease, caused by the parasite *Haplosporidium nelsoni*, are major causes of mortality for Eastern oysters (Ford and Trip 1996). Both diseases are more prevalent in high-salinity water.

To account for the heterogeneous population structure among oyster bars in the Chesapeake Bay, we developed a spatially explicit model that incorporates interactions between hydrologic conditions and oyster populations. The demographic model accounts for variation among bars in several ways. First, larval oysters are distributed among bars by linking the demographic model with predictions from the larval-transport model developed by North et al. (2006; 2008). The larval-transport model combines hydrodynamic modeling of the Bay during different weather conditions (inflow, wind, tides, etc) and observed characteristics about the vertical swimming behavior of larvae to forecast the distribution of larvae among bars. A second source of spatial variation included in the demographic model is salinity, which is predicted for each bar based on location and weather and used to adjust recruitment, disease prevalence, and natural mortality rates. Finally, variation in growth is modeled spatially at the level of state (Maryland or Virginia portions of the Bay) to match empirical data, although growth rates did not appear strongly related to inflow or salinity.

A large set of variables related to larval dispersion patterns, growth, recruitment, survival, hydrologic conditions, available habitat, and starting population size were parameterized for inclusion in the model. For clarity, we describe the specific parameterization of individual components first, then implementation and performance of the model in general. First we list the data sources for estimating input parameters and how their mean trends and variability were calculated for inclusion in the model (Section 2). We then describe how these components were combined to predict oyster abundance in the demographic model in Section 3, Model Structure. We follow the description of the model with a list of specific management scenarios simulated (Section 4), and an evaluation of model performance using a data set from the James River, Virginia (Section 5). Finally, we provide results for model runs involving the restoration alternatives that relate to Eastern oysters only (EIS alternatives 1-3; Section 6). Finally, we describe additional model runs to quantify model sensitivity (Section 7).

2.0 Data Sources and Parameter Estimates

2.1 Maryland Department of Natural Resources Annual Fall Survey

The Maryland Department of Natural Resources' (DNR) annual fall dredge survey served as an essential source of data for the demographic model. Data from the survey were used to parameterize growth, recruitment, and survival. Because these data were included in many parameterizations, we describe the survey in general here and refer to specific components as appropriate in the following sections. It is important to note that this survey was not designed for the purpose of developing model parameters, but provided the only comprehensive source of data useful for that purpose. As described for individual parameter estimation procedures, this required that the data be manipulated in a number of different ways. Additional details of DNR's fall survey are described by Tarnowski et al. (2003) and Coakley (2004).

Data collected from representative oyster bars throughout the Bay from 1980 to 2006 as part of the annual survey were used in the demographic model. The survey was conducted in October or early November each year using a standard 36-in wide (91.4-cm) oyster dredge to collect live oysters and shells of dead oysters. Approximately 200 to 400 representative bars throughout the Maryland portion of the Bay were sampled each year. Bars were divided into several classifications that received varying levels of sampling effort, as described below.

Forty-three bars known as "disease bars" were sampled from 1990 to 2006 to estimate disease prevalence. Disease bars were sampled by combining two ½-bushel subsamples from replicate dredge tows into a composite sample of one Maryland bushel (0.046 m^3). All oysters in the sample were counted and measured to the nearest 5-mm shell height (defined as the distance between the shell hinge and the farthest point from the hinge where the two shell halves meet). Spat were also identified morphologically. Spat have one valve that is thinner and narrower than the other (the lower valve if they are oriented parallel to the substrate). The number of articulated shells of dead oysters (known as boxes) was recorded for all bars sampled. A subsample of 30 oysters that were 40 mm or larger from each bar were diagnosed for the presence of Dermo and MSX diseases. We used these data to estimate mortality rates in the demographic model. The data were also included in modeling growth rates and the stock-recruitment relationship.

Fifty-three bars known as "key bars" were sampled each year and used to calculate an annual index of spatfall. Thirty-one of the key bars were also disease bars in the period from 1990 to 2006. Key bars were sampled using the same methods as disease bars, except that no disease sampling was conducted, and shell heights were measured to the nearest 5 mm only at bars that were also disease bars. For the remainder of the key bars, adult oysters captured were measured to the nearest size category as small (41-75 mm) or market-size (≥ 76 mm)[1]. Spat were identified morphologically at all bars as described above. These data were used, in part, to model growth rates and the stock-recruitment relationship in the demographic model.

At an additional 95 to 266 bars sampled per year (mean 202), adult oysters were measured to the nearest size category as small (41-75 mm) or market-size (≥ 76 mm), and spat were identified morphologically. These included managed bars where shell or seed had been planted and natural bars where there had been no management. Some of these bars were "seed production" areas that were established to produce seed oysters when a large spat set occurred. If a large spat set occurred, some spat were relocated to bars in other areas with lower disease pressure. Seed-production bars were sampled by pooling five, 0.2-bushel subsamples from replicate tows. All other bars were sampled by collecting one, 0.5-bushel (0.0223 m^3) sample. These data were included in the demographic model to estimate the starting population and stock-recruitment relationship.

2.2 Available Habitat

Procedures used to develop the oyster habitat layer are described in detail in a DNR internal report by K. Greenhawk dated December 2005 (Attachment 1).

[1] The size categories of spat, small and market have traditionally been used in oyster surveys in the Bay but do not have consistent biological meaning; while the category of spat always consists of a single yearclass, the small and market categories may include multiple yearclasses of oysters.

The total amount of habitat available for oyster settlement in the Bay was estimated based on historic survey data, records of leased-bottom culture areas, and known oyster restoration sites. Major sources of data included the Maryland Bay Bottom Survey conducted from 1975 to 1983, and an earlier study conducted by Yates from 1906 to 1911. These data were combined in a geographic information system to produce a series of polygons indicating areas that generally contained cultch or hard-bottom substrate suitable for oyster settlement. The amount of habitat has greatly decreased since much of the survey work was conducted in the 1970s and 1980s due to sedimentation. To account for the estimated reduction in habitat, polygons were reduced proportionally but retained the same center location (most were reduced to 29.17% of their original area; Smith et al. 2005).

A total of 8,480 polygons were identified and included as individual oyster bars in the demographic model. Polygons varied greatly in their size, relief, and abundance of oysters. Some polygons consisted of smaller areas of shell that were aggregated but had some unsuitable habitat between them. Although not all polygons resembled classical three-dimensional reef structures, we refer to them consistently as “bars” throughout this manuscript.

2.3 Starting Population

Procedures used to estimate the starting population in Maryland are described in detail in two DNR internal reports: one by K. Greenhawk and T. O’Connell dated June 2007 (Attachment 2), and one by L. Barker dated 14 March 2007 (Attachment 3).

The abundance, distribution, and size structure of the initial population of oysters at the start of all scenarios was based on data provided by MDNR for Maryland, and by R. Mann (Virginia Institute of Marine Science) for Virginia, for the year 2004. In Maryland, the densities of small and market-size oysters were estimated for each basin from bars sampled in DNR’s fall dredge survey (Section 2.1), as described by Greenhawk and O’Connell (2007; Attachment 2). Size-specific data obtained from the nearest disease bars sampled in the survey were used to estimate the size structure (by 5-mm size class) and proportion of spat, by National Oceanic and Atmospheric Administration (NOAA) regions. After size frequencies and densities were calculated for each NOAA region, total populations were calculated by expanding densities for each 5-mm size class by the estimated habitat available (Section 2.2).

An important limitation of the DNR survey is that the area swept by dredge tows was not recorded historically because the survey was not designed specifically to estimate population size. The area swept is needed to estimate relative or absolute density. The DNR conducted a study in 2001 and 2002 to estimate the mean tow area needed to collect one bushel of oysters (Attachment 2). Based on the study, DNR calculated densities assuming mean areas swept of 78 m^2/bushel and 10% dredge catch efficiency for all dredge tows in all years. We considered these data to be suitable for modeling the starting population in Maryland with unestimated variance. However, this limitation makes the data unsuitable for analysis as a time series of historical abundance, and the data could not be used for model validation.

The starting population for Virginia was estimated based on surveys and data synthesis conducted by the Virginia Institute of Marine Science, and published by the

Chesapeake Bay Program (Virginia Institute of Marine Science 2004 Chesapeake Bay Oyster Population Estimation; http://www.vims.edu/mollusc/cbope/vabasin.htm; and R. Mann and J. Harding, pers. comm.). Estimates were made for each basin based on a combination of fishery-independent survey data using patent tongs, fishery-dependent data, surveys of restoration efforts, and aquaculture data. The estimated total number of oysters was allocated to bars in the habitat layer (Section 2.2) in proportion to bar size. The size distributions (5-mm classes) were estimated differently depending on the basin because the amount of data varied. For the James River, we used the observed size-distribution data for 2004. For the Great Wicomico, Rappahannock, and Piankatank rivers, we used the average size distribution off all three rivers in 2004 because individual sample sizes were relatively low. For the Potomac River, Eastern Shore, and Tangier areas of Virginia, we used the average size distribution from the Maryland portions of these basins because few samples were taken in Virginia. For the York/Mobjack, Lynhaven, and Poquoson/Back basins, we used a size distribution based on unpublished data provided by R. Mann and J. Harding. Similarly to the Maryland data, we considered the Virginia data to be suitable for use as a starting population but inappropriate for use in additional model validation. This is because the precision and accuracy of the data from some of the input sources could not be estimated.

The starting population was estimated to be larger in Virginia than in Maryland (Table 1). The number of market size oysters was only about 35% greater in Virginia, but the number of small oysters was estimated to be nearly ten times greater, and the number of spat was estimated to be more than 45 times greater. The starting population is depicted graphically in Figure 1, and described in greater detail in Attachment 2 (Maryland), and at http://www.vims.edu/mollusc/cbope/vabasin.htm (Virginia).

2.4 Flow Regime

2.4.1 *Weather years*

The annual flow regime was entered into the model as a categorical variable called "weather year," with three levels: dry, average, or wet. Weather years were used to adjust salinity (Section 2.5), intensity of disease (Section 2.9), and freshets (Section 2.4.2) on individual bars. Weather years also had cascading effects via salinity in the model, because salinity affected recruitment (Section 2.6), and natural mortality rates (Section 2.10).

Weather years were classified based on annual discharge into the Bay from 1937 to 2005, as reported by the U.S. Geological Survey (USGS) Chesapeake Bay Activities (Figure 2; http://md.water.usgs.gov/monthly/bay.html). Years when annual inflow was in the 25^{th} to 75^{th} percentile were defined as average. Years when inflow exceeded or failed to reach this range were classified as wet or dry years, respectively. Weather-years were simulated in the demographic model by randomly selecting a ten-year block from the historical data. A starting year from 1937 to 1996 was selected randomly, and the type of weather for that year and the next nine were used for years 1 through 10 in the model.

Years were selected in blocks because the climate historically has tended to shift between wet and dry conditions over several years. That is, wet or dry years tended to occur in clusters through time; however, rainfall patterns have shifted between wet and dry years more randomly during the last ten years. These unpredictable changes in climate may become more prevalent as global temperatures increase (U.S. Global Change Research Program 2000). An additional set of model runs was conducted to quantify sensitivity to weather patterns in which the type of weather was selected randomly for each year, and the probability of selection was equal to the proportion of each type of weather-year in the historical data (25.37% dry, 52.24% average, and 22.39% wet). These additional runs are reported in Section 7, Model Sensitivity.

2.4.2 *Freshets*

Freshets severe enough to kill oysters were simulated for individual bars in the demographic model. Freshets occurred only during wet years on bars that were predicted to have low salinity (Section 2.7). During a wet year, summer freshets occurred at random with an 8.3% (1/12) chance on low-salinity bars, and winter freshets occurred with a 16.7% (1/6) chance. If a winter freshet occurred, 5% of the oysters in all size classes were removed from the affected bar for the current year. If a summer freshet occurred, 65% of all oysters were removed. Because a complete historical record of freshet occurrences is not available for all portions of the Bay, these rates were estimated based on the data and recollection of a group of regional researchers at a working group meeting held 25 October 2005 at Horn Point Laboratory, Maryland. We note that freshets have the same average effect on all alternatives simulated; therefore, freshets are not expected to introduce a bias into the comparison of alternatives, even if their relative frequency of occurrence was not estimated precisely.

2.5 Salinity

The salinity submodel was provided by P. Genovese MDNR in the form of spreadsheet files.

Salinity was assigned to each bar for a model year based on extrapolation of measurements taken by the Chesapeake Bay Program at monitoring stations throughout the Bay during 1995 to 1999 (Figure 3). These included two dry years (1995 and 1999), two wet years (1996 and 1998), and one average year. The MDNR used this range of weather-years to predict the effects of freshwater inflow on temporal variation in salinity at individual bars. A salinity class was assigned to each bar in the model for each weather-year based on the nearest monitoring station, or by interpolating between stations by kriging. Bars were assigned to one of three salinity classes as low (< 11 ppt), medium (11-15 ppt), or high (≥ 15 ppt). These ranges coincide with biologically important thresholds for changes in oyster survival and recruitment rates reported in the scientific literature (e.g., Calvo et al. 1999, 2001; Grabowski et al. 2004; Jordan et al. 2002). Eastern oysters generally do not live in areas where salinity is less than 5 ppt for extended periods (Shumway 1996). We assigned salinities to bars for a simulated year in the demographic model by randomly selecting the 1995 or 1999 salinity pattern if the year was dry, and the 1996 or 1998 salinity submodel if the year was wet. During average weather-years, bars were assigned salinity classes based on the 1997 salinity submodel.

2.6 Recruitment

2.6.1 *Recruitment Data Sources*

Recruitment of spat onto oyster bars was modeled using the empirical relationship between the relative numbers of spat counted in DNR's annual fall survey (Section 2.1) and the estimated number of sexually mature female spawners from counts of market-size oysters. The relationship was modeled using data collected between 1980 and 2006, after yearly reproduction and spatfall. To avoid bias, the data were limited to bars that were not seeded with spat from elsewhere or planted with shell during the last five years to augment production. Within this set, oyster heights were measured with different precision depending on the kind of bar sampled, as described in Section 2.1. Data were available for 41 to 62 bars per year (mean 51) where oyster heights were measured to the nearest 5-mm height class (disease bars from 1990-2004), and 95 to 266 bars per year (mean 202) where height was measured to the nearest size category (spat 0-40 mm, small 41-75 mm, or market ≥ 76 mm).

Two additional relationships obtained from the literature were used to model the stock-recruitment relationship. First, the ratio of female to male oysters was assumed to increase with mean size of oysters as described by Kennedy (1983) and presented in Table 2. This relationship reflects the fact that oysters are hermaphroditic and begin changing from males to females as they grow (Kennedy 1983). Second, the number of eggs attributable to female oysters of different size classes was based on the relationship

$$(1)\quad F_{ind} = 39.06 \times (0.000423 \times H^{1.7475})^{2.36},$$

where F_{ind} is the fecundity (number of eggs produced) of individual females in millions, and H is shell height in millimeters (Mann and Evans 1998).

2.6.2 *Recruitment Model*

Stock-recruitment relationships in fisheries typically project numbers of recruits as a function of numbers or biomass per unit of area (e.g., Quinn and Deriso 1999). For this model, absolute abundance or biomass of oysters by size could not be estimated from the survey data (Section 2.3); thus, a typical stock-recruitment approach could not be employed. Because of this data limitation, we modeled recruitment based on the ratio of spawners to spat measured in the survey. First we verified that relative numbers of spat and adult oysters could reasonably be estimated from dredge surveys based on the scientific literature. Chai et al. (1992) compared the sampling efficiency of dredge surveys and diver-harvest surveys using a replicated study in the Chesapeake Bay. They found that density estimates from dredge surveys were only 2-32% of the diver estimates (Figure 4A). However, the relative numbers of spat, small, and market-size oysters were similar between the two survey methods (Figure 4B). The site-by-site comparison was not strictly valid because the dredge survey sampled a significantly larger area from each bar than the diver-harvest survey. Despite this limitation, the study suggests that there is no consistent bias in the ratios of spat to small or market-size oysters derived from dredged samples.

That is, spat do not appear to be captured disproportionately more or less frequently than larger oysters in a dredge. We proceeded to model using the ratio of spawners to spat in fall survey data, which was the only information available at a broad spatial scale with which to model the stock-recruitment relationship.

The ratio of spat to female spawners measured in DNR's survey was not directly comparable across bars because fecundity increases non-linearly with oyster size (Mann and Evans 1998). Therefore, the number of spat per spawner depends on the size structure of the population. One method of dealing with this problem is to calculate a stock-recruitment relationship between the biomass of the spawning stock and corresponding number of recruits (Quinn and Deriso 1999). This method incorporates information about the size structure of the population because biomass is a function of the number of animals present and their sizes. Although biomass was not measured directly in the DNR survey, it could be estimated using an empirical relationship between oyster height and weight. The relationship listed in Equation 1 includes a conversion from height to weight, and an additional conversion from weight to estimated fecundity for an oyster of a given size. We assumed that the size-specific fecundity relationship, as determined from laboratory experiments (Mann and Evans 1998), would provide a better estimate of an oyster's contribution to the number of recruits than an estimate based on biomass alone. A similar fecundity relationship will also likely be the only information available about the stock-recruitment relationship for Suminoe oysters. Our strategy for modeling the stock-recruitment relationship was to adjust the estimated number of female spawners using the egg-size relationship in Equation 1 so that they were expressed as the number of females of a standard size that would produce the equivalent number of eggs. Numbers of females were converted to equivalent numbers of standard-size females using size-specific estimates of fecundity as a common currency. In this way, the egg-size relationship was used to account for differences in sex ratios and size distribution among bars and years, although eggs themselves were never actually quantified. The number of spat enumerated in the survey was then modeled as a function of the number of standardized female oysters to predict spat production in the demographic model.

Oyster recruitment is also strongly affected by, and generally positively related to salinity (Ulanowicz et al 1980; Tarnowski et al. 2005). Therefore, we developed the recruitment submodel and estimated recruitment in the demographic model by salinity class. Numbers of sexually mature female oysters were standardized for each year and salinity class (low, medium, or high) using the following procedure. First, means were calculated for the number of eggs produced by market-size and small oysters for the subset of bars where 5-mm height classes were sampled (disease bars). The number of female oysters present was estimated for each bar and height class by multiplying the total number of oysters counted in the sample by the appropriate sex ratio listed in Table 2:

$$(2)\quad Nf_{bc} = N_{bc} \times R_r,$$

where Nf is the number of sexually mature female oysters; N is the total number of oysters; b is bar; c is 5-mm size class; R is the sex ratio; and r is the class listed in Table 2.

The number of eggs produced was calculated by bar and 5-mm size class using Equation 1; the midpoint of the height class was entered as the size of all oysters in the class (e.g., 42.5 was entered as the size of oysters in the 40-45 mm height class):

$$(3)\quad F_{bc} = Nf_{bc} \times F_{ind\ bc},$$

where F_{bc} is the total fecundity for a bar and 5-mm size class.

The mean number of eggs produced by a small ($\overline{F}_{small}$) or market-size ($\overline{F}_{market}$) oysters for each year and salinity class was calculated as

$$(4)\quad \overline{F}_{small} = \frac{\sum_{b=1}^{B} \sum_{c=42.5,47.5...}^{72.5} F_{bc}}{\sum_{b=1}^{B} \sum_{c=42.5,47.5...}^{72.5} Nf_{bc}}, \qquad \text{and} \qquad (5)\quad \overline{F}_{market} = \frac{\sum_{b=1}^{B} \sum_{c=42.5,47.5...}^{72.5} F_{bc}}{\sum_{b=1}^{B} \sum_{c=77.5,82.5,...}^{90} Nf_{bc}}$$

For years when no data were recorded by height class (1980-1989), average numbers were calculated for market-size and small oysters using the same procedure, except that numbers were also summed across years. Because the subset of bars sampled by 5-mm height classes was spread throughout the Bay, these numbers were approximately representative of the size distribution of oysters within the larger categories of small or market-size for a year and salinity class.

After mean fecundities were calculated, Equations 4 and 5 were used to extrapolate the total number of eggs produced for all bars sampled in a year and salinity class, not just those where shell heights were measured to 5-mm height classes. This was done to obtain mean fecundities for a year and salinity class that better reflected the size structure for the entire Bay, because many more bars were sampled where measurements were recorded only to the level of small or market sizes. First the numbers of small and mature female oysters were calculated for all bars sampled using Equation 2, except that we denote the results as Nf_{small} and Nf_{market}, respectively. The sums of these numbers were multiplied by the mean fecundities for small and market-size oysters and added to obtain total fecundity for a year and salinity class (F_{tot}).

$$(6)\quad F_{tot} = \overline{F}_{small} \times Nf'_{small} + \overline{F}_{marketl} \times Nf'_{market}$$

The total number of eggs produced by market-size and small oysters was then divided by the number of eggs produced by a 77-mm oyster (Equation 1) to estimate the equivalent number of standardized female oysters present in a year and salinity class. We selected 77 mm as a standard size because the 75-mm to 80-mm size class was observed most frequently in the data set when data for all years were pooled:

$$(7)\quad Ns = \frac{F_{tot}}{25.7023},$$

note that $39.06 \times (0.000423 \times 77^{1.7475})^{2.36} = 25.7023$, Equation 1.

It is well documented that episodic large oyster spat sets periodically occur in the Bay (e.g., Ulanowicz et al. 1980; Tarnowski et al. 2005). This phenomenon was accounted for in the recruitment submodel in the following manner. The number of spat produced was calculated as the number of standardized females multiplied by a ratio of spat to standardized female spawners (*Ns*). The specific ratio used was selected randomly from a submodel that reflected either a typical recruitment year or an episodic large spat set. Unusually large spat sets were identified in the survey data by calculating which spat-to-spawner ratios exceeded the 75th percentile of all of the data by more than 1.5 times the interquartile range (i.e., outliers on a boxplot; Emerson et al. 1983). This threshold was 3.0 spat per female spawner (Figure 5). Of the 78 total observations, 58 were in medium or high salinity, and 10 of these were outliers with spat-to-spawners ratios that exceeded 3.0. No outliers occurred in low salinity. Therefore we modeled episodic large spat sets for a year in the model with a probability of 10/57. If a large spat set occurs, the number of spat on bars located in medium or high salinity is calculated by multiplying the number of standardized females by a ratio that is randomly selected from one of the ten extreme values (3.30, 3.50, 3.60, 3.70, 4.00, 5.08, 5.11, 7.30, 7.93, and 8.90). Large spat sets never occur at low salinity bars in the model because they were never observed in the survey.

If a large spat set is not predicted to occur for a year (probability 68/78), numbers of spat are predicted based on spat-to-spawner ratios with the outliers removed. These ratios were modeled as functions of salinity with unequal variance among salinity classes. The resulting mean ratios from the categorical model were 1.44 (SE = 0.195) spat per female spawner in high salinity, 0.47 (SE = 0.082) in medium salinity, and 0.08 (SE = 0.018) in low salinity. All three estimates were statistically significant with $P < 0.001$. Ratios of spat to spawners are randomly selected for normal recruitment years in the model based on these relationships. A random residual is selected from the standard normal curve for each basin and year, and used to select a spat-to-spawner ratio for each bar based on the bars salinity:

$$(8)\quad Nspat = Ns \times (Ratio_s + SE_s \times Residual),$$

where *Nspat* = the number of spat produced on a bar in the model, *Ratio* is the mean ratio of spat to female spawners predicted for salinity class *s* (1.44, 0.47, or 0.08), SE_s is the appropriate standard error for salinity class *s*, and *Residual* is the randomly selected residual from a standard normal curve. Newly recruited spat were assigned to 5-mm height classes in proportion to the occurrence of spat in normal distributions of age-0 oyster sizes, as modeled for the growth portion of the demographic model (Section 2.7).

2.7 Larval Transport

Spat were distributed among some of the modeld bars according to the larval-transport model reported by North et al. (2006; 2008). The larval-transport model couples a hydrodynamic circulation model with information about the vertical swimming behavior of Eastern and Suminoe oysters to predict the proportions of spat that will set on each bar. The transport model run was for conditions that occurred in the Chesapeake Bay between 1995 and 1999. These years were selected to include a broad range of physical conditions such as wind, tributary inflow, and annual precipitation (Section 2.5). Separate runs were made for Eastern oysters and Suminoe oysters to reflect the fact that Eastern oyster larvae tend to swim up in the water column in response to salinity gradients, but Suminoe oyster larvae tend to swim down (Newell et al. 2005). The larval-transport model included predictions for 2,776 of 8,480 bars in the demographic model. However, that subset of bars accounted for 64% of the total habitat acreage in the habitat layer. The modeled predictions were incorporated into the demographic model as a 2,776 × 2,776 matrix of bars for each species and year simulated. Cells in the matrix indicated the number of simulated particles (representing oyster larvae) that were transferred from bars listed in columns of the matrix to bars listed in rows. For bars that occurred in the demographic model but not the larval-transport model, spat were assumed to be distributed evenly within the basin where they were located, in proportion to the bar's area. Larval-transport data were integrated into the demographic model by converting numbers in the matrix to proportions and allocating the estimated number of spat produced by each bar in the demographic model according to these proportions. For an average weather-year in the demographic model, the matrix for year 1997 was used to allocate spat. For dry or wet years in the demographic model, one of the two matrices for a corresponding weather-year was selected randomly with equal probability (1995 and 1999 dry, 1996 and 1998 wet).

2.8 Growth

Oyster growth rates were modeled in yearly increments as changes in shell height. The general strategy for modeling growth was to calculate a series of von Bertalanffy growth functions (von Bertalanffy 1938) and to select one of the growth functions for each simulation, with a probability based on an empirically measured mean annual growth rate and variability about that mean.

2.8.1 *Growth Data Sources*

Growth of Eastern oysters was modeled based on four sets of empirical data. Three of the sets were used to develop a model for use in Maryland waters and the Potomac River, and one set was used to create a model for Virginia waters, except for the Potomac River. This was because the empirically-derived growth rates for the upstream portion of the Bay in Maryland were greater than the empirically-derived growth rates for Virginia. We were informed that growth rates for basins other than the Potomac River in Virginia were similar to the rates in the James River (R. Mann, unpublished data and pers. comm.). Although some laboratory studies indicate that Eastern oyster growth rates are higher in high salinities than in lower salinities, growth rates in this model were not adjusted for salinity. This was because no significant differences were found among salinity classes in the empirical data from which the growth functions were developed. As a result, the trend in growth versus salinity employed here was opposite that found by other researchers; mean growth was slightly greater in low salinity than in high salinity. Such a discrepancy could be accounted for by site-specific environmental factors other than salinity.

The data sources were

(1) Coakley data – 29 bars in Maryland sampled as part of DNR's annual survey from 1990 to 2001 were analyzed by Coakley (2004). Heights-at-age were determined for these data using maximum-likelihood modal analysis on height frequencies. Mortality rates of larger oysters were relatively high because these data included many bars with high disease prevalence and some that were heavily fished (Coakley 2004). This caused fitted models of growth to be much lower than actual growth when ages 3 and greater were included in the data because the larger oysters of these ages were no longer represented; therefore, we restricted this data set to ages 0 to 2 in our model.

(2) Paynter data – 27 bars in Maryland that have been managed as a restoration project from 1998 to the present for the U.S. Army Corps of Engineers have been monitored by the University of Maryland Center for Environmental Science. Data were available for the period 1998 to 2004 (courtesy of K. Paynter, UMCES). Disease prevalence was low on these bars during the time period (although it was high elsewhere in the Bay), and no fishing occurred. Oysters were planted at known dates and measured four times per year to obtain growth estimates.

(3) Rothschild data – These data were obtained from seven studies where oysters of known age were planted in the Bay, primarily in Maryland and the central portion of the Bay. The studies were reported in the literature between 1950 and 1966 and summarized by Rothschild et al. (1994). Specifically, they were Beaven (1950 and 1953), Butler (1953), McHugh and Andrews (1955), Shaw (1966a and b), and Shaw and Merrill (1966). The data were restricted to studies that occurred before disease was prevalent in the Bay and where the authors reported no unusual mortality; consequently, growth rates reported in these studies are unlikely to be biased by differential mortality among size groups.

(4) Mann data – The Virginia model was based on a single data set from 17 bars in the James River that were monitored by the Virginia Institute of Marine Science from 1995 to 2003 (courtesy of R. Mann, VIMS). Age classes were determined through visual identification of height-frequency modes. Disease prevalence was relatively low, and the

bars received little or no fishing pressure; therefore, these data likely reflect the true growth rate of oysters in the James River and similar areas of the lower Bay.

2.8.2 *Growth Model*

Each data set provided measurements of mean height-at-age for a particular bar and year (Figure 6) that were assumed to come from a random sample of size-at-age data from all possible bars and years in Maryland or Virginia. Height-at-age was assumed to be normally distributed with an estimated mean equal to the mean height for that age and state, and standard deviation equal to the standard deviation of the same data. Our strategy was to develop a series of growth functions that reflected the spatial and temporal variability observed by fitting functions through a range of percentiles of these normal distributions at age, and selecting one of the resulting growth functions randomly (with replacement) for each bar and year in the demographic model.

For each state, growth was modeled as a function of age using the von Bertalanffy growth function:

$$(9)\quad H_t = H_\infty(1-\exp(-K(t-t_0))),$$

where H_t is the shell height at time t (a particular age); H_∞ is the asymptotic or maximum height that an average oyster is expected to achieve; K is the Brody growth coefficient (cf, Quinn and Deriso 1999); and t_0 is the time of oyster settling.

First, the mean height and standard deviation were estimated for each age 0 to 30 (the estimated maximum age an oyster could live; Kennedy et al. 1996). The mean height was calculated for ages 0 to 4, and the von Bertalanffy function was fit to these means using the non-linear, least-squares procedure of the 'nlme' library (Pinheiro et al. 2006) in the statistical software package R (Version 2.4.0; R Development Core Team 2006). Data for ages 5 and 6 were not used because too few points were available to estimate variance reliably. The mean heights at ages 5 to 30 then were estimated as the fitted values from the resulting function. Mean H_∞ was fixed at 177 mm for both the Maryland and Virginia models. This was the mean of all values reported in the studies summarized by Rothschild et al. (1994). We did not attempt to estimate H_∞ from the recent data sets because they did not include any very large, older oysters that would be needed to make the estimate without extrapolating well beyond the range of the data. The standard deviation of heights at ages 5 to 30 and H_∞ were estimated from the coefficients of variation for ages 0 to 4. The mean coefficient of variation for ages 0 to 4 (22% for Maryland and 17% for Virginia) was multiplied by the mean height at ages 5 to 30, and by H_∞, to obtain their estimated standard deviations. This approach assumes that variance increases in proportion to height, a pattern that commonly occurs for growth of fish and shellfish (Quinn and Deriso 1999) and fits the observed data well (Figure 6).

After the set of means-at-age and associated standard deviations was calculated, a set of 999 growth functions was generated for each state by fitting the von Bertalanffy function through the 0.1th to 100th percentiles (by 0.1) of each normal curve. For example, the growth function for the 50th percentile was calculated by fitting a model through the mean at ages 0 to 30 and H_∞ of 177. Growth then was simulated by randomly selecting one of the 999 functions, with replacement, for each basin and year and applying the curve to all bars in the basin.

An additional adjustment of the Paynter data set was required before those data could be integrated with the other data for Maryland. The other Maryland data were based on surveys taken during the fall; therefore, all heights-at-age could be combined to estimate a single normal distribution. That is, all oysters of a particular age were measured at about the same time – at the end of the annual growing season. In the Paynter data set, height measurements were taken at different times throughout the year. To standardize Paynter's data for use in the normal distributions, the von Bertalanffy function was fit to the data, and the modeled values at rounded age increments were used in the distributions (e.g, at ages 0, 1, 2, etc. at the end of the growing season).

Growth was simulated in the demographic model by randomly selecting a growth curve for a year and basin as described above and adding the difference in shell height that oysters in a 5-mm size class were calculated to have one year after growth along the curve, at the midpoint of the height class. This was necessary because the demographic model is not cohort based. Oysters are accounted for as the number on each bar by 5-mm height class. Thus, all oysters in a height class grow in lock step. A maximum size class of 320 to 325 mm was imposed to reflect the largest size that any oyster would be likely to attain (Kennedy et al. 1996; this differs from H_∞ [177] in that H_∞ is a mean maximum size with an associated distribution).

Biomass was estimated from the number of oysters in each size class using the conversion

$$(10)\quad \text{Biomass (g carbon)} = 0.0002115 \times H^{1.7475}$$

This relationship was obtained by dividing the conversion from shell height to dry weight reported by Mann & Evans (1998) by two to estimate grams of carbon (C. Cerco, U.S. Army Corps of Engineers, pers. comm.).

2.9 Disease Intensity

Individual oyster bars were ranked according to mean intensity of Dermo disease based on the observed frequency of diseased Eastern oysters at 'disease bars' surveyed by DNR annually from 1990 to 2005. Subsamples of 30 oysters from each of these bars were examined for Dermo and MSX diseases by the Sarbanes Cooperative Oxford Laboratory, Oxford, MD. Each bar was ranked as fitting into one of three 'tiers' of Dermo intensity. Tier 1 indicates the greatest intensity, and Tier 3 the least. Tiers reflect concentrations of pathogen in hemolymph or solid tissue (Gieseker 2001) of greater than 2.85 (Tier 1), 2.0 to 2.85 (Tier 2), or less than 2.0 (Tier 3). These boundary values indicate statistically significant break points in disease prevalence during the period, as determined using a multiple comparison based on Friedmans's Rank Sum Test (Tarnowski et al. 2003).

In the demographic model, a disease tier was assigned to a bar as a random function with probability equal to the observed distribution of mean disease intensity in DNR's survey (Table 3). Dermo was more likely to occur at high intensity (Tier 1) in dry years than in wet years. Disease tiers were assigned to bars independently of the previous year's tier. The effects of Dermo were included in the model by increasing natural mortality rates as Dermo intensity increased to match mortality rates calculated using DNR's survey data (Section 2.1).

The effects of MSX disease on eastern oysters were included in the model only if two or more dry years occurred in a row (based on data from M. Tarnowski, MDNR, personal communication). If two dry years in a row were encountered during simulation, MSX events were assigned to bars at random with a probability of 0.38 for low salinity bars, 0.71 for medium salinity bars, and 1.00 for high salinity bars. A bar's status in the previous year did not affect the probability of being affected by MSX. These probabilities were derived from a study of the Choptank River, Maryland, as described by Vølstad et al. (2008). The effects of MSX were modeled by increasing natural mortality rates as described in Section 2.10.

2.10 Natural Mortality

Procedures used to estimate natural mortality are described in greater detail in Attachment 4, an article by J. Vølstad, J. Dew, and M. Tarnowski that has been accepted for publication in the Journal of Shellfish Management.

We estimated natural mortality rates using data from DNR's fall oyster survey from 1991 to 2006 (200-400 bars per year; Section 2.1). Estimates were based on ratios of live oysters to articulated shells of oysters that had died recently (i.e., boxes; Southworth et al. 2005; Ford et al. 2006). Boxes were categorized as 'recent' if they contained tissue, or if there was no fouling or sedimentation on the inner surfaces of the valves. The general strategy for estimating mortality was to pool data across bars within the same size class (small or market), salinity zone, and measured disease intensity to achieve sufficient sample sizes, and then use recent box counts to estimate annual proportional mortality rates (Ricker 1975).

A key parameter of this model is the average time that boxes are assumed to remain in the recent category, which serves as an estimate of the time since death (TSD). This is because TSD is used to calculate proportional annual mortality. A shorter assumed TSD would correspond to a greater estimated mortality rate because recent boxes would be interpreted to have died in a shorter period. Vølstad et al. (2008; Attachment 4) estimated the mean time during which a box would be classified as recent in the Chesapeake Bay to be one to two weeks after death. They obtained this estimate by comparing mortality rates calculated using different sedimentation times with interannual patterns in salinity and disease intensity that are known to affect mortality rates. That is, estimated mortality rates increased in years when salinity and disease intensity were measured to be higher than average in the Bay, and vice-versa. To account for the uncertainty in time that oysters were categorized as recent, we calculated pooled mortality estimates for one to two weeks TSD. Pooled mortality rates were calculated from one-week and two-week estimates by combining bootstrap resamples from each type of estimate, as described below.

We calculated mean annual mortality rates for each size category (small or market-size), salinity zone j, and disease tier k, based on counts of live oysters and boxes from all bars sampled in the group over time ($i = 1,...,n_{jk}$), using the following equations:

$$(11) \quad s_{jk} = \frac{\sum_i live_{ijk}}{\sum_i (live_{ijk} + newbox_{ijk})},$$

$$(12) \quad m_{jk} = -\log(s_{jk}),$$

$$(13) \quad totm_{jk} = 1 - \exp^{(-m_{jk} \times T)}$$

where s_{jk} is the 1- or 2 -week survival rate; $live_{jk}$ is the number of live oysters; $newbox_{jk}$ is the number of recent boxes; m_{jk} is the instantaneous (1- or 2 -week) mortality; T is the expansion factor to the total number of weeks (20) during which natural mortality occurs (T = 20 for 1-week mortality, and T = 10 for 2-week mortality); and $totm_{jk}$ is the mean annual mortality rate.

These calculations correspond to instantaneous mortality rates (Equation 12) and annual proportional mortality (Equation 13) rates, as described by Ricker (1975). The ratio estimator (Equations 11) provides weighted-mean mortality across bars in which weights are proportional to the number of live and dead oysters at each bar. This was necessary because the distribution of mortality estimates for individual bars was highly skewed by catches with no boxes (i.e., mortality estimates of zero), so pooling was necessary to obtain means over all bars in a salinity class and disease tier. We assumed that the instantaneous mortality rate was constant from June through October and that most oyster mortality occurred during this period; therefore, the expansion factor, T, was set to calculate annual mortality for a 20-week period, approximately from June 1 to October 31. This is because most predation and disease mortality occurs in summer, and overwinter mortality rates are believed to be negligible in comparison (cf., Vølstad et al. 2008, and references therein).

We calculated mortality rates from Equations 11 and 13 and associated variances by bootstrapping (Efron and Tibshirani 1993). We ran 1,000 bootstrap resamples with one-week TSD, and 1,000 resamples with two-weeks TSD. Each resample consisted of n_{jk} randomly selected observations (with replacement) where n_{jk} was the number of samples collected across all bars over the time series of fall surveys, in the respective salinity zone and disease tier. We then pooled the two bootstrap distributions to obtain 2,000 resamples for each estimate of mean mortality. The standard errors for the annual mean mortality rates were estimated directly from the distribution of the bootstrap estimates and are reported in Table 4. These results matched the expected trends in mortality with changes in disease intensity and salinity, indicating that the estimates were credible (Figure 7; Vølstad et al. 2008).

Mortality rates for Eastern oysters were selected by bar and size category by selecting the appropriate rates for the bar's salinity class and disease tier (Table 4). Variation in mortality rates was simulated by adding a random residual selected for each basin and year to the estimate. This was calculated by selecting a number from the standard normal distribution and multiplying by the standard error associated with the estimate.

Spat were assigned the same mortality rates as small oysters on all bars. This is because estimates were made for fall, after most of the mortality for spat was expected to occur. The next period when appreciable mortality would likely occur would be the following spring through fall, when most spat from the previous year would be reaching small sizes.

2.11 Harvest

Eastern oyster harvest rates were estimated by dividing statewide reported landings in Maryland (courtesy T. O'Connell, DNR) by the statewide population estimates (Section 2.2) for years 1994 to 2004. On average, 47% of all market-size oysters were estimated to be harvested during this period. Confidence intervals could not be calculated for the population estimates, and reported landings sometimes exceeded population estimates for individual tributaries; therefore the estimated average harvest rate of 47% probably has a large, but unknown, variance. To bound the effects of harvest, we applied a range of harvest mortalities. We conducted model runs with harvest rates of 20%, 40%, 60%, and 80% of all market-size oysters on bars that were not in sanctuaries or protected areas. Harvest rates were modeled as the proportion of the market-size population present at the end of the fall that is caught during the winter harvest season. This corresponds to the exploitation rate (*F*; Ricker 1975) for the winter, after natural mortality for the calendar year is assumed to occur (Section 2.10). For runs that included harvest, some small oysters also were removed to reflect incidental harvest. The number of small oysters removed was equal to 10% of the total catch (Powell 2005). We assumed bars that could not be harvested legally (e.g., sanctuaries and closed areas) were respected completely (i.e., the model does not account for illegal harvest). Sanctuaries and closed areas composed 29% of all bars in the model, 23% of the total area of bars modeled, and 22% of the starting population of market size oysters.

2.12 Habitat Improvements

EIS alternatives 1 and 3 include restoration activity at the current level. Alternative 2 includes enhanced restoration, as specified by MDNR (details are presented in Attachment 5).

The model simulates the effects of restoration in two ways. First, spat planted on bars are added to the population after natural recruitment and larval transport are calculated. Planted spat are assumed to experience 50% mortality between the time they are planted and the end of the growing season for that year (C. Judy, DNR, pers. comm.). Their size distribution is assumed to be the same as that of their natural counterparts. The second method of habitat improvement incorporated into the model is shell planting, which improves recruitment of spat by creating additional substrate for settlement. This improvement is gradually lost as planted shell becomes covered with sediment. We modeled this relationship based on empirical data provided by DNR (C. Judy, pers. comm.) and published data describing the rate at which planted shell is inundated with sediment in the Chesapeake Bay (Smith et al. 2005).

The initial improvement in recruitment after planting shells was estimated from MDNR's data based on 155 samples of spat density (spat/bushel from standardized tows as an index to density) collected from 1994 to 2004 on bars that had been replenished with shells earlier in the same season. As a control, the density of spat was sampled at one or more bars that were located within 1.6 km (1 mile) of each replenished bar and that had not been replenished within the last five years. First the mean densities of adjacent unreplenished control bars were averaged to provide a single number for paired comparisons with each replenished bar. Then overall mean densities were calculated for replenished bars and unreplenished bars (i.e., the mean for unreplenished bars was a mean of means). A ratio of the resulting means was calculated to estimate the improvement in spat settlement that was associated with repletion of bars, and this ratio was used as a scaling factor for recruitment. On average, the index of spat density was 4.5 times greater on bars that had been replenished (219.3 oysters/bushel) than on comparable bars that had not been replenished within five years (48.6 oysters/bushel). We verified that the increase was statistically significant using a paired t-test ($t = 10.4$, $df = 154$, $p < 0.01$; data were transformed to $\log_e + 1$ to meet the assumption of equal variance among treatments).

The decline in condition of replenished bars over time was modeled using the function described by Smith et al. (2005):

$$(14)\quad \textit{Shell condition} = 1.593 + [0.939 \times \log_e(\textit{age})],$$

where shell condition was categorized into five levels. Condition-class 1 was the best condition, indicating that no sediment was present on the shells. Condition-class 5 was worst, indicating that shells were buried with sediment completely (after about 35 years). We assumed that condition-class 1 corresponded to newly replenished bars and that condition class-3 (i.e., shell cups and interstitial spaces sedimented, but entire shell outlines visible) corresponded to the condition of average unreplenished bars in the model (cf., Table 2 of Smith et al. 2005). We therefore used the function to model the effect of shell planting for shell conditions 1, 2, and 3 only.

We applied the rate of decay in Equation 14 to MDNR's data to model how the expected improvement in spat settlement at replenished sites (a scaling factor in the model) degrades back to the baseline level (i.e., a scaling factor of unity) at unreplenished sites over time. Replenished sites that follow this function degrade non-linearly from about condition-class 1 to condition-class 3 by year 5 (Figure 8). The same rate of decay in habitat improvement was applied to DNR's data to estimate the recruitment scaling factor for each year after replenishment. Replenished bars were assigned a scaling factor of 4.5 for the first year to match the observed data, and modeled scaling factors of 3.0, 2.1, 1.5, and 1.0 for years 2 through 5 following the rate of decline in the above function.

The scaling factors were used to adjust the number of spat recruited to replenished bars in the model until replenishment no longer improved spat set above the level of a natural bar. That is, the number of spat predicted from modeling for an unreplenished bar would be multiplied by 4.5 for replenished bars the first year, by 3 in the second year, etc. Replenishment attracted no more spat than natural bars in year 5, as indicated by a scaling factor of 1.

3.0 Model Structure

The demographic model is spatially explicit. It projects abundance of oysters internally by 5-mm size class and individual bar, although results are aggregated to larger spatial scales for output. The model starts with the current state of the population in the fall, either as starting values at the beginning of a simulation or output from the previous year. The steps in modeling oyster dynamics for an individual bar *j*, year *i*, and population *P* (i.e., Eastern oysters or Suminoe oysters) are depicted in Figure 9.

First the type of weather-year is assigned for year *i* (Section 2.4.1), and salinity is assigned to each bar based on its location and the type of weather-year (Section 2.5). If the simulation includes harvest (Alternatives 1 and 2 for Eastern oysters, Section 4), and the bar may be legally harvested (i.e., it is not located in a sanctuary), a portion of the market-size oysters equal to the estimated harvest rate is removed from the population. A smaller portion of the small oysters also is removed. The portion is calculated based on the harvest rate so that small oysters constitute 10% of the total catch (Section 2.11). All harvest is assumed to occur in the winter before the following growing season. Freshet mortality is then applied to selected bars by removing a portion of all oysters on the bar (Section 2.4.2). Although freshets may occur in the winter or spring-summer, all freshet mortality is applied at the same time in the model. This does not change the model result because all freshet mortality occurs before recruitment is estimated, and freshet mortality is independent of size.

Next a growth model is selected based on the state in which the bar is located, and a growth curve is randomly selected from the model as described in Section 2.8. For each 5-mm size class, oyster sizes are incremented by the appropriate amount based on the selected growth curve. Growth is assumed to occur during the summer months before spawning.

Disease tier is selected by weather-year (Section 2.9). After disease tiers are assigned to bars, and natural mortality rates are selected, oysters that succumb to natural mortality are removed. Natural mortality is assumed to occur during summer, at the same time as growth (Section 2.10).

Recruitment is calculated after annual growth and mortality are simulated (Section 2.6). If the bar has been planted with shell to improve habitat during the last four years, the estimated number of spat is increased as described in Section 2.12. The final number of spat present on bar *j* is adjusted according to the larval-transport model by moving spat to and from other bars in proportion to the larval-transport matrix (Section 2.7). If the bar is also planted with spat, planted spat are added to the bar but are assumed to experience 50% mortality (Section 2.12).

The population on a bar is then ready for output. Numbers or estimated biomass of oysters is summed by size class and over bars to produce an estimate for a larger area, such as a state or the entire Bay, for one year. The model begins another iteration for the next year, until it has completed year 10, when it exits.

Model predictions are based on 1,000 simulations. We report the median value of the 1,000 runs as the estimated result, and the 5^{th} and 95^{th} percentiles as approximate 95% confidence intervals.

4.0 Description of Proposed Action and Alternatives

The purpose of the actions being evaluated is to establish an oyster population that reaches a level of abundance in Chesapeake Bay that would support sustainable harvests comparable to harvest levels recorded during the period 1920 to 1970. The proposed action is to establish a naturalized, reproducing, and self-sustaining population of *C. ariakensis* in the tidal waters of Maryland and Virginia through introductions while continuing efforts to restore *C. virginica* using best available restoration strategies and stock assessment techniques. The following specific alternative strategies also are being considered (FR 2004):

- **Alternative 1 - No Action:** Continue Maryland's present Oyster Restoration and Repletion programs, and Virginia's Oyster Restoration Program under current program and resource management policies and available funding using the best available restoration strategies and stock assessment techniques.

- **Alternative 2 - Expand Native Oyster Restoration Programs:** Expand, improve, and accelerate Maryland's Oyster Restoration and Repletion programs, and Virginia's Oyster Restoration Program in collaboration with federal and private partners. This work would include, but would not be limited to, an assessment of cultch limitations and long-term solutions for this problem and the development, production, and deployment of large quantities of disease resistant strain(s) of *C. virginica* (Eastern oyster) for broodstock enhancement.

- **Alternative 3 - Harvest Moratorium:** Implement a temporary harvest moratorium on native oysters and an oyster-industry compensation (buy-out) program in Maryland and Virginia, or a program that offers displaced oystermen on-water work in a restoration program.

- **Alternative 4 - Aquaculture:** Establish and/or expand state-assisted, managed or regulated aquaculture operations in Maryland and Virginia using the native oyster species.

- **Alternative 5 - Aquaculture:** Establish state-assisted, managed or regulated aquaculture operations in Maryland and Virginia using a suitable triploid, non-native oyster species.

- **Alternative 6 - Introduce and Propagate an Alternative Oyster Species (other than *C. ariakensis*) or an Alternative Strain of *C. ariakensis*:** Introduce and propagate in the state-sponsored, managed or regulated oyster restoration programs in Maryland and Virginia, a disease resistant oyster species other than *C. ariakensis*, or an alternative strain of *C. ariakensis*, from waters outside the U.S. in accordance with the ICES 2003 Code of Practices on the Introductions and Transfers of Marine Organisms.

- **Alternative 7** – Establish a naturalized, reproducing and self-sustaining population of *C. ariakensis* in the tidal waters of Maryland and Virginia through introductions beginning in 2005 (or when EIS is completed) but discontinue *C. virginica* restoration efforts.

- **Alternative 8 - Combination of Alternatives**

The demographic model will be used to project oyster abundance for Alternatives 1, 2, 3, and potentially for Alternative 8. These alternatives are modeled by selecting appropriate input parameters for harvest levels, shell planting, and spat planting, as previously described. The specific allocation of spat and cultch within the Bay for alternatives 1 and 2 are listed in Attachment 5 (an undated report by P. Jones, MDNR). Two plans have been developed for Alternative 2, which we modeled individually as alternatives 2a and 2b. The plans employ the same numbers of planted spat and cultch overall but differ in the numbers and locations of managed sanctuaries. Specifically, seven more bars would be stocked under alternative 2b (total 39) than alternative 2a. Six fewer bars located in low salinity waters would be stocked, but 13 more bars located medium- or high-salinity waters would be stocked (Attachment 5). For Alternative 3, all factors except the harvest level were assumed to be the same as for Alternative 1.

The oyster demographic model was developed to support an Ecological Risk Assessment and an Environmental Impact Statement. The underlying concept was that vital parameters of a model developed using the extensive data available for the Eastern oyster could be modified to reflect different vital parameters of the Suminoe oyster that would be established based on findings of extensive research conducted on that species over the past four to five years. The model could then be run to project potential outcomes of the proposed action. A draft model documentation report that included suggested approaches to modeling the Suminoe oyster was reviewed by the Oyster Advisory Panel (OAP). The view of the OAP was that, given the substantial uncertainty in the model projections for the Eastern oyster and the limited information available on many of the factors that could affect Suminoe oyster outcomes in the Bay, application of the model to the proposed action would yield outcomes with extremely high levels of uncertainty. After consideration of the OAP comments, the demographic modeling team concurred with the OAP that application of the model to the Suminoe oyster would not be appropriate. Thus, alternatives involving Suminoe oysters will not be modeled. However, the total number of triploid Suminoe oysters likely to be reared in aquaculture operations throughout the Bay has been estimated by economic analysis (D. Lipton, University of Maryland) and these data will be combined with model output for natural production of Eastern oysters to evaluate alternatives 4 and 5.

5.0 Model Performance

The validity of any model is normally assessed by comparing model output to an independent data set representing the modeled outcome. In the case of this Bay-wide oyster demographic model, no long-term, Bay-wide, spatially specific oyster abundance data sets are available that could serve as a basis for model validation. Although the MDNR survey used to develop many of the model parameters represents the most spatially and temporally extensive survey data available, these data are only available for Maryland and absolute or relative densities of oysters cannot be estimated correctly from the survey data, as we have described above. Conversely, Virginia conducts intense sampling of some localized areas, but with less spatial coverage than the Maryland survey.

Because validation of the demographic model was not possible, we reviewed all existing data identified in the course of model development to assess whether any data sets were available that would allow for some level of checking of model function. Data from an oyster survey in the James River, conducted by the Virginia Institute of Marine Science (data provided courtesy of R. Mann, Virginia Institute of Marine Science), could serve that purpose. This data set was long term, provided rigorous annual population estimates (i.e., the survey was designed to estimate population size), and provided annual population composition information. Density was estimated in this survey using patent tongs at randomly selected 1-m^2 areas of bottom. All oysters captured were counted and measured to the nearest 5-mm class. Total numbers of oysters were estimated by multiplying mean densities at a bar by the bar’s area.

Although these data provide a suitable time series for checking model functionality, they are not suitable for validating the model. The data represent oyster population behavior in a single small tributary of the Bay, but the model employs population vital parameters that are in essence Bay-wide averages of those rates. For example, James River survival and recruitment rates are likely to be substantially different than the Bay-wide average. Thus, we used the James River data to test model performance broadly by comparing predicted values from a modified version of the model with survey estimates. Modeled trends that diverged from the James River sampled abundance by a large amount would suggest that the model parameterization was incompatible with a known starting population or that there was an error in model specification.

In order to conduct this model check using James River data, the demographic model had to be modified in several ways. The model was run for nine years rather than ten, 1994-2003. Weather years, salinities, disease tiers, and MSX outbreaks were input from historical data rather than modeled. Harvest levels were likewise based on historic data on oyster landings (courtesy J. Wesson, Virginia Marine Resource Commission). This was done by removing a constant fraction of the population from each bar in the simulation to obtain a total harvest equal to the reported landings for the year. The model was also modified to accept fall survey estimates of spat abundance < 30 mm instead of estimating recruitment each year (most spat were <30 mm in the James River because of their slow growth; Section 2.8). These runs were used primarily to evaluate the growth and mortality portions of the model. When recruitment was estimated, spat were distributed in proportion to the area of each bar within salinity zones so that no larvae were imported or exported to other basins. We conducted 1,000 runs of the demographic model for the James River in which historical spat abundance was input, and another 1,000 runs in which recruitment was modeled normally.

The model produced estimates similar to the survey for abundance of small oysters, but projected that more market-size oysters would be present for runs in which spat < 30 mm were input (Figure 10A). The greater number of market sized oysters projected by the model suggests that James River mortality rates were actually greater than those used in the model. A possible explanation for this result is that oysters in the James River are exposed to disease and predation for a longer period at a given size because of their relatively slow growth rate (Section 2.8), resulting in a greater natural mortality than was modeled for Bay conditions on average. Trends in abundance were similar between model projections and survey estimates. We judged model performance for mortality and growth parameterization to be reasonable based on these results.

Differences between model projections and survey estimates were greater when recruitment was also modeled (Figure 10B). Abundance of market-size oysters was projected to be greater than survey estimates, as above. Conversely, abundance of spat was projected to be less than the survey estimates. This resulted in fewer small oysters present in model projections than in survey estimates during years 2-6. In the actual data set, an exceptionally large spat set occurred during 2001, which was not matched by the model projection. Such rare large spat sets occur randomly in the demographic model, as described in Section 2.6. They are partly reflected by the wide confidence intervals in years 5-8. The predicted model trend, however, does not exhibit such large episodic events because it is the median of many runs. This is an important difference between model projections and the actual survey data. The survey represents a single realized time series; it is unknown if the series was a statistically rare event. The large spat set was quickly reduced as a result of high natural mortality. This resulted in similar estimates of abundance between the model and survey the next year. The final modeled numbers of oysters were similar to the survey for all size classes in year 9, and most of the field values were within a factor of 1 to 4 of the predicted values. These results suggest that the demographic model projects reasonable mean abundance estimates given the large uncertainty in parameter estimates, and that projections are suitable for comparing alternative restoration strategies for the EIS.

6.0 Alternative 1-3 Results

Abundance of market-size Eastern oysters was predicted to remain near present low levels in the simulation for EIS alternative 1, no action (Figures 11A, 12) and declined slightly for small oysters and spat (recall that the no action alternative includes restoration activity at current levels). High natural mortality rates strongly controlled the population, resulting in variation in simulated abundances of only about 25% for harvest rates ranging from 20 to 80% on harvestable bars (71% of all bars simulated). A detailed explanation for the limited effect of harvest when natural mortalities are high is presented in Attachment 6. Abundance was projected to increase in range of 250-450% by year 10 under EIS alternatives 2A and 2B, enhanced restoration. However, the large percentage increase is from a very small starting population. Variation in these enhanced restoration simulations was much greater than in the no-action alternative. Some differences between the 10th and 90th percentiles ranged more than 500%, resulting in some overlap with alternatives 1 and 3. Fishing had a greater effect on abundance for alternatives 2A and 2B than it did for alternative 1, indicating that harvest had a larger proportional effect as abundance increased. Winter harvest rates of 20-80% resulted in differences in median predicted abundance greater than 100% for alternatives 2A and 2B. Small oysters and spat were predicted to increase less than market-size oysters for alternatives 2A and 2B, in the range of 100% and 200% respectively. The occurrence of episodic large spat sets resulted in these distributions tending to be skewed positively, particularly for spat. Projections for EIS alternatives 2A and 2A were similar, indicating that the reduction in seed planting of 6 bars in low salinity waters was largely offset by additional seed planting at 13 bars in medium- or high-salinity waters. Predictions for alternative 3, no harvest, resulted in a 56% increase in median abundance from the starting population, indicating that high natural mortality rates strongly controlled even unharvested populations. The increase was much less than those predicted for alternatives 2A and 2B.

Abundance of all size classes was predicted to increase at least somewhat in Maryland under all alternatives (Figures 11B, 13), and to decrease in Virginia (Figures 11B and 14), because a greater proportion of bars in Maryland were located in low salinity waters where natural mortality rates were relatively low. Although the proportional increase in spat and small oysters was predicted to be much greater in Maryland for alternatives 2A and 2B (Figure 11B), the differences in actual abundance were much less (Figure 11C). This is because many more spat and small oysters in the starting population were located in Virginia (Table 1). Distributions tended to be skewed positively in Virginia because episodic high-recruitment events occurred more frequently in higher salinity waters. Conversely, distributions of small and market-size oysters tended to be skewed slightly negatively for Maryland because lower salinity conditions resulted in some high-mortality events in dry years, and some freshet mortality occurred during wet years (but few large spat sets occurred).

Bars located in low salinity were predicted to have the greatest increases in abundance of market-size oysters under each scenario, but the poorest recruitment of spat (Figure 11D, 15-17). Bars located in high salinity exhibited much greater and more variable recruitment of spat and small oysters, but they were quickly overwhelmed by high natural mortality rates as they reached market sizes. Confidence intervals were also asymmetric for bars in low salinity (Figures 15-17) because salinity changed with annual precipitation in the model (Section 2.5). During dry years, abundance was projected to be very low because few bars were located in low salinity, and those bars exhibited characteristically low recruitment (Section 2.6). During wet years, more bars were located in low salinity, but recruitment was still low in these areas.

Trends in abundance were related to specific management scenarios. For alternative 2A, abundance of spat increased with seed planting in Maryland until year 7, when planting reached its maximum, and remained relatively constant thereafter (Figure 13). Abundance of small oysters also remained constant during the final years of the simulation for Maryland, suggesting that the population would reach a new equilibrium near the abundance levels projected for year ten if this level of management activity were maintained. Spat abundance was projected to decline during years 9 and 10 in Virginia because habitat improvements were reduced in years 8 and 10, and the effect of previous habitat improvements was reduced with time (Section 2.12). Temporal trends were similar between alternatives 2A and 2B overall, by state (Figures 13-14) and by salinity zone (Figures 15-17).

The goal specified in the EIS is to establish an oyster population that reaches a level of abundance in Chesapeake Bay that would support sustainable harvests comparable to harvest levels recorded during the period 1920 to 1970. Assuming the best point estimate of current harvest (47%) is sustainable, the population needed to support the mean harvest level during 1920 to 1970 would be 1.16×10^{10} market-size oysters[2]. Alternatives 2A and 2B were projected to reach, even at the 95th percentile, only about 1/6 of this level. None of simulations conducted projected a population increase that could reach the goal of the EIS in ten years with 90% confidence).

We note that projected abundances of spat, small, and market-size oysters were similar and relatively constant (Figure 13) despite the fact that many young oysters must be present to

[2] Bay-wide annual harvests (expressed in Maryland bushels) for the years 1920 to 1970 were averaged. Bushels were converted to number of market-sized oysters using the equation 1 oyster = 0.0009 bushels. The resulting number of oysters was divided by 0.47 to derive the numerical goal.

produce older oysters when mortality rates are high. This pattern is a result of the small and market classes representing more than one cohort. An average oyster remains in the small size class between 2 (mean size 70 mm) and 3 (mean size 88 mm) years in Maryland, and for about 4 years (mean size 71 mm) in Virginia (Figure 6). The market size class includes larger oysters from all cohorts. Furthermore, spat are counted in the fall in the demographic model, after the period in which they experience the greatest mortality. Most have nearly reached the small size class at this time.

7.0 Model Sensitivity

Additional model runs were conducted to quantify the effects of model parameterization on overall predictions of abundance. Parameters generally were varied by conducting four additional runs for each parameter; runs were conducted with increases of 10% and 25%, and decreases of 10% and 25%. Except for the parameter that was varied, each run was conducted using the same parameterization as alternative 1, no action, and a 40% harvest rate. Sensitivity was quantified by comparing the median value in model-year 10 from each run to the median value in year 10 of the run for alternative 1, 40% harvest (e.g., 3.4^8 market-size oysters; Figure 10). We analyzed only the change in median values for these runs. No attempt was made to adjust a parameters variance. To avoid reporting an inordinate number of simulations with all combinations of alternatives and variables, we limited analysis of higher order interactions in which more than one parameter was changed to the most extreme combinations of parameters (all +25% or -25%) for recruitment, growth, and mortality only. Results of all runs are summarized in Table 5 as the percent change in estimated abundance.

Varying growth parameters affected predictions in a way that would be biologically important. An increase or decrease of 25% in K resulted in a corresponding change in predicted abundance of about 25% for market-size oysters. The model was more sensitive to changes in the H_∞ parameter than K. Changes of 25% in H_∞ resulted in greater than 30% changes in market-size oyster abundance. Model projections changed by more than 50% for market-size oysters when both parameters were varied simultaneously. The effect was greater for a 25% increase in K and H_∞ (87%) than for a decrease (-54%). The sensitivity of the H_∞ parameter creates uncertainty in the model that cannot be quantified easily given the limitations in available data. The estimate is based on historical data because few oysters now survive long enough to reach H_∞ (Section 2.8). Varying recruitment parameters had relatively small effects on predicted abundance. Changes of 10% or 25% in the spat to spawner ratios all changed abundance of market-size oysters less than 10%. Reducing the spat to spawner ratio by 10% did not change the predicted population of small oysters in the expected direction (a 1% increase resulted). This is likely because the effect of the parameter increase was small relative to the random variation in medians resulting from 1,000 runs. Eliminating episodic large spat sets had a larger effect than decreasing the spat to spawner ratio even by 25%. This result supports the idea that infrequent large spat sets are important in supporting the population. Varying egg-production coefficients that were used in estimating recruitment also had small and inconsistent effects on model predictions.

The mortality rates entered into the model had important effects on predicted abundance. A 25% decrease in mortality rates resulted in a 94% increase in abundance of market-size oysters, and an increase of more than 100% in spat and small oysters. This result demonstrates not only the importance of obtaining reliable data with which to estimate mortality, but also that oyster populations would likely increase if natural mortality rates could be reduced.

The model was most sensitive to increases in multiple parameters that interacted. Increases in the ratio of spat to spawners interacted non-linearly with growth and mortality, resulting in large increases in population size when 25% adjustments were made. The largest population increases occurred when growth and the spat to spawner ratio were both increased by 25%. This model caused more than a ten-fold increase in the abundance of market-size oysters. When a reduction in mortality rates of 25% was added to the interaction, the increase was nearly thirty-fold.

Use of the larval transport model did not have a large effect on model results; simulations in which spat settled within the basin that they were produced rather than according to the larval transport model produced results within 5% of the corresponding simulations that used the transport model. This was expected because most larvae remain within the same basin even when the larval transport model is used (>90% for most basins; North et al 2006). The larval transport model would be important for predicting dispersal of oysters among basins if we had modeled an establishing population of Suminoe oysters. The model was likewise relatively insensitive to freshets.

Modeling random weather years instead of selecting blocks of weather years from the historical data, and simulating illegal harvest on protected bars, had moderate effects on projections. These results suggest that the effects of climate change and illegal harvest may have to be considered in designing an oyster recovery program.

The model was relatively insensitive to 10 or 25% changes in the starting population (predicted abundance changed <10%), but more sensitive to very large increases in the starting population. We conducted additional sensitivity analyses where the starting population was multiplied or divided by 100 because of the great uncertainty associated with this input parameter. The model was relatively insensitive to reducing the starting population by dividing it by 100. However, increasing the starting population by 100× resulted in 1,767% increase in market-size oysters under alternative 1. Alternatives were affected differently by such a large increase. Restoration had a much smaller relative effect when the population was 100× larger; market-size oysters were predicted to increase by 471% for alternative 2A. Fishing had a much greater relative effect; market-size oysters were predicted to increase 3,853% for alternative 3, no harvest.

8.0 Data and Uncertainty

The demographic model integrates data about population dynamics and environmental conditions to produce abundance predictions that are suitable for comparing alternative management strategies in the EIS. The model produces results that appear credible given the data currently available for oysters in the Bay. We emphasize that the model should be viewed as a tool to provide an integrated view of a complicated multivariate problem, not a predictor of absolute abundance of oysters in the Bay. This is because the model produces expected trends in abundance, but a single realized event that involves random probabilities actually occurs. The starting population provides a demonstration. For example, the number of spat in the starting population is fewer than the number of small or market-size oysters in Maryland (Table 1). This is unsustainable for a long period and, thus, cannot represent and 'average' condition. If the result is not due to sampling error, then it represents recruitment failure, an extreme event. The small number of spat causes a mismatch between the starting population and model parameterization that leads to rapid changes in the projected population for the first several years of the simulation (Figures 13.1-13.4, and 13.13). The number of market-size oysters then becomes low relative to the number of spat and small oysters given the modeled mortality rates for market-size oysters. This causes the population of market-size oysters to increase for several years after the number of spat and small oysters reaches a relatively constant level. Similarly, the starting population is based on a wet year, 2004. The starting population is much greater than the modeled predictions for year 1 in low salinity (Figure 15) because many bars are included in low salinity that, on average, would be classified as having a greater salinity. The opposite occurs for high salinity (Figure 17). The demographic model is designed to provide a weight-of-evidence approach to evaluating alternatives, not to predict a specific outcome with certainty.

Confidence intervals estimated from the results of 1,000 model runs were relatively wide for all restoration scenarios. These results reflect the great uncertainty associated with model parameterization, and stochastic events that determine oyster population-vital rates. Nevertheless, these results provide an integrated view of what is known about oyster population dynamics in the Chesapeake Bay. They are intended to serve as probabilistic descriptions of different scenarios rather than hypothesis tests. For example, model results indicate the 95th percentile for alternative 1 with a 40% harvest rate is a 97% increase in market-size oysters. This is the greatest increase that is likely to be attainable (Figures 11A and 12). The lower 5th percentile for alternative 2A with a 40% harvest rate indicates a 92% increase. Although there is some overlap between these alternatives, nearly all of the runs for alternative 2A indicated an increase of 100% or more. Therefore, alternative 2A is much more likely to result in an increase in oyster abundance of 100% or more than alternative 1.

In practice, the uncertainty associated with implementing a restoration strategy is probably even greater than the confidence limits indicate because many real-world processes that affect oyster populations are not modeled. For example, harvest rates may interact with disease resistance, and available habitat may change during the ten-year period, as described below. The variation reported here only reflects the propagation of uncertainty in modeled parameters. The quality and spatial coverage of data sets used to develop model parameters also increases the uncertainty associated with the model. Data used in the modeling effort generally were collected for other research projects and later contributed for model development. The MDNR data used to develop the starting population and several other parameters were collected using a survey where area swept was not recorded because the purpose was simply to collect oysters for disease sampling. The effect of an error in the starting population is not expected to be large if the error is within 25%, but would be important if the starting population is badly underestimated (i.e., 100×; Table 5). Another important limitation is that growth data for the James River were applied to oysters throughout most of Virginia. Although these rates are believed to be generally representative of growth rates in Virginia as a whole (Section 2.8), the model would be biased to an unknown extent if large differences exist. Model results are likely to be valid only within the spatial and temporal scales at which we present the data. Despite the fact that oyster dynamics were modeled on individual bars, they are aggregated to salinity zones, states, or the entire Bay. This is because many of the input parameters of the model were averages over many bars. Therefore, the demographic model is expected to perform well over larger spatial scales but not specifically for individual bars. It would also be inappropriate to run the model for more than the 10-year period programmed in the current implementation. A major reason for this is that the model uses a fixed habitat layer. That is, the model does not include any changes to habitat availability, either as a change in the size of individual bars or creation of new bars. The amount of habitat could change as sedimentation reduces the area of suitable bars and shells deteriorate (Smith et al. 2005), or as oyster populations increase and create additional habitat. The model also does not simulate any long-term changes in environmental conditions such as water quality and disease intensity that would affect oyster population dynamics. An unorthodox approach was required to model recruitment because of the unique nature of the data available. The data differed from those typically used to develop a stock-recruitment relationship in several ways: 1) only the ratios of spat and spawners were available, not absolute or relative density estimates; 2) unpredictable large episodic spat sets were known to be important in sustaining the population; 3) no weight measurements were available; and 4) no observations were available at high stock levels where density-dependent interactions were likely to occur. The approach taken here produced reasonable results because the magnitude or normal and episodic large spat set increased with standardized stock size (Figure 5). The recruitment submodel will almost certainly overestimate recruitment at some very large stock sizes because density-dependent reductions in recruitment would occur. We had no data with which to estimate the magnitude of density dependence or the stock size at which it would begin to occur; however, we assume that the stock size would have to be many orders of magnitude greater before density-dependent effects became important because the Bay has historically supported much larger populations. Another limitation of the recruitment submodel is that it is difficult to determine which spawners contributed to recruitment on a particular bar because oyster larvae may be transported by wind and current from throughout the Bay. We assumed that calculating an average Bay-wide recruitment by salinity zone and redistributing some spat according to the larval-transport model (Section 2.7) would provide the best overall estimates, although localized predictions based on this model would not be appropriate. Sensitivity analyses indicated that some inaccuracy in the estimation of recruitment alone did not have large effects on model outcome, but the interaction between recruitment and growth or mortality did have large effects. Data from surveys currently under development by the MDNR should be useful for future validation and refinement of this important part of the model.

9.0 Conclusions

Under current conditions, the model indicated that high natural mortality rates strongly controlled the population. Harvest did not have a large effect for alternative 1, but became increasingly important as populations increased in alternatives 2A and 2B. This is because most large oysters died quickly whether they were harvested or not, and the cohort just reaching market size tended to dominate. We provide a mathematical explanation for this unintuitive result in Attachment 6. The large fraction of bars that were not harvested in the model (sanctuaries and closed areas) also acted to stabilize populations because oysters from these bars were available to spawn under any harvest rate. If an appreciable amount of illegal harvest occurs, the model projections may not accurately reflect the importance of harvest (Table 5). We do not suggest that managing harvest is unimportant for oysters in the Bay under current conditions, only that it did not have a large effect on absolute numbers in alternative 1 because populations are very low and natural mortality rates very high. If a portion of oysters were modeled to develop disease resistance, for example, the rate at which they were harvested would have important effects.

The model indicated that alternatives 2A and 2B were most likely to increase oyster abundance. However, none of the alternatives modeled were likely to reach the EIS goal within ten years. This is partly because the ten-year period established for recovery is too short for a long-lived species such as the Eastern oyster to increase its population to that degree. Even if Dermo disease level was low (tier 3), no MSX events occurred, and no harvest was conducted, an exploratory simulation projected that the population would likely reach about half of the goal in ten years (Table 5).

The data sets used to develop the demographic model are not comprehensive, nor were they collected in an ideal manner for model development. Some limitations of the data create uncertainty in model results that cannot be quantified. Nevertheless, the demographic model provides a structured evaluation of the relative effect of different management scenarios using the best data currently available. It provides the only realistic way to integrate the large number of parameters that control oyster abundance in the Bay to visualize the likely effects of different management alternatives for Eastern oysters.

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11.0 Tables

Table 1. Number of oysters in the starting population at model initiation by state, salinity zone, and aggregated to the entire Bay. Estimates are based on abundance for 2004, a wet year. Note that the area of salinity zones (low < 11 ppt, medium 11-15 ppt, or high ≥ 15 ppt) fluctuates with annual precipitation. Thus, oysters on individual bars may change salinity zones during different years in the model.

	State		Salinity zone			
Oyster size	Maryland	Virginia	Low	Medium	High	Whole Bay
Market	126,754,209	173,832,742	155,289,829	80,528,252	64,768,870	300,586,951
Small	101,298,360	984,801,546	603,194,238	387,756,300	95,149,368	1,086,099,906
Spat	23,558,031	1,099,596,029	649,253,828	413,617,154	60,283,078	1,123,154,060

Table 2. Estimated proportions of female oysters in the population (sex ratio) by size class. Data are based on field experiments reported by Kennedy (1983). Proportions are denoted as R in Equation 3, where r = (0-40), (41-80), …, (>160).

Size class (height in mm; r)	Proportion of females (R)
0-40	0.50
41-80	0.44
81-120	0.63
121-160	0.67
>160	0.83

Table 3. Probability of selecting disease tier 1, 2, or 3 based on the current weather year for individual bars in the demographic model. Probabilities are based on mean disease intensities measured at disease bars in the MD DNR fall survey for the years 1990-2005.

	Disease Tier		
Weather Year	1	2	3
Dry	0.80	0.20	0.00
Average	0.00	0.75	0.25
Wet	0.00	0.17	0.83

Table 4. Average annual natural mortality rates based on recent box counts for eastern oysters by salinity class and disease tier. Average time-since-death of recent boxes was assumed to be between 7 and 14 days. The relative standard error, RSE = SE/Mean; LCL and UCL are the upper and lower 95% confidence limits, respectively.

		Market-Sized Oysters				Small Oysters			
Salinity	Tier	Mean	RSE	LCL	UCL	Mean	RSE	LCL	UCL
High	1	0.79	0.14	0.57	1.00	0.69	0.18	0.45	0.93
High	2	0.51	0.24	0.27	0.75	0.47	0.25	0.25	0.70
High	3	0.23	0.31	0.09	0.37	0.34	0.28	0.16	0.53
Med	1	0.59	0.21	0.34	0.83	0.56	0.22	0.31	0.80
Med	2	0.43	0.26	0.21	0.64	0.39	0.27	0.18	0.59
Med	3	0.13	0.32	0.05	0.21	0.16	0.31	0.06	0.26
Low	1	0.34	0.29	0.15	0.54	0.29	0.30	0.12	0.46
Low	2	0.22	0.31	0.08	0.35	0.15	0.33	0.05	0.25
Low	3	0.10	0.33	0.03	0.16	0.08	0.33	0.03	0.13

Table 5. Sensitivity of demographic model to variation in underlying parameters. All sensitivity runs were compared to the run for alternative 1, no action, with a 40% harvest rate (Figure 11) unless otherwise specified. Results are reported as the percent change in median oyster abundance at year ten of the model.

Model tested	Percent difference between model tested and no-action model in median oyster abundance at year ten		
	Spat	Small	Market
Recruitment			
Spat/spawner ratio +10%	9	6	-1
Spat/spawner ratio -10%	-2	1	-4
Spat/spawner ratio +25%	15	10	1
Spat/spawner ratio -25%	-11	-6	-6
No episodic large spat sets	-12	-11	-6
Egg production ($F_{ind} = 39.06 \times [0.000423 \times H^{1.7475}]^{2.36}$; Eqn. 1)			
Egg production inner coefficient +25%	1	2	-1
Egg production inner coefficient -25%	-2	-1	-1
Egg production inner exponent +25%	5	5	3
Egg production inner exponent -25%	-1	-2	-3
Egg production outer exponent +25%	2	2	2
Egg production outer exponent -25%	2	0	0
Growth (H_∞ and K from the vonBertalanffy growth equation)			
H_∞ +10%	9	2	14
H_∞-10%	-4	-1	-14
H_∞ +25%	35	11	44
H_∞ -25%	-6	-8	-37
K +10%	6	3	13
K -10%	-3	-2	-9
K +25%	21	7	29
K -25%	-4	-9	-25
H inf and K +25%	71	35	87
H inf and K -25%	-1	-12	-54
Mortality			
Mortality -10%	29	28	28
Mortality +10%	-16	-17	-21
Mortality -25%	113	108	94
Mortality +25%	-30	-37	-40
Interactions			
H_∞ and K +25%, mortality -25%	544	384	400
H_∞ and K -25%, mortality +25%	-18	-40	-72
H_∞, K, and spat/spawner ratio +25%	1,965	1,264	1,457
H_∞, K, and spat/spawner ratio -25%	-65	-46	-45
Mortality -25%, spat/spawner ratio +25%	890	902	523
Mortality -25%, spat/spawner ratio -25	-24	-5	-32
H ∞, K, and spat/spawner ratio +25%, mortality - 25%	3,792	2,651	2,980
H ∞, K, and spat/spawner ratio -25%, mortality + 25%	-24	-5	-32
Other parameters			
Randomly-selected weather years	-4	-7	-11
No larval transport model	2	3	5
No freshets	0	2	6
Starting population +10%	1	2	1
Starting population -10%	-1	-2	-4
Starting population +25%	7	6	5
Starting population -25%	-4	-5	-7
Starting population × 100	1,465	1,433	1,767

Table 5. Continued

Model tested	Percent difference between model tested and no-action model in median oyster abundance at year ten		
	Spat	Small	Market
Starting population / 100	-17	-17	-21
Alternative 2A, starting population × 100	445	391	471
Alternative 2A, Starting population / 100	-5	-5	-6
Alternative 3, Starting population × 100	3,478	3,146	3,853
Alternative 3, Starting population / 100	-31	-30	-39
10% Illegal harvest in closed areas	-2	0	-13
25% Illegal harvest in closed areas	-6	-3	-16
Tier 3 mortality (low disease), no MSX, no harvest	2,983	2,629	1,641

12.0 Figures

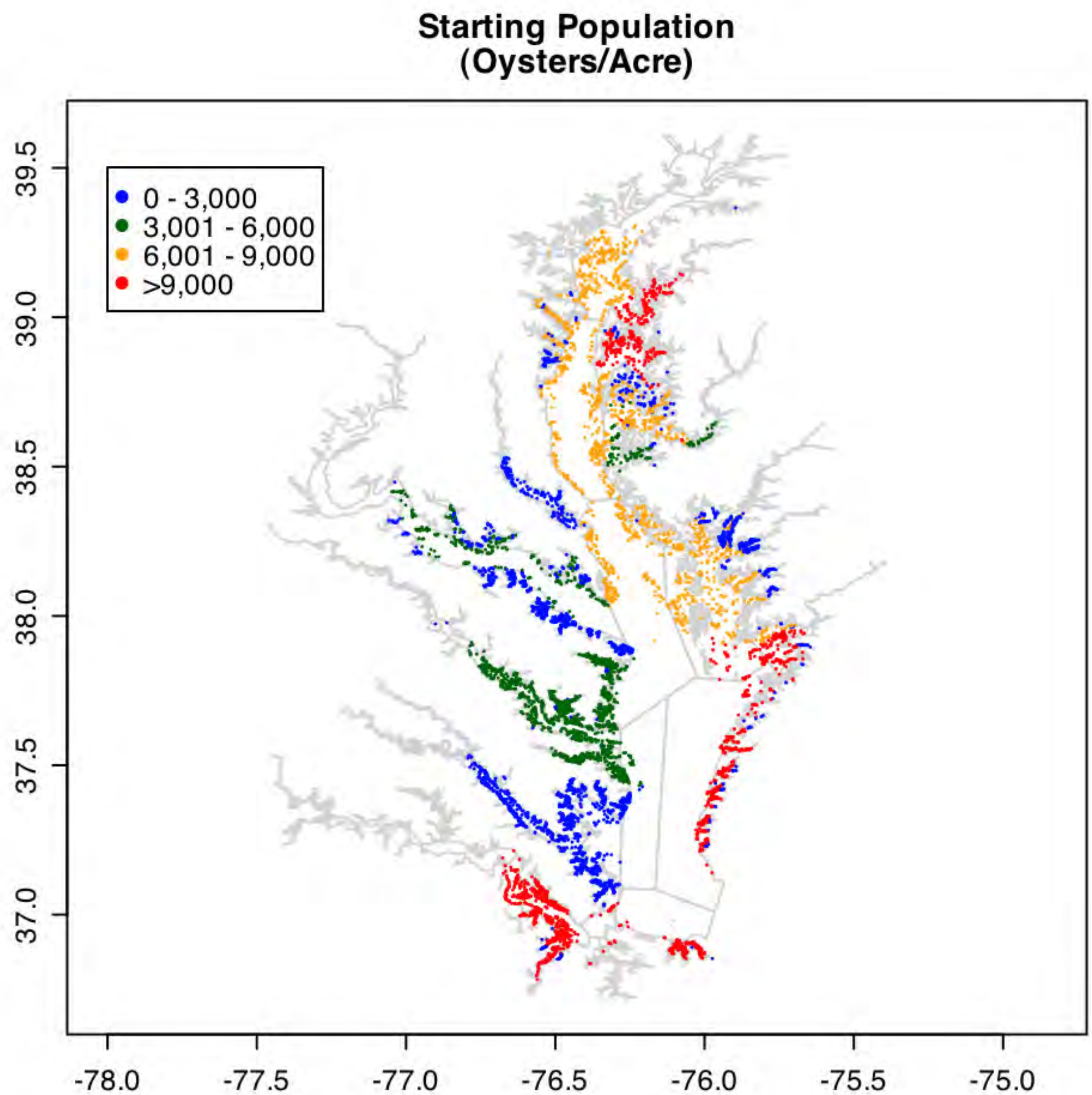


Figure 1. Estimated density and distribution of oysters in the starting population (spat, small, and market sized) for 8,480 bars included in the demographic model, based on year 2004.

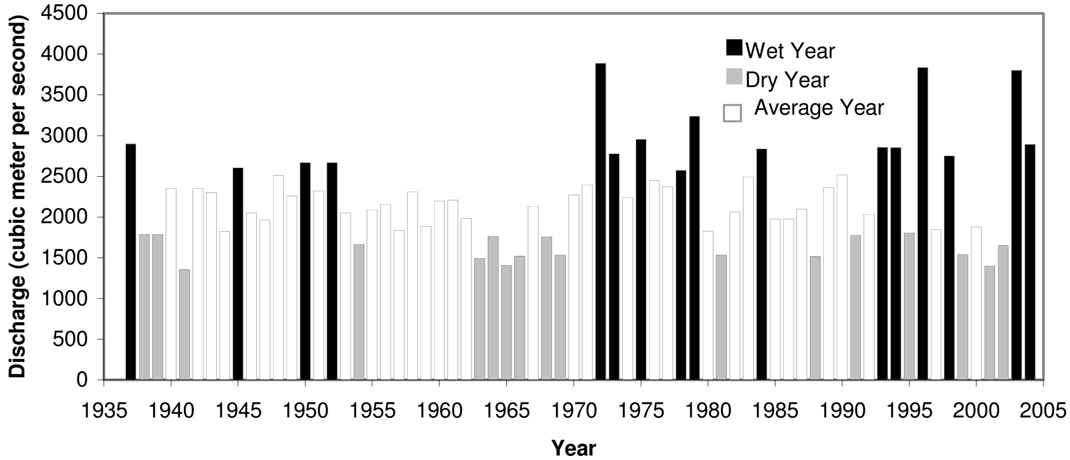


Figure 2. Mean annual discharge into the Chesapeake Bay between 1937 and 2005 (Source U.S. Geological Survey, Chesapeake Bay Activities, http://md.water.usgs.gov/monthly/bay.html).

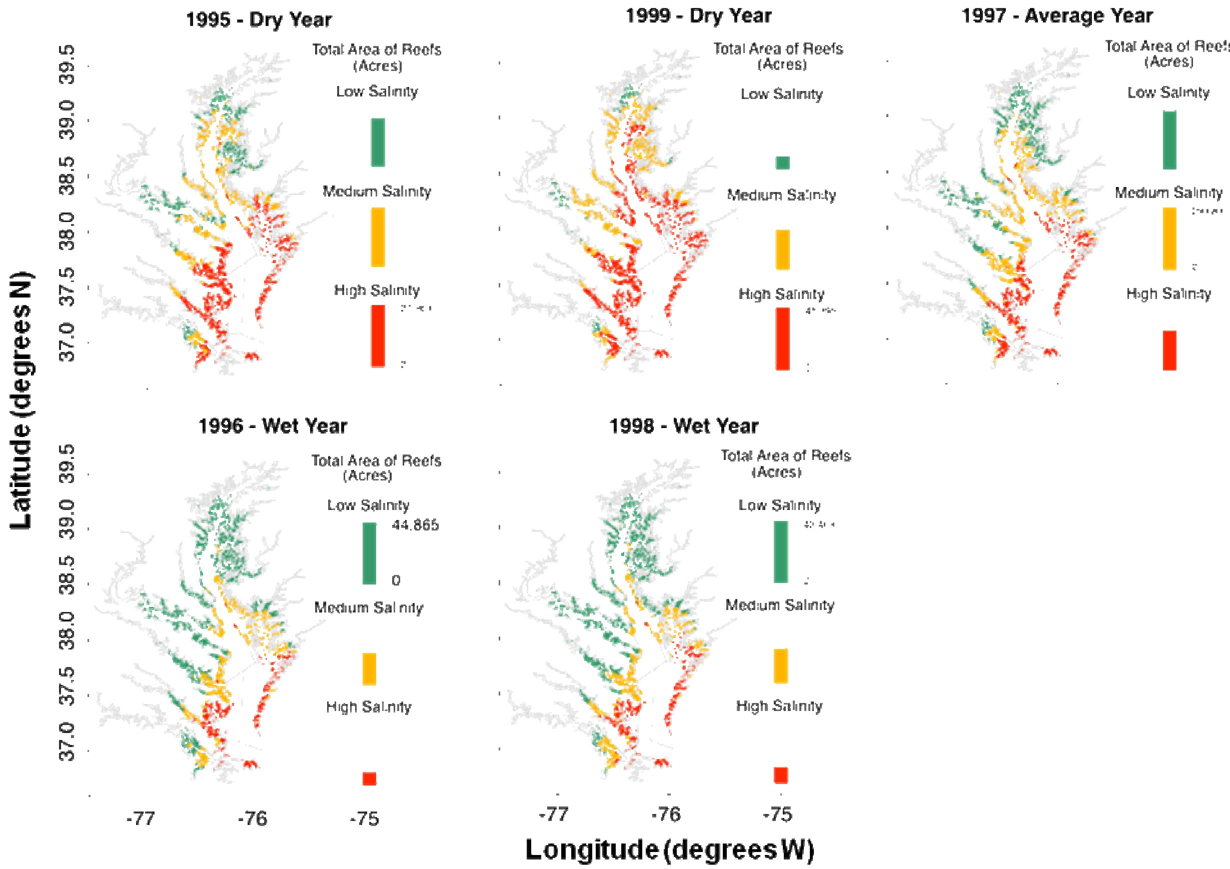


Figure 3. Salinity classes (low < 11 ppt, medium 11-15 ppt, or high ≥ 15 ppt) of oyster bars in the demographic model during 1995-1999.

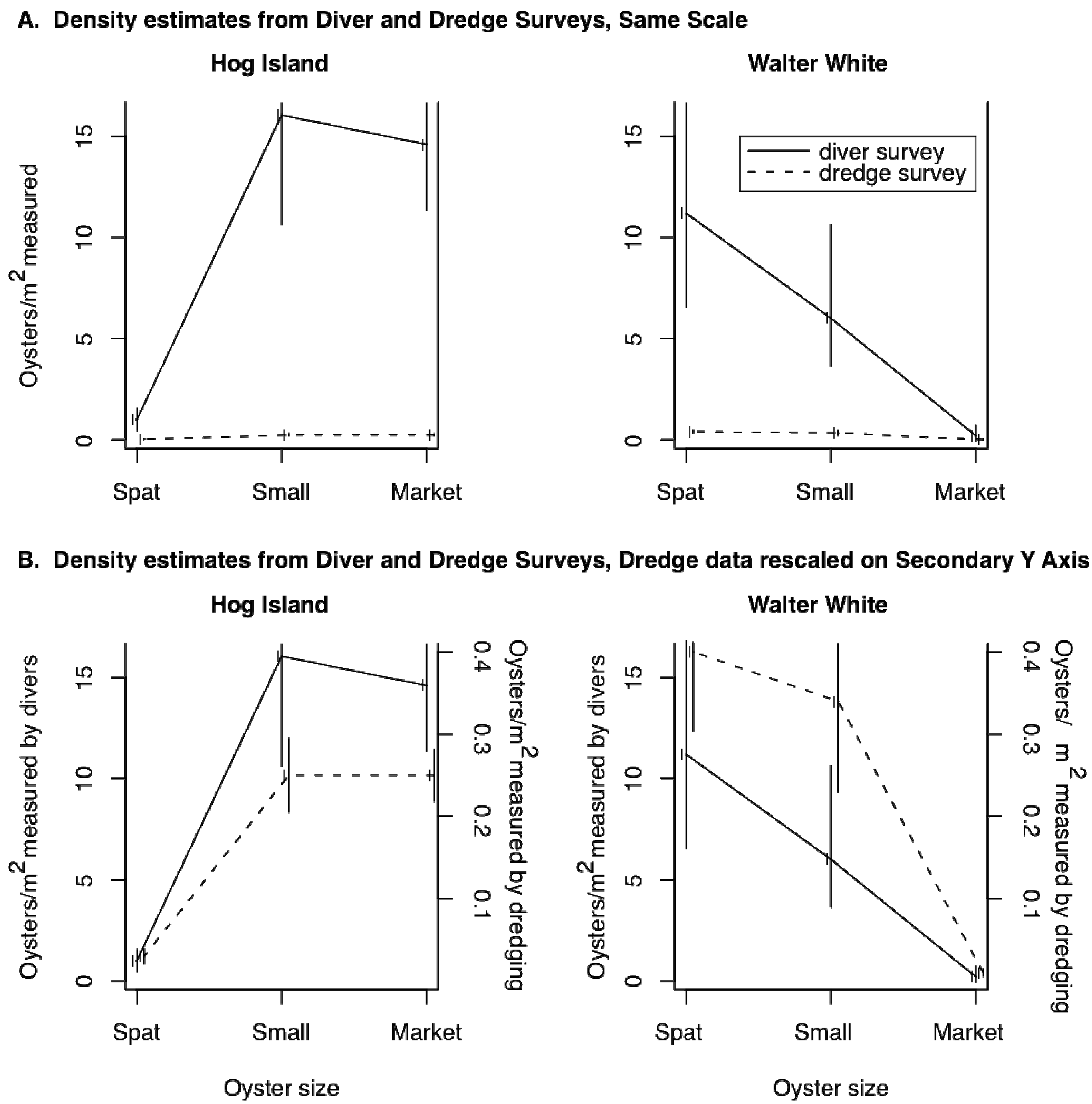


Figure 4. Comparison of sampling efficiency of dredging versus diver harvest reported for replicated studies at Hog Island and Walter White reefs in the Chesapeake Bay by Chai et al. (1992). Efficiency of the dredge was low for both reefs (A). Numbers of spat captured relative to small and market-size oysters were similar, as indicated by the same data plotted on different scales (B). Estimates from the dredge survey are scaled by 40.6 times on the secondary axis in B. Vertical bars indicate approximate 95% confidence intervals.

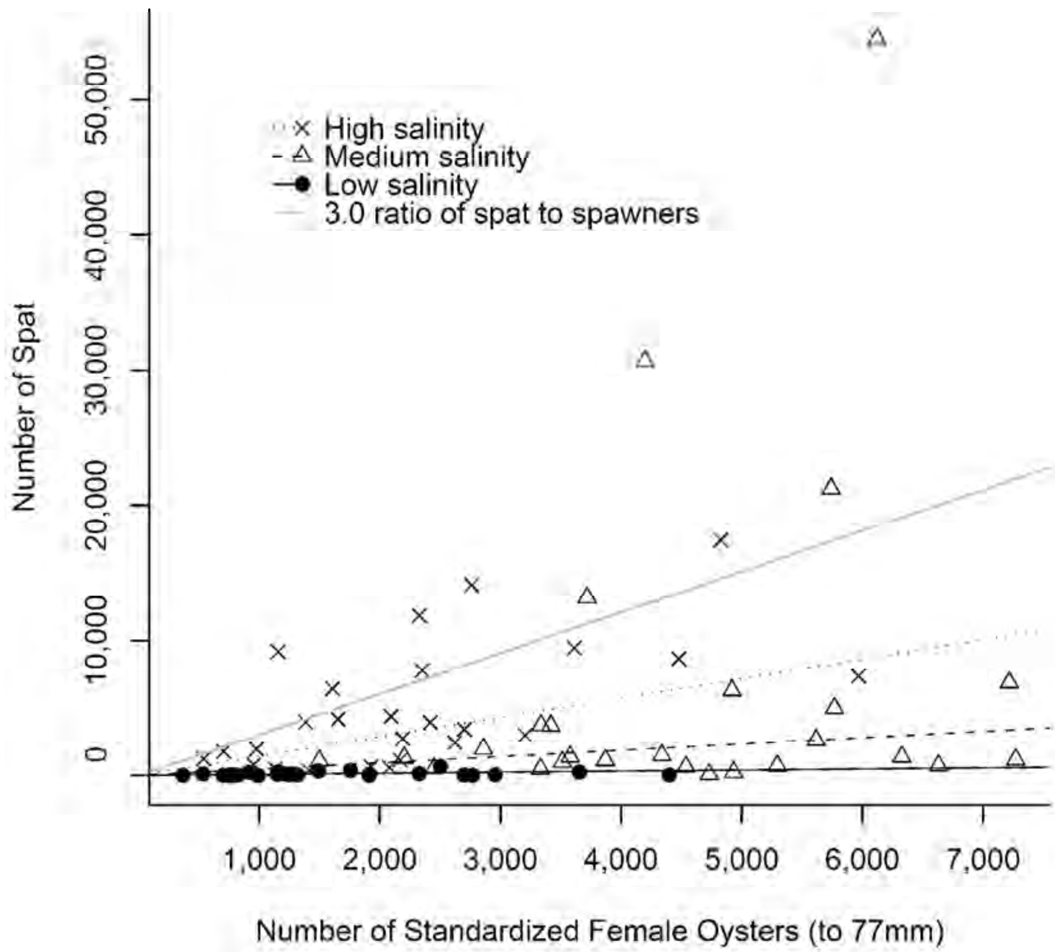


Figure 5. Relationship between number of standardized female spawners (to 77 mm) and spat based on the DNR annual dredge survey, 1990-2006. Gray line indicates a ratio of 3.0 spat per spawner. Observations with higher ratios were considered outliers and used to model episodic large spat sets. Spat were modeled according to salinity as indicated by the dark lines in normal recruitment years

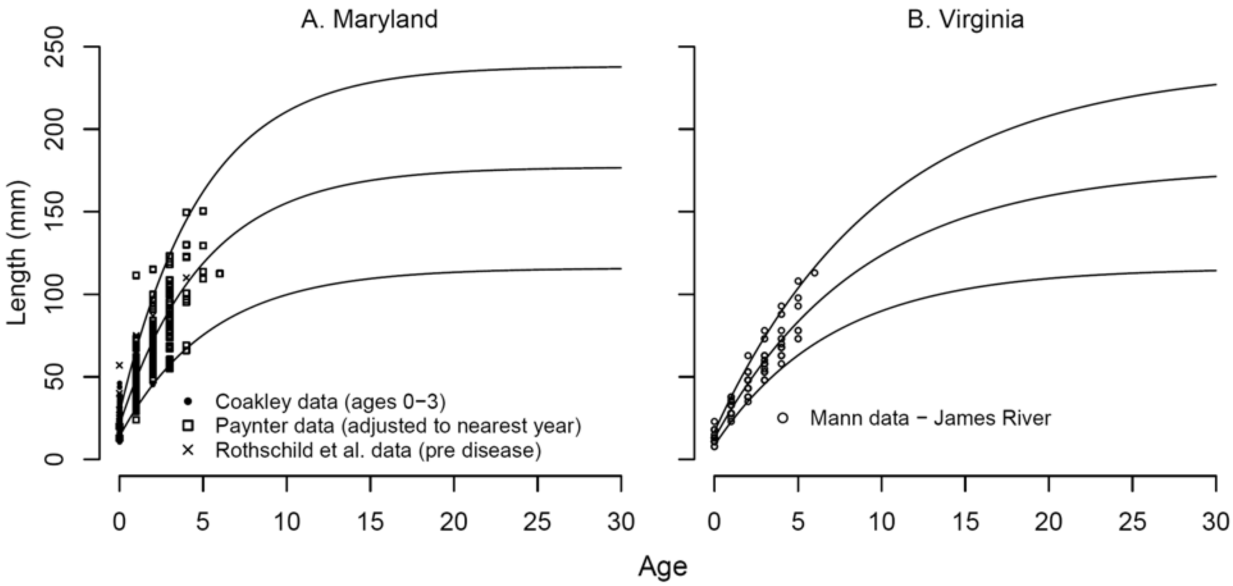
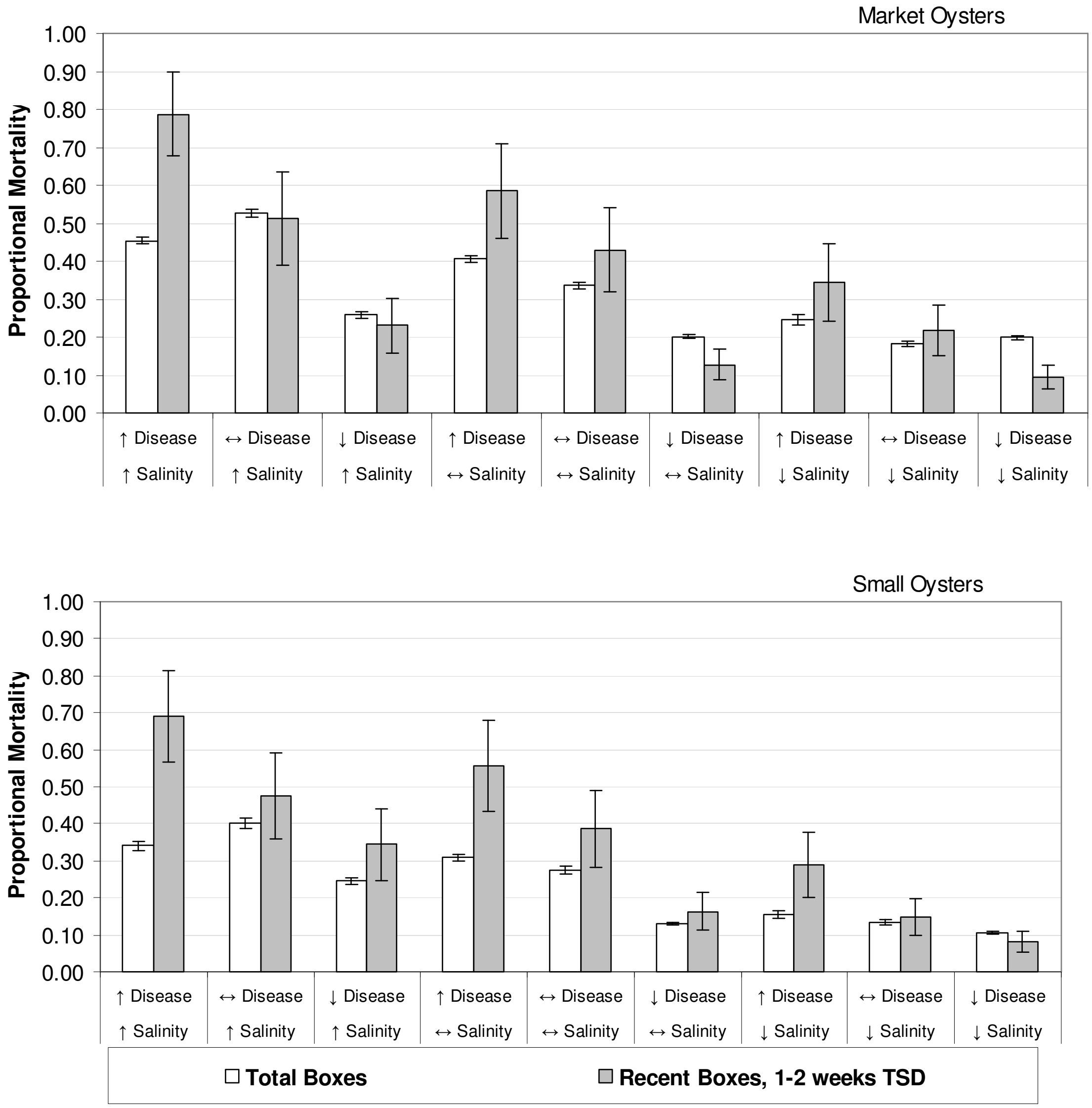


Figure 6. Height-at-age distributions used to model oyster growth in the Chesapeake Bay. A. Data from two recent studies and a literature review that were applied to Maryland and the Potomac River. B. Data from a survey of the James River that were applied to Virginia except the Potomac River. Lines indicate the 5th, 50th, and 95th percentiles of each model. The mean maximum size of oysters H∞ was assumed to be 177 mm in both models based on literature (Rothschild et al. 1994) because data were not available for older oysters. The median line for Maryland is H∞ = 177 * (1 – exp(-0.1834 * (age + 0.7232). The median line for Virginia is H∞ = 177 * (1 – exp(-0.1078 * (age + 0.7414).



↑ High Salinity; Tier 1 (High Dermo Prevalence)

↔ Medium Salinity; Tier 2 (Medium Dermo Prevalence)

↓ Low Salinity; Tier 3 (Low Dermo Prevalence)

Figure 7. Mean annual natural mortality rates by disease level (tier 1 = high dermo intensity; tier 2 = medium dermo intensity; and tier 3 = low dermo intensity) and salinity class for small and market-size oysters over all years (1991-2005). Error bars represent 95% confidence intervals. We assumed an average TSD of 1-year for total boxes, and 1-2 -weeks for recent boxes.

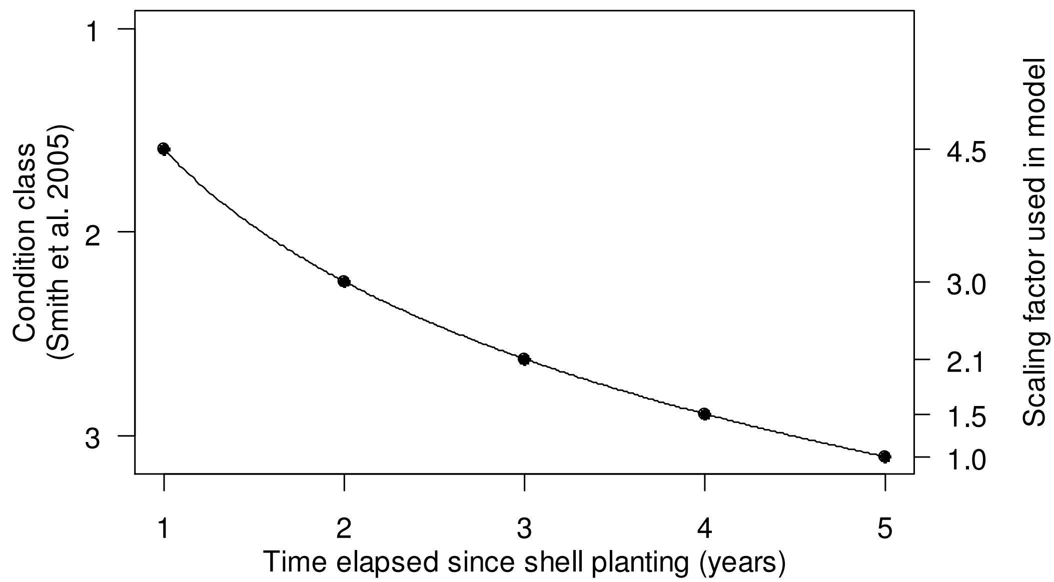
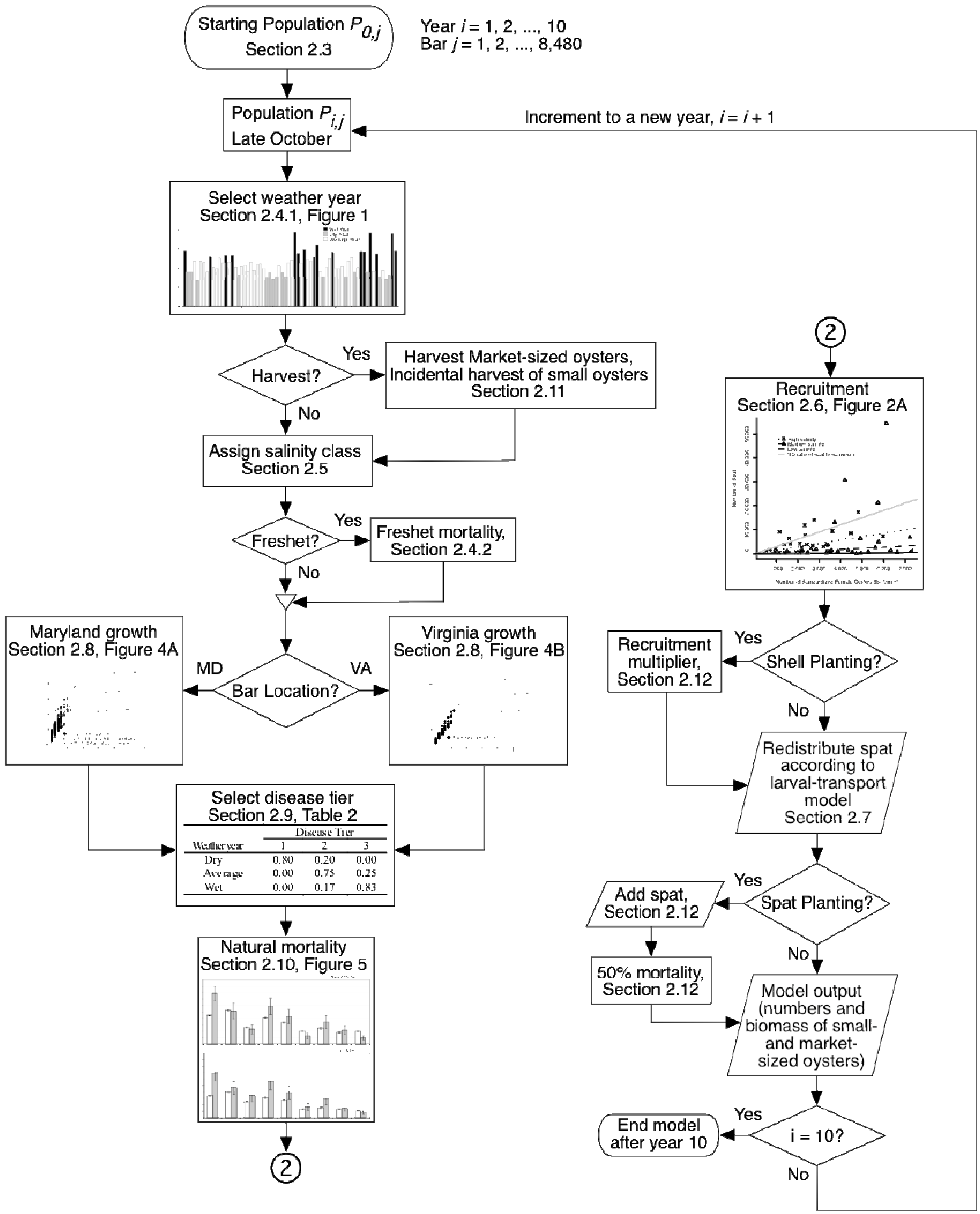


Figure 8. The function: Shell condition = 1.593 + [0.939 × loge(age)] describes a decline in the quality of planted shell for oyster recruitment as planted shell is covered with sediment (Smith 2005; left axis). Condition-class 1 indicates clean shell with no sediment. Condition-class 3 represents shells that have received some sedimentation but are similar to unreplenished bars. Mean spat settlement was observed to be 4.5 times greater on newly replenished bars than on unreplenished bars (MDDNR, unpublished data). Thus, a scaling factor of 4.5 (right axis) was applied to replenished bars in the demographic model for the first year, and the scaling factor was decreased through time following the same rate of decline as the shell-condition model.



Weather year	Disease Tier 1	2	3
Dry	0.80	0.20	0.00
Average	0.00	0.75	0.25
Wet	0.00	0.17	0.83

Figure 9. Flow diagram of oyster demographic model.

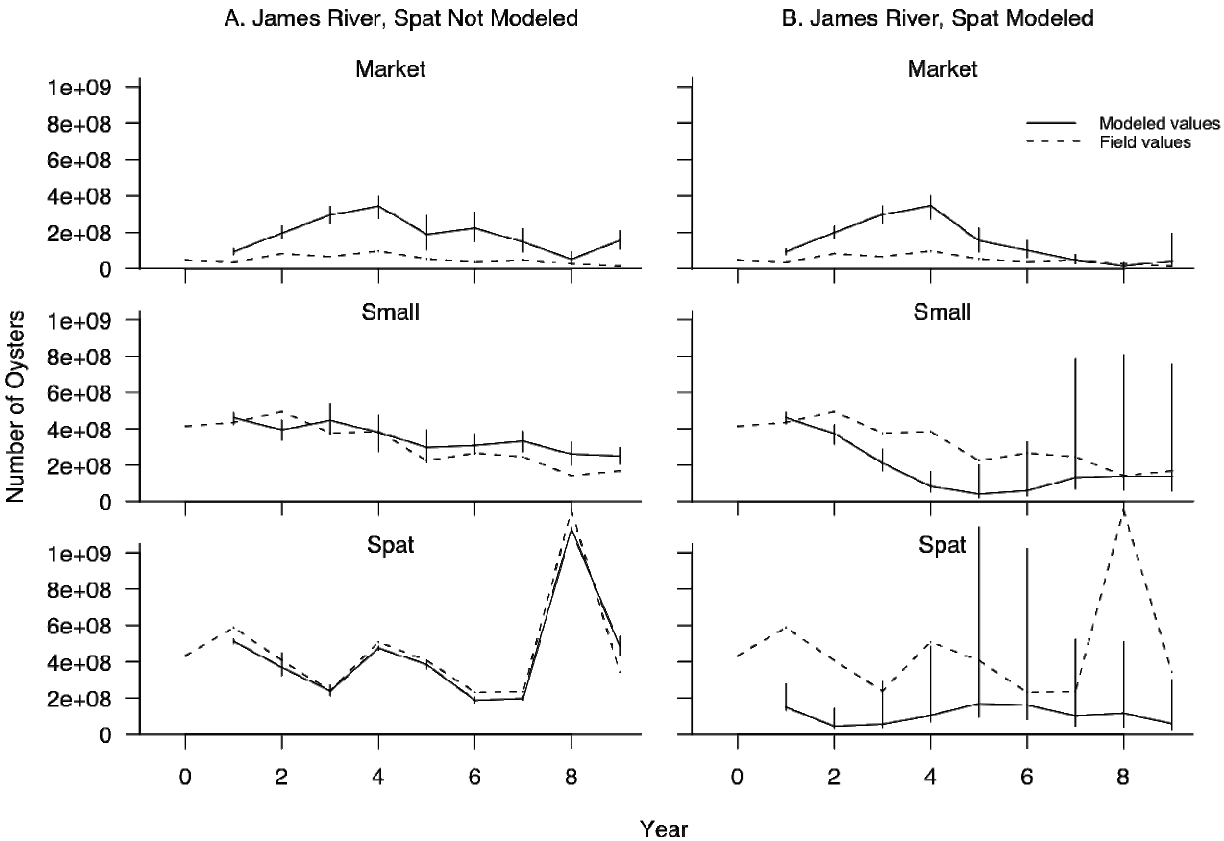
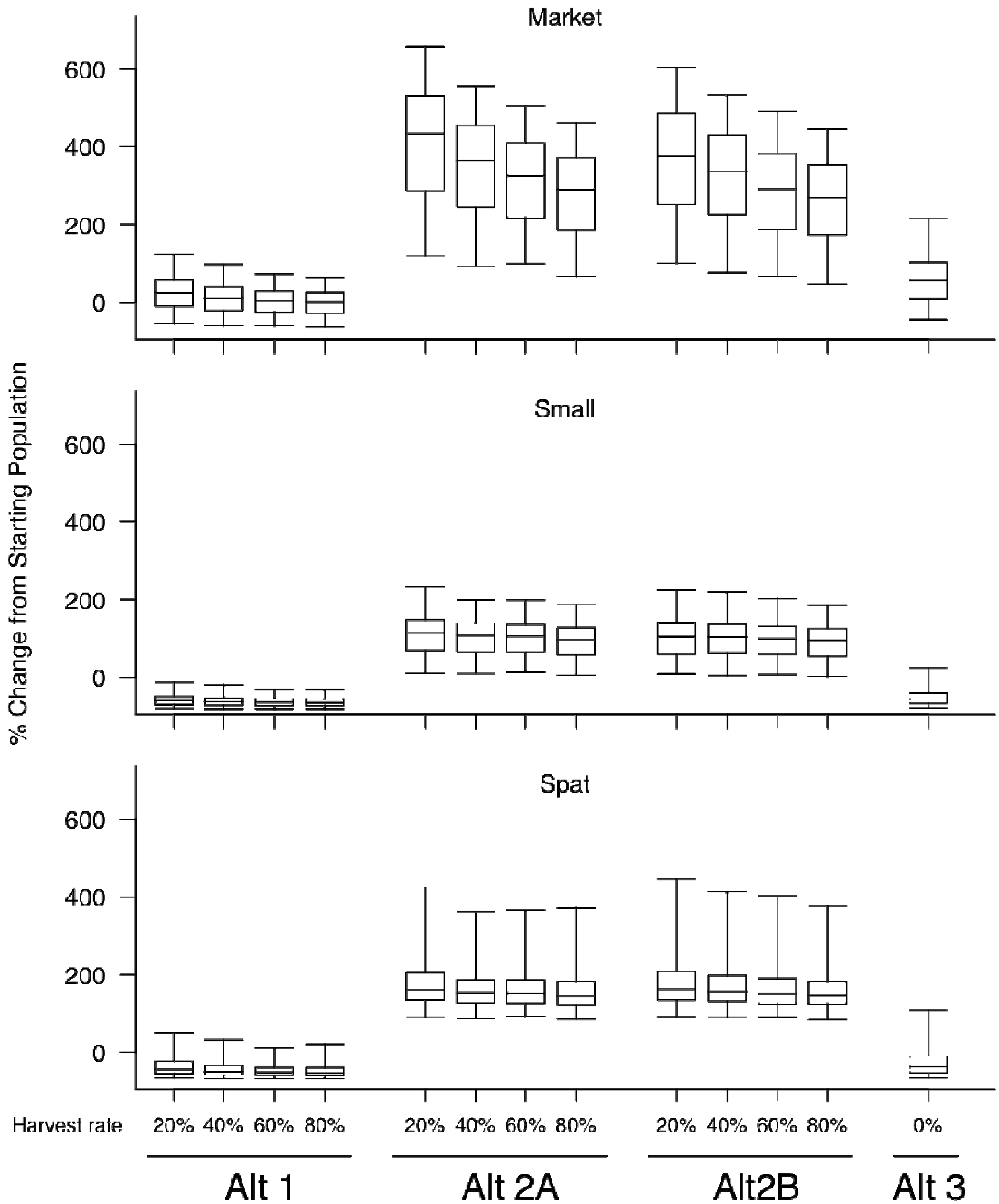


Figure 10. Abundance of oysters in the James River, Virginia, as predicted by 1,000 runs of the oyster demographic model (solid line), and field samples (dashed line). The number of spat < 30 mm was input into the model each year for run A, and estimated by the model for run B. Model estimates are the median value of all runs. Vertical bars indicate 90% confidence intervals, as estimated by the 5th and 95th percentile of all runs.

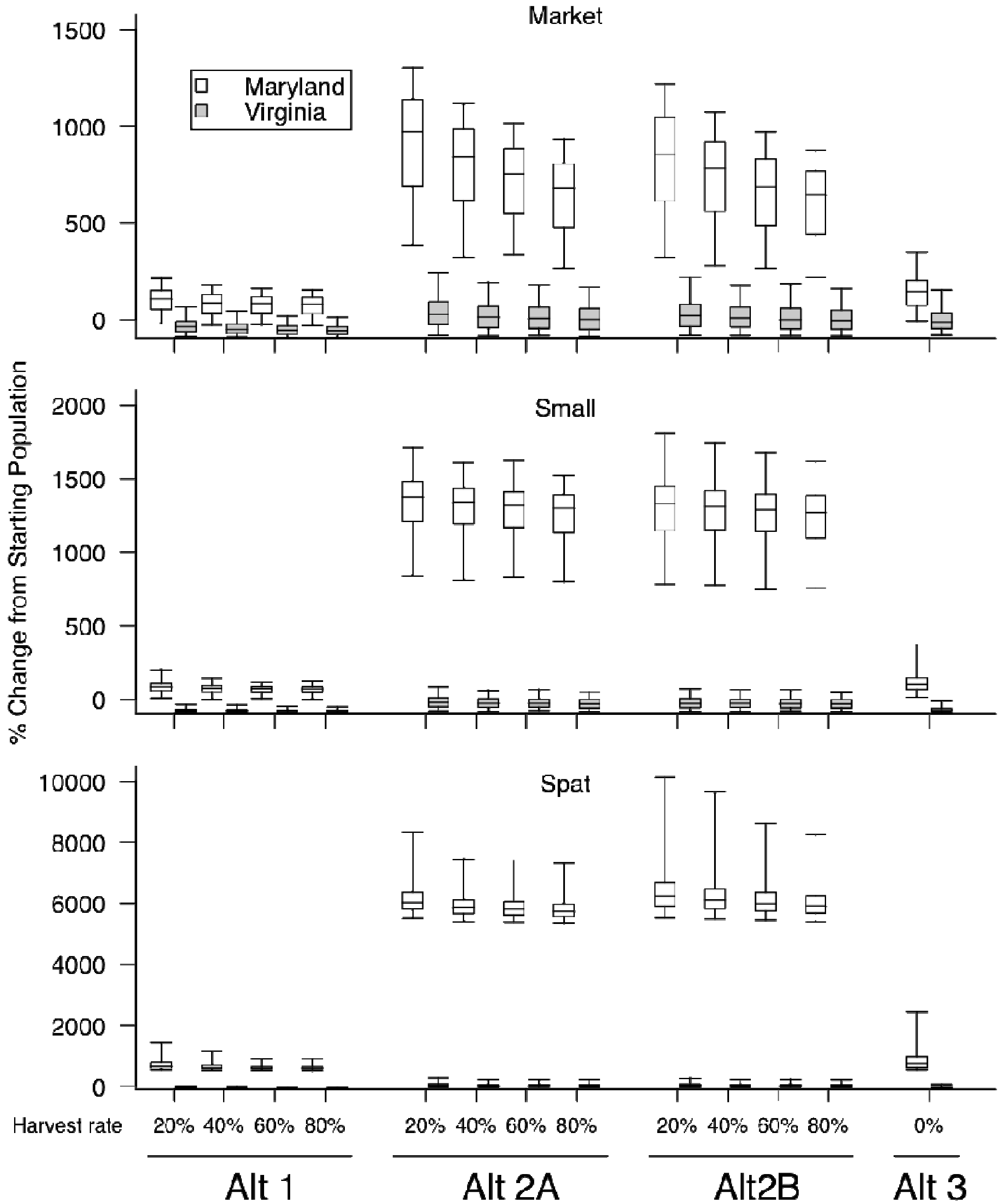
Figure 11. Change in oyster abundance from the starting population to year 10 projected by 1,000 runs of the demographic model for EIS alternatives 1 (status quo management), 2A, 2B (enhanced restoration), and 3 (no harvest). Harvest rates indicate winter exploitation rates of 20 to 80% on legally harvestable bars (71% of the total), after natural mortality has occurred. Boxes indicate the range of the 25th to 75th percentile of all runs. Vertical bars extend to the 5th and 95th percentile of all runs. Results are presented for the entire Bay (A), Maryland and Virginia (B), and by salinity zone (D). Results for Maryland and Virginia are also presented as change in predicted total abundance rather than percent change from the starting population (C). Note that scales differ among plots for spat, small, and market-size oysters on some panels.

A. Whole Bay



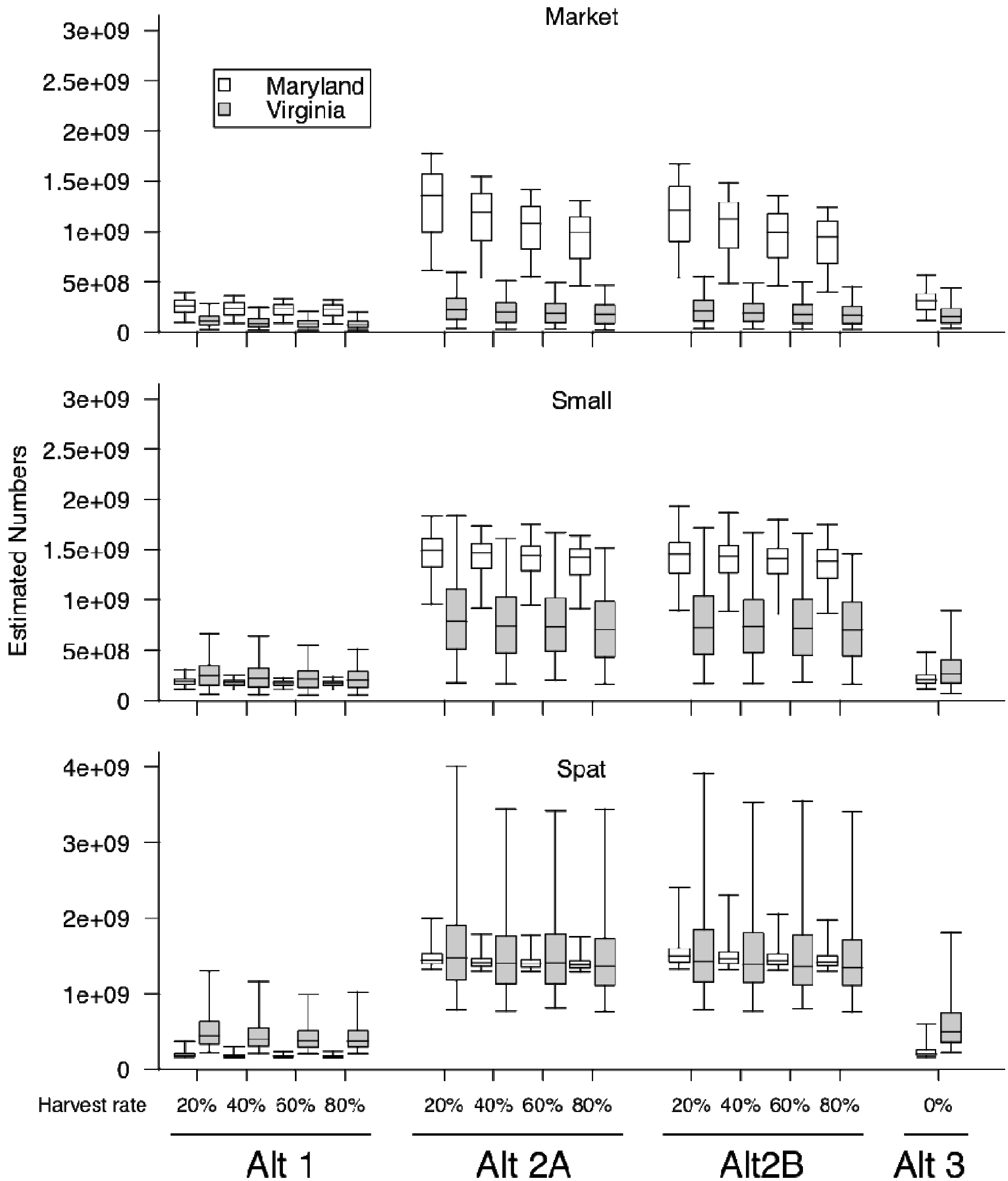
Market
Small
Spat
% Change from Starting Population
600
400
200
0
Harvest rate
20% 40% 60% 80%
20% 40% 60% 80%
20% 40% 60% 80%
0%
Alt 1
Alt 2A
Alt2B
Alt 3

B. By States

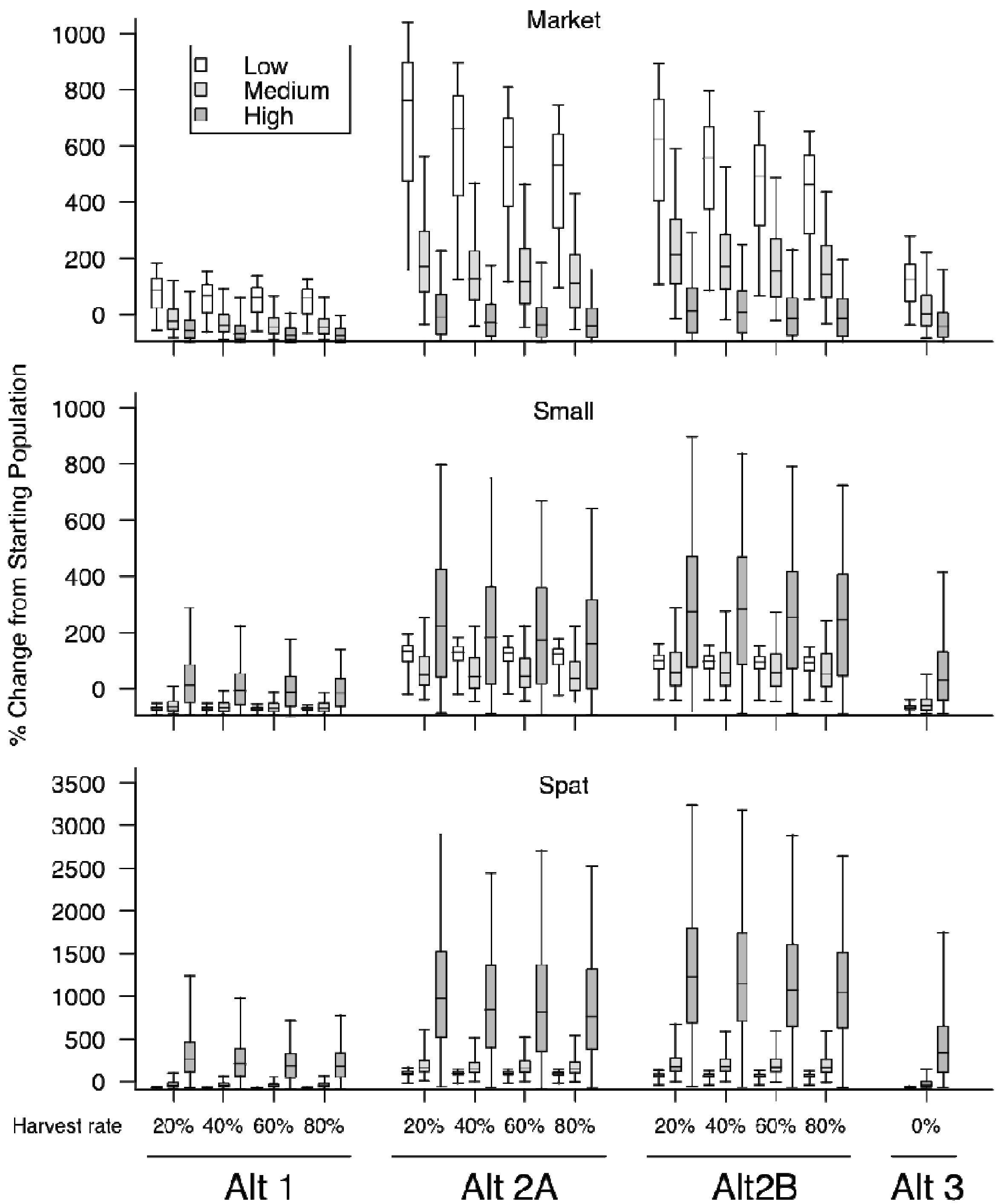


Market
Maryland
Virginia
Small
Spat
% Change from Starting Population
1500
1000
500
0
2000
1500
1000
500
0
10000
8000
6000
4000
2000
0
Harvest rate
20% 40% 60% 80%
20% 40% 60% 80%
20% 40% 60% 80%
0%
Alt 1
Alt 2A
Alt2B
Alt 3

C. Estimated **abundance** by State



D. By salinity zone



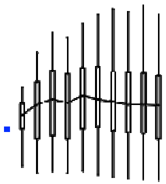
Figures 12-17. Oyster abundance projected by state in 1,000 runs of the demographic model for EIS alternatives 1 (status quo management), 2A, 2B (enhanced restoration), and 3 (no harvest). Results are reported for harvest rates (winter exploitation rates) of 20 to 80% on legally harvestable bars (71% of the total), after natural mortality has occurred, and categorized by the entire Bay, states, and salinity zones. Tables indicate percent changes in abundance from the starting population at the 5th, 25th, 50th (median), 75th, and 95th percentile for each year of the simulation. Data are depicted as boxplots to the right of each table to illustrate trends. Square symbols indicate the starting population (0% change). Scales differ for each plot. Note that salinity zones do not represent fixed areas. Individual bars may change salinity depending on annual precipitation, but the starting population is for a single wet year based on 2004.

Figure 12 . Whole Bay

12.1 Alternative 1, 20% harvest

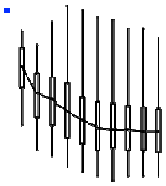
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	44	83	104	99	114	123	130	126	133	123
P75	27	51	63	59	66	67	62	61	60	57
P50	15	26	32	28	36	32	29	26	26	25
P25	0	−11	−8	−11	0	2	−2	−4	−5	−11
P5	−41	−48	−46	−48	−46	−50	−53	−54	−55	−56



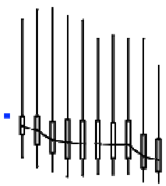
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−10	−17	−6	2	0	−4	−5	−9	−9	−14
P75	−19	−31	−33	−36	−43	−45	−46	−47	−48	−49
P50	−28	−41	−44	−50	−54	−58	−59	−59	−60	−60
P25	−38	−53	−57	−63	−66	−69	−68	−69	−69	−70
P5	−57	−69	−72	−77	−80	−82	−84	−82	−82	−82



Spat

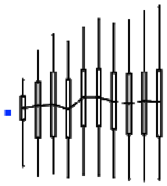
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	96	106	107	99	95	76	80	76	76	50
P75	−1	−1	−6	−4	−5	−5	−7	−5	−19	−23
P50	−10	−15	−24	−26	−28	−28	−29	−29	−40	−44
P25	−19	−29	−37	−42	−43	−43	−42	−42	−52	−55
P5	−41	−51	−55	−61	−60	−58	−59	−57	−65	−66



12.2 Alternative 1, 40% harvest

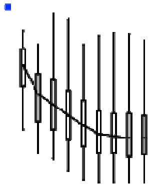
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	30	56	71	65	78	85	81	84	93	97
P75	15	28	37	30	39	40	36	35	37	39
P50	4	6	7	3	14	14	10	8	11	10
P25	−7	−23	−22	−23	−12	−12	−15	−20	−20	−22
P5	−49	−57	−55	−59	−56	−57	−59	−61	−62	−61



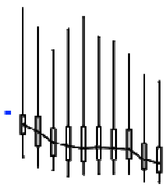
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−11	−18	−3	−6	−18	−14	−12	−13	−16	−20
P75	−20	−32	−35	−40	−45	−50	−51	−51	−52	−53
P50	−28	−42	−47	−52	−57	−61	−62	−63	−63	−63
P25	−38	−55	−59	−64	−67	−70	−70	−72	−71	−72
P5	−59	−70	−73	−79	−83	−84	−84	−84	−84	−84



Spat

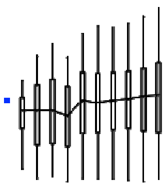
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	103	84	62	82	94	75	70	58	37	31
P75	−3	−4	−15	−13	−13	−13	−16	−17	−30	−34
P50	−11	−19	−29	−33	−35	−34	−35	−36	−46	−50
P25	−21	−33	−42	−47	−48	−46	−46	−45	−55	−58
P5	−43	−53	−56	−63	−61	−60	−59	−59	−67	−68



12.3 Alternative 1, 60% harvest

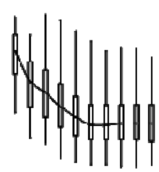
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	15	35	44	34	52	58	57	60	65	72
P75	2	12	16	11	22	21	22	23	25	29
P50	−8	−8	−8	−12	0	−2	0	1	3	4
P25	−22	−35	−34	−36	−26	−25	−23	−22	−24	−25
P5	−54	−61	−59	−64	−61	−62	−62	−63	−64	−61



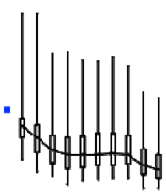
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−12	−21	−11	−14	−19	−24	−29	−27	−28	−32
P75	−21	−34	−38	−45	−51	−55	−55	−55	−55	−55
P50	−29	−44	−49	−56	−61	−65	−65	−64	−64	−64
P25	−40	−56	−61	−66	−70	−72	−72	−72	−72	−73
P5	−59	−71	−74	−81	−83	−84	−84	−85	−85	−84



Spat

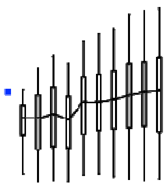
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	83	84	49	50	43	42	46	38	15	10
P75	−7	−13	−22	−24	−23	−20	−20	−22	−34	−39
P50	−14	−24	−35	−39	−39	−39	−38	−39	−48	−52
P25	−24	−37	−46	−51	−50	−48	−48	−47	−56	−59
P5	−43	−54	−57	−65	−62	−61	−59	−59	−68	−68



12.4 Alternative 1, 80% harvest

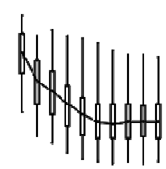
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	2	18	27	21	38	43	46	57	60	62
P75	−10	−2	4	−3	11	13	16	21	22	26
P50	−19	−19	−16	−20	−7	−7	−5	−2	0	1
P25	−32	−42	−40	−41	−31	−28	−27	−26	−25	−29
P5	−60	−66	−65	−66	−61	−60	−62	−64	−65	−64



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−13	−23	−20	−23	−24	−26	−30	−32	−32	−33
P75	−22	−35	−40	−47	−53	−56	−56	−56	−57	−56
P50	−31	−45	−50	−56	−61	−65	−66	−65	−65	−65
P25	−41	−56	−61	−67	−71	−73	−73	−73	−72	−73
P5	−60	−72	−75	−80	−83	−84	−85	−84	−85	−84



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	54	63	53	48	40	32	28	26	24	21
P75	−9	−16	−26	−25	−27	−26	−28	−27	−34	−39
P50	−16	−27	−37	−41	−42	−41	−41	−40	−48	−53
P25	−27	−40	−47	−52	−52	−50	−49	−48	−57	−60
P5	−47	−55	−58	−65	−63	−62	−60	−59	−67	−68

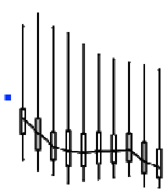
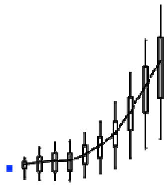


Figure 12 . Whole Bay (continued)

12.5 Alternative 2A, 20% harvest

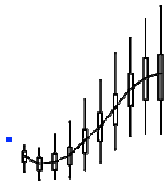
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	44	83	106	112	142	188	266	387	517	658
P75	25	49	62	61	90	128	189	290	412	531
P50	15	24	29	31	57	91	141	227	332	434
P25	1	−11	−11	−8	16	45	88	153	227	286
P5	−41	−48	−48	−49	−38	−23	1	42	80	119



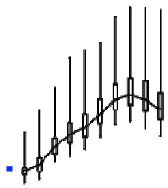
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−10	−15	8	30	70	103	150	177	209	232
P75	−20	−31	−25	−13	18	47	78	115	140	148
P50	−28	−42	−38	−27	−1	22	55	88	107	114
P25	−38	−53	−52	−44	−24	−3	26	58	69	69
P5	56	70	67	65	53	39	18	5	10	10



Spat

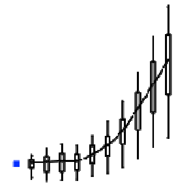
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	98	159	217	299	321	339	410	433	430	426
P75	3	29	83	124	146	187	227	245	236	205
P50	−4	11	59	92	111	146	185	199	185	160
P25	−15	−7	41	69	87	123	158	172	155	134
P5	−36	−27	20	34	53	87	120	129	109	89



12.6 Alternative 2A, 40% harvest

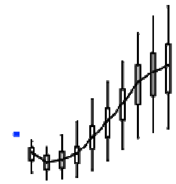
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	31	53	68	63	98	150	218	319	449	556
P75	12	27	37	35	62	97	156	251	359	455
P50	4	6	9	9	34	65	117	197	280	365
P25	−13	−26	−25	−21	2	30	69	120	183	245
P5	−51	−58	−57	−56	−45	−31	−12	23	60	92



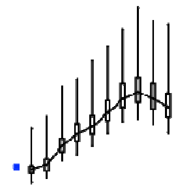
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−10	−20	−2	19	55	81	112	156	182	199
P75	−20	−33	−28	−19	13	40	69	107	126	139
P50	−29	−43	−39	−30	−5	20	48	81	97	107
P25	−40	−55	−53	−45	−23	−5	21	46	60	64
P5	60	71	69	66	56	40	24	6	4	9



Spat

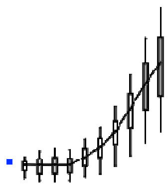
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	97	127	204	224	271	307	350	405	370	362
P75	1	19	72	110	129	169	211	228	211	187
P50	−6	5	53	84	102	137	173	190	173	152
P25	−17	−11	37	63	83	117	151	164	147	126
P5	−40	−30	16	31	52	85	115	122	107	86



12.7 Alternative 2A, 60% harvest

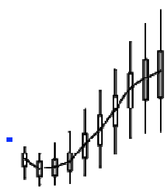
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	16	35	42	39	75	114	182	286	406	505
P75	2	10	15	12	43	79	134	224	324	409
P50	−8	−9	−9	−9	16	48	98	174	256	325
P25	−26	−37	−36	−33	−13	15	57	113	171	217
P5	−54	−62	−64	−62	−50	−39	−13	21	65	99



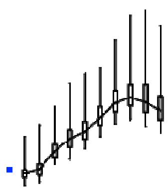
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−12	−22	−7	12	45	75	107	150	177	198
P75	−21	−34	−31	−21	9	37	66	102	123	135
P50	−30	−45	−42	−34	−8	15	45	79	94	105
P25	−41	−57	−56	−49	−29	−9	20	48	61	64
P5	−60	−71	−70	−68	−55	−42	−22	3	11	13



Spat

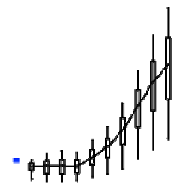
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	83	113	160	217	243	259	328	391	403	365
P75	−1	13	63	99	121	160	200	214	214	186
P50	−9	0	46	77	95	131	169	183	171	151
P25	−21	−15	31	56	76	112	147	162	146	125
P5	−41	−33	14	25	52	83	115	126	109	93



12.8 Alternative 2A, 80% harvest

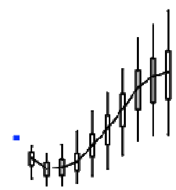
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	2	19	27	23	61	102	171	272	378	462
P75	−10	−3	1	0	31	66	127	212	299	372
P50	−19	−18	−18	−19	9	41	92	165	238	290
P25	−29	−40	−41	−38	−15	9	49	101	150	185
P5	−59	−65	−64	−63	−53	−41	−26	3	32	65



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−12	−24	−10	10	39	67	101	146	166	187
P75	−21	−36	−32	−23	6	33	64	99	117	127
P50	−30	−45	−43	−35	−11	14	43	74	91	97
P25	−40	−56	−55	−49	−28	−10	16	41	52	57
P5	−60	−70	−70	−67	−56	−46	−26	−4	4	5



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	77	101	145	182	204	267	320	360	375	371
P75	−3	11	57	92	116	151	194	214	204	181
P50	−12	−2	43	71	92	127	164	182	167	145
P25	−21	−15	30	55	76	110	146	159	143	122
P5	−42	−32	14	27	50	82	111	123	101	85

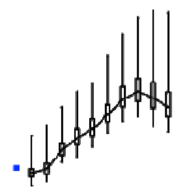
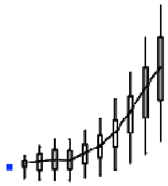


Figure 12 . Whole Bay (continued)

12.9 Alternative 2B, 20% harvest

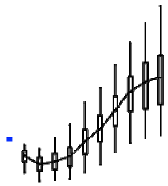
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	43	80	106	106	138	182	256	356	484	604
P75	27	50	64	62	87	120	175	267	374	487
P50	16	25	30	28	53	82	130	208	297	375
P25	2	−11	−7	−7	13	38	79	129	186	252
P5	−42	−48	−48	−50	−40	−29	−9	16	51	100



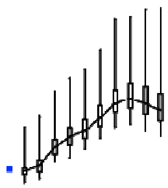
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−10	−16	2	24	62	87	124	163	195	224
P75	−19	−31	−25	−14	16	40	72	106	128	141
P50	−28	−42	−38	−29	−4	17	48	81	96	104
P25	−38	−54	−52	−45	−26	−5	22	46	50	59
P5	−57	−70	−68	−66	−56	−43	−23	−7	2	8



Spat

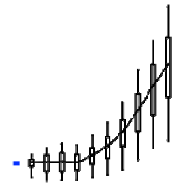
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	117	145	215	252	274	330	415	421	441	445
P75	3	23	81	115	137	176	217	237	227	208
P50	−4	9	59	89	105	141	181	195	181	163
P25	−15	−7	40	65	84	118	158	168	152	133
P5	−38	−28	19	32	55	85	116	124	105	92



12.10 Alternative 2B, 40% harvest

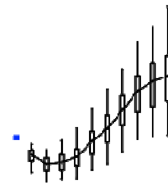
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	29	54	68	62	94	137	208	319	417	534
P75	14	28	35	30	54	90	147	235	335	428
P50	4	5	6	4	28	59	109	180	264	336
P25	−11	−27	−27	−24	−4	18	59	109	165	225
P5	−49	−59	−58	−58	−47	−38	−22	13	52	76



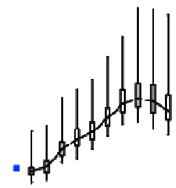
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−11	−21	−5	16	47	81	113	159	184	219
P75	−21	−34	−29	−19	10	37	70	103	123	136
P50	−29	−44	−41	−32	−6	15	46	78	94	103
P25	−39	−56	−55	−47	−28	−8	20	42	52	61
P5	−59	−72	−69	−68	−55	−44	−23	−3	2	4



Spat

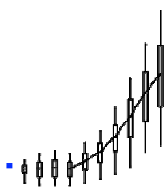
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	99	114	190	211	239	299	354	431	429	413
P75	1	18	71	106	123	162	211	228	224	198
P50	−7	4	51	78	97	135	173	188	179	155
P25	−16	−11	34	59	78	115	151	165	150	130
P5	−39	−32	15	27	51	86	119	125	106	89



12.11 Alternative 2B, 60% harvest

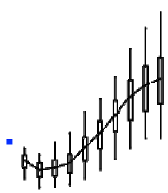
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	17	36	47	39	72	111	182	275	387	491
P75	2	12	18	12	39	71	128	212	299	382
P50	−8	−8	−7	−9	15	43	93	156	232	291
P25	−22	−35	−35	−34	−14	11	47	92	142	187
P5	−54	−63	−62	−64	−55	−42	−26	−3	43	66



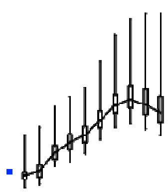
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−11	−20	−1	13	47	66	101	146	178	202
P75	−21	−34	−29	−20	7	32	64	97	119	131
P50	−30	−44	−41	−34	−9	13	41	71	88	99
P25	−41	−56	−55	−49	−31	−12	15	33	48	59
P5	−59	−72	−71	−68	−59	−44	−28	−11	5	6



Spat

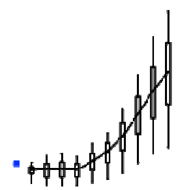
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	93	114	164	190	214	279	347	387	401	402
P75	−2	16	66	95	115	154	195	219	208	190
P50	−9	1	47	74	93	129	168	184	170	150
P25	−20	−14	31	55	74	111	149	161	145	124
P5	−41	−33	14	26	45	81	113	121	108	91



12.12 Alternative 2B, 80% harvest

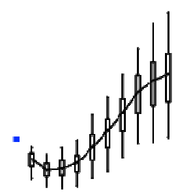
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	3	21	29	20	57	90	157	258	369	446
P75	−10	−1	4	−1	29	60	117	195	282	353
P50	−19	−17	−17	−18	7	35	81	145	214	269
P25	−29	−40	−39	−39	−20	3	38	87	133	173
P5	−59	−64	−65	−66	−54	−46	−27	2	29	47



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−12	−23	−13	−2	35	62	94	133	169	185
P75	−21	−36	−32	−24	6	29	59	93	113	125
P50	−30	−45	−43	−35	−12	12	39	69	86	95
P25	−40	−55	−54	−48	−31	−13	11	38	49	54
P5	−59	−69	−71	−69	−58	−47	−27	−6	−4	2



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	69	76	147	172	192	247	307	354	402	377
P75	−5	8	58	88	109	148	190	211	208	181
P50	−11	−3	43	69	89	126	164	179	168	147
P25	−20	−15	31	54	74	108	146	160	144	124
P5	−41	−33	13	27	47	79	115	122	103	84

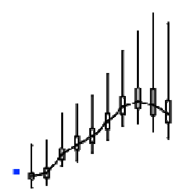
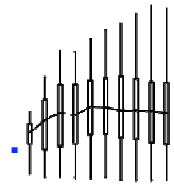


Figure 12 . Whole Bay (continued)

12.13 Alternative 3 (no harvest)

Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	58	110	150	149	167	181	192	205	218	215
P75	40	75	98	98	105	109	111	108	103	102
P50	26	45	56	53	65	64	60	60	59	56
P25	9	0	5	9	23	24	19	17	12	8
P5	−37	−42	−41	−43	−43	−42	−46	−46	−46	−45



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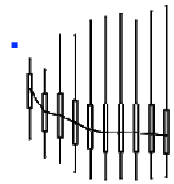
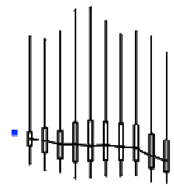
Percentile	1	2	3	4	5	6	7	8	9	10
P95	−9	−15	6	6	15	17	19	15	21	24
P75	−18	−30	−30	−34	−37	−36	−36	−36	−37	−40
P50	−27	−41	−43	−48	−52	−54	−54	−54	−55	−56
P25	−39	−53	−57	−61	−64	−66	−66	−66	−66	−67
P5	58	69	72	78	82	83	82	83	82	81



Spat

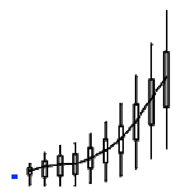
Percentile	1	2	3	4	5	6	7	8	9	10
P95	129	125	137	165	168	149	133	137	129	107
P75	1	6	2	14	17	15	13	11	−2	−10
P50	−7	−11	−16	−16	−18	−17	−19	−20	−31	−38
P25	−18	−26	−35	−39	−38	−37	−37	−38	−47	−53
P5	−42	−50	−53	−61	−60	−58	−58	−57	−65	−66



12.14 No harvest and Alt 2B

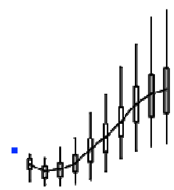
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	58	109	146	158	204	255	340	472	622	782
P75	40	75	98	106	138	174	238	339	457	588
P50	27	47	55	60	87	123	177	258	368	467
P25	12	1	6	13	39	69	111	173	245	327
P5	−39	−40	−40	−42	−31	−22	6	39	89	132



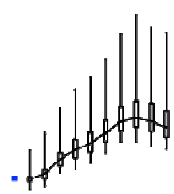
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	−9	−16	5	25	72	108	161	206	259	271
P75	−17	−30	−24	−10	23	52	84	124	147	159
P50	−27	−41	−37	−25	2	26	55	90	109	119
P25	−37	−53	−51	−42	−22	−2	28	56	65	72
P5	−59	−68	−68	−65	−56	−42	−16	0	8	14



Spat

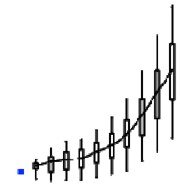
Percentile	1	2	3	4	5	6	7	8	9	10
P95	98	159	247	311	356	417	508	574	529	513
P75	5	31	89	136	161	205	251	274	261	238
P50	−2	16	67	100	123	159	200	212	201	179
P25	−11	−2	44	72	92	128	168	180	165	144
P5	−39	−28	21	33	53	88	127	127	116	102



12.14 No harvest and Alt 2A

Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	58	108	146	154	199	258	351	479	653	797
P75	39	72	93	105	138	180	247	346	483	612
P50	27	47	56	63	95	124	179	271	383	486
P25	15	0	11	19	41	69	115	173	254	343
P5	−37	−43	−42	−42	−31	−15	4	49	98	161



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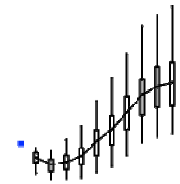
Percentile	1	2	3	4	5	6	7	8	9	10
P95	−9	−14	7	32	80	123	169	222	240	259
P75	−18	−30	−23	−9	25	53	89	120	144	152
P50	−27	−40	−35	−24	4	26	59	91	108	115
P25	−36	−53	−49	−41	−23	−3	26	54	68	71
P5	57	69	68	64	55	44	23	2	12	18



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	109	164	275	370	407	505	471	521	519	469
P75	7	32	95	145	169	205	251	263	256	227
P50	−2	16	69	105	127	157	198	207	195	168
P25	−10	−2	47	75	95	127	165	175	156	134
P5	−36	−27	18	35	54	83	120	128	111	95

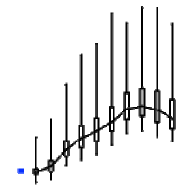
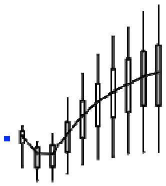


Figure 13 . Maryland

13.1 Alternative 1, 20% harvest

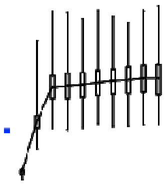
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	20	−5	6	65	104	134	165	178	203	214
P75	11	−15	−12	26	60	88	111	128	141	150
P50	4	−24	−25	7	37	59	75	87	100	106
P25	−8	−47	−46	−22	1	20	33	43	53	53
P5	−45	−68	−58	−56	−43	−34	−29	−24	−22	−21



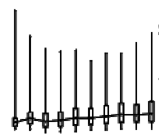
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−61	148	196	194	183	197	186	177	197	204
P75	−64	25	90	94	95	99	101	105	107	108
P50	−66	16	72	74	76	79	82	83	86	86
P25	−70	5	53	53	55	58	60	61	63	59
P5	80	30	4	2	5	11	7	8	10	11



Spat

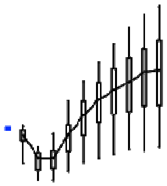
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1640	1406	1283	1263	1273	1170	1236	1241	1334	1432
P75	628	687	669	689	725	726	750	769	755	783
P50	595	626	602	610	629	630	644	659	657	667
P25	559	580	552	556	568	574	583	593	597	599
P5	522	519	495	500	502	512	518	527	530	531



13.2 Alternative 1, 40% harvest

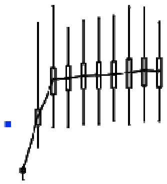
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	5	−28	−8	41	70	98	125	149	168	182
P75	−3	−36	−33	6	40	68	88	104	118	130
P50	−10	−43	−43	−9	20	43	57	69	83	86
P25	−18	−61	−59	−34	−10	9	21	25	33	34
P5	−52	−76	−77	−63	−51	−43	−38	−31	−33	−28



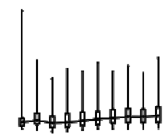
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−62	146	170	139	149	152	155	169	168	147
P75	−64	21	81	84	87	89	90	93	95	95
P50	−66	12	64	66	69	70	71	75	78	77
P25	−69	−1	43	48	51	51	52	52	56	54
P5	80	32	4	4	0	0	4	1	4	4



Spat

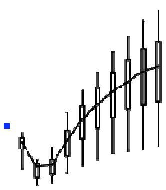
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1573	1124	967	1054	1026	1107	1026	1081	1008	1151
P75	601	647	617	641	666	669	667	694	687	705
P50	570	586	562	568	582	595	604	614	613	621
P25	539	553	523	529	541	550	561	567	568	570
P5	504	498	478	486	493	504	504	507	509	513



13.3 Alternative 1, 60% harvest

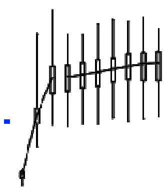
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−10	−47	−31	19	49	75	103	124	146	160
P75	−17	−53	−47	−6	27	53	75	91	107	117
P50	−23	−57	−55	−20	9	30	48	61	76	83
P25	−32	−71	−67	−42	−19	−3	12	23	29	34
P5	−60	−83	−79	−65	−56	−46	−39	−35	−33	−27



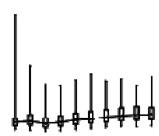
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−62	111	141	110	110	124	129	127	131	118
P75	−64	17	70	71	74	79	81	86	87	88
P50	−67	9	56	57	60	63	67	70	73	74
P25	−71	−2	35	39	43	45	50	53	52	52
P5	−81	−32	−4	−6	−3	−3	5	1	4	7



Spat

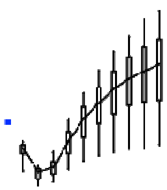
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1380	983	834	831	870	915	862	879	831	892
P75	567	597	572	588	609	622	636	650	660	651
P50	540	548	528	539	557	565	579	589	598	601
P25	514	520	501	512	523	534	541	552	557	562
P5	484	478	471	475	484	492	502	510	505	513



13.4 Alternative 1, 80% harvest

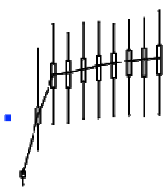
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−26	−60	−41	3	40	71	97	118	141	153
P75	−31	−64	−54	−13	21	48	70	90	103	114
P50	−36	−68	−62	−26	5	26	46	60	70	80
P25	−43	−78	−71	−43	−21	−2	11	23	28	30
P5	−67	−87	−82	−65	−53	−46	−41	−37	−35	−31



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−63	82	112	101	113	114	112	116	118	128
P75	−65	12	64	68	71	74	77	80	83	87
P50	−67	4	52	54	58	62	65	68	70	72
P25	−71	−7	36	36	43	44	47	51	50	52
P5	−81	−36	−8	−6	−1	0	2	3	2	4



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1151	875	752	850	784	767	793	823	862	909
P75	531	565	555	573	580	597	611	626	639	650
P50	512	524	513	530	542	553	566	579	591	596
P25	493	498	489	504	513	527	536	547	555	558
P5	466	465	460	469	482	490	497	505	508	506

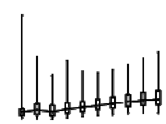
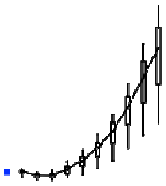


Figure 13 . Maryland (continued)

13.5 Alternative 2A, 20% harvest

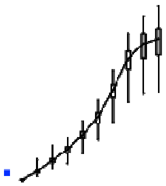
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	20	−4	12	85	167	291	455	696	1000	1304
P75	10	−15	−13	39	117	231	385	595	867	1136
P50	3	−24	−26	18	87	189	318	506	736	971
P25	−5	−47	−47	−13	42	120	226	372	540	689
P5	−44	−68	−69	−49	−20	25	91	181	283	385



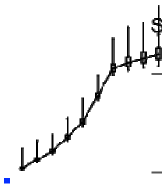
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−61	144	278	364	537	747	1052	1425	1614	1712
P75	−64	23	149	265	423	616	907	1251	1423	1483
P50	−66	14	130	240	392	572	851	1174	1327	1375
P25	−69	2	109	208	352	511	773	1064	1181	1214
P5	−79	−31	41	98	199	339	518	730	813	843



Spat

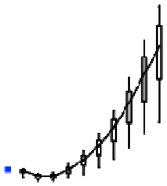
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1556	1931	2184	2983	3954	5038	6770	7332	7587	8354
P75	628	1063	1488	2166	2932	4207	5585	5907	6142	6360
P50	594	993	1403	2064	2809	4050	5358	5648	5839	6021
P25	563	948	1353	1994	2723	3952	5208	5460	5641	5814
P5	521	890	1291	1919	2613	3829	5056	5268	5398	5505



13.6 Alternative 2A, 40% harvest

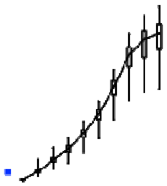
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	5	−29	−18	45	126	247	402	626	887	1119
P75	−3	−36	−34	15	93	200	342	532	770	985
P50	−10	−42	−44	−1	67	165	290	457	654	840
P25	−20	−61	−59	−25	28	98	194	318	467	617
P5	−55	−77	−76	−55	−31	13	72	154	245	323



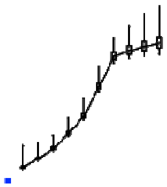
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−62	124	241	333	494	688	992	1340	1522	1612
P75	−64	20	140	256	409	603	887	1213	1377	1436
P50	−67	11	122	231	382	566	835	1142	1292	1344
P25	−70	[illegible]	101	200	341	516	748	1025	1118	1194
P5	−81	−34	35	89	187	328	514	700	781	809



Spat

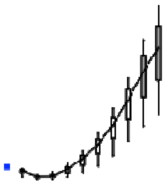
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1497	1586	1935	2673	3514	4892	6059	6598	7116	7462
P75	600	997	1437	2099	2854	4138	5473	5763	5956	6104
P50	571	949	1365	2023	2749	4003	5311	5558	5722	5876
P25	540	914	1322	1966	2684	3921	5164	5399	5553	5671
P5	504	862	1272	1900	2610	3802	5020	5225	5344	5401



13.7 Alternative 2A, 60% harvest

Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−11	−48	−34	27	100	212	369	561	803	1016
P75	−18	−52	−48	0	72	175	308	490	703	883
P50	−23	−57	−56	−14	52	141	264	421	600	751
P25	−33	−71	−68	−36	11	84	180	298	440	549
P5	−59	−82	−81	−61	−34	5	71	162	257	337



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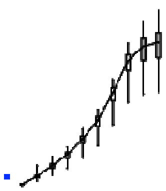
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−62	116	203	293	472	664	957	1307	1512	1626
P75	−65	15	130	243	399	590	875	1197	1355	1414
P50	−67	7	113	222	373	555	825	1136	1278	1319
P25	−71	−3	92	187	335	497	747	1040	1143	1170
P5	−80	−36	25	86	188	307	512	731	811	835



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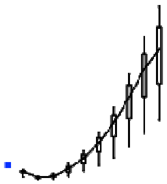
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1407	1437	1691	2587	3295	4555	5931	6325	7022	7397
P75	568	957	1389	2059	2800	4084	5413	5691	5903	6050
P50	543	912	1333	1989	2722	3973	5247	5514	5667	5808
P25	518	883	1298	1939	2659	3890	5137	5378	5504	5626
P5	486	843	1256	1886	2596	3790	4998	5202	5297	5387

13.8 Alternative 2A, 80% harvest

Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−26	−61	−45	11	85	193	340	533	752	933
P75	−32	−65	−56	−8	62	160	296	470	653	806
P50	−36	−68	−62	−20	42	131	251	399	566	680
P25	−41	−77	−71	−40	10	78	168	272	401	478
P5	−66	−86	−82	−62	−33	−1	45	115	187	263



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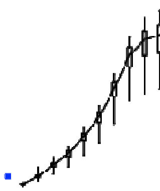
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−63	82	176	272	441	650	940	1283	1458	1522
P75	−65	11	122	236	384	582	862	1188	1335	1389
P50	−68	3	109	217	368	551	813	1117	1259	1302
P25	−70	−5	89	185	335	496	736	1008	1110	1134
P5	−81	−38	24	87	198	302	467	697	762	802



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1236	1276	1594	2352	3166	4411	5854	6326	6741	7316
P75	535	926	1358	2023	2777	4029	5360	5668	5843	5980
P50	513	887	1316	1966	2699	3939	5232	5477	5624	5739
P25	496	865	1286	1928	2646	3871	5118	5346	5471	5571
P5	470	832	1247	1881	2581	3787	4967	5195	5256	5359

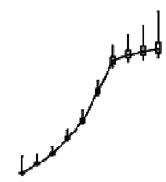
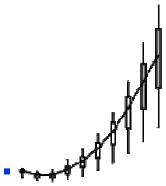


Figure 13 . Maryland (continued)

13.9 Alternative 2B, 20% harvest

Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	20	−5	10	88	159	268	426	657	942	1219
P75	11	−15	−14	33	107	211	358	552	792	1046
P50	4	−23	−26	13	77	168	292	463	661	855
P25	−6	−48	−48	−17	30	100	198	318	457	612
P5	−45	−68	−70	−54	−31	9	60	133	224	324



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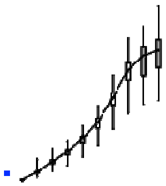
Percentile	1	2	3	4	5	6	7	8	9	10
P95	−61	155	266	345	516	729	1069	1461	1586	1811
P75	−64	22	143	255	406	597	875	1200	1374	1449
P50	−66	13	124	232	376	554	818	1119	1274	1332
P25	−69	3	103	200	328	489	740	1005	1062	1148
P5	−81	−35	26	83	176	298	481	652	749	786



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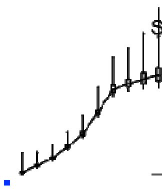
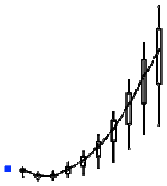
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1734	1763	2135	2915	3854	5530	7263	7812	8681	10133
P75	629	1041	1485	2162	2930	4213	5634	5989	6363	6679
P50	594	987	1406	2058	2794	4052	5390	5728	5993	6243
P25	558	946	1355	1993	2720	3949	5239	5562	5730	5912
P5	523	882	1292	1916	2616	3828	5061	5298	5455	5517



13.10 Alternative 2B, 40% harvest

Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	5	−28	−19	43	114	221	373	584	827	1073
P75	−3	−37	−36	10	81	180	316	497	717	919
P50	−10	−42	−46	−5	56	146	267	423	611	783
P25	−19	−62	−61	−31	15	82	182	297	426	561
P5	−54	−76	−76	−61	−34	0	51	127	228	282



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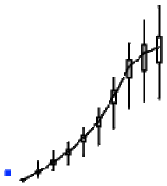
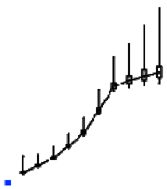
Percentile	1	2	3	4	5	6	7	8	9	10
P95	−61	118	233	314	468	685	1002	1360	1592	1745
P75	−64	18	132	245	396	584	866	1187	1345	1422
P50	−67	8	114	222	368	543	810	1112	1254	1313
P25	−70	−3	93	189	325	487	733	993	1072	1153
P5	−81	−37	27	88	179	295	467	677	751	779



Spat

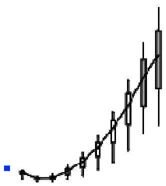
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1472	1543	1966	2673	3578	5134	6935	7665	8667	9670
P75	596	988	1421	2090	2856	4122	5527	5896	6224	6464
P50	566	944	1363	2009	2756	3998	5342	5661	5886	6095
P25	539	910	1321	1958	2688	3910	5198	5481	5680	5831
P5	502	860	1267	1895	2592	3804	5058	5278	5385	5486



13.11 Alternative 2B, 60% harvest

Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	−10	−46	−33	22	93	193	340	532	761	971
P75	−17	−53	−49	−2	63	157	289	455	657	830
P50	−23	−57	−56	−16	42	127	244	378	549	685
P25	−31	−70	−67	−37	6	71	156	264	374	486
P5	−59	−82	−81	−64	−42	−7	38	108	211	264



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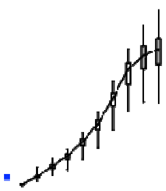
Percentile	1	2	3	4	5	6	7	8	9	10
P95	−62	105	193	283	447	655	964	1296	1527	1679
P75	−65	14	129	235	385	576	849	1157	1327	1393
P50	−67	5	111	214	359	537	793	1089	1225	1292
P25	−70	−6	89	180	318	477	719	932	1092	1143
P5	−81	−36	22	77	178	297	473	662	756	749



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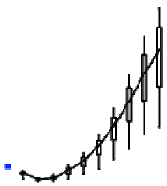
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1315	1397	1706	2507	3387	4952	6373	7521	8244	8626
P75	566	961	1385	2050	2813	4081	5452	5829	6055	6356
P50	542	911	1330	1986	2724	3964	5286	5617	5799	5986
P25	516	885	1298	1937	2660	3884	5164	5447	5602	5751
P5	485	838	1257	1884	2585	3781	5032	5258	5342	5448

13.12 Alternative 2B, 80% harvest

Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	−26	−61	−46	6	73	171	320	512	716	877
P75	−31	−65	−57	−11	51	143	271	437	618	769
P50	−36	−67	−62	−22	32	116	227	360	516	644
P25	−42	−77	−71	−42	0	64	146	249	363	441
P5	−66	−86	−63	−67	−41	−14	41	105	177	218



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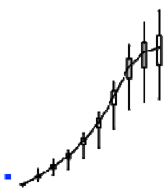
Percentile	1	2	3	4	5	6	7	8	9	10
P95	−63	77	164	260	425	633	922	1289	1500	1623
P75	−65	9	118	229	379	568	843	1155	1313	1384
P50	−67	3	104	208	354	533	789	1081	1222	1267
P25	−71	−6	83	176	316	481	706	968	1069	1100
P5	−81	−40	19	75	178	284	469	665	732	760



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	1128	1165	1626	2396	3254	4654	6263	7069	7720	8260
P75	533	911	1360	2029	2782	4050	5424	5763	6044	6252
P50	514	883	1314	1972	2703	3947	5261	5570	5776	5920
P25	496	863	1284	1929	2650	3869	5157	5409	5557	5692
P5	470	831	1249	1881	2576	3779	5001	5230	5340	5401

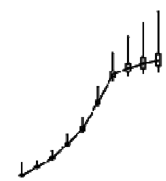
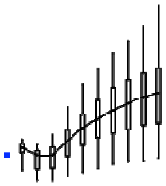


Figure 13 . Maryland (continued)

13.13 Alternative 3 (no harvest)

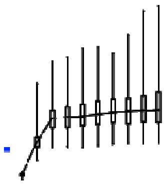
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	35	24	46	111	163	199	235	264	298	348
P75	26	10	18	58	95	127	156	175	191	202
P50	17	−1	−1	32	64	84	104	120	135	144
P25	5	−33	−31	−3	22	40	50	59	69	74
P5	−36	−60	−60	−50	−41	−32	−22	−16	−15	−7



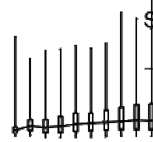
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−60	173	230	242	264	266	252	299	363	375
P75	−63	31	101	110	117	127	132	134	140	149
P50	−66	20	81	84	87	92	97	99	101	102
P25	−69	7	57	58	62	65	69	66	71	70
P5	80	28	3	7	5	10	14	16	16	17



Spat

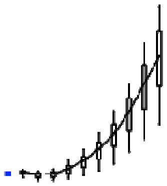
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1923	1631	1730	1748	1797	1762	1847	2264	2177	2426
P75	666	760	762	817	863	863	899	937	968	978
P50	626	678	661	676	701	715	728	740	757	749
P25	581	621	594	594	609	619	627	634	635	634
P5	538	541	514	518	522	523	527	535	537	531



13.14 No harvest and Alt 2A

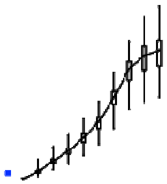
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	35	23	40	124	224	369	509	825	1187	1530
P75	25	9	16	71	159	283	452	686	989	1299
P50	17	−2	−1	47	123	225	364	569	823	1069
P25	8	−33	−31	6	61	135	249	390	589	797
P5	−34	−60	−59	−42	−15	27	90	199	317	452



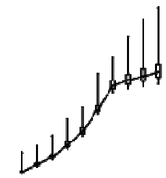
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−60	159	298	432	621	814	1153	1510	1775	1907
P75	−63	29	159	280	444	637	932	1272	1445	1518
P50	−65	18	140	252	405	586	865	1191	1342	1397
P25	−68	3	115	219	351	505	782	1057	1175	1220
P5	79	33	40	100	203	327	507	724	816	864



Spat

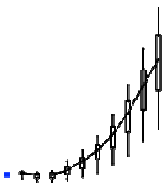
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1724	2084	2644	3610	4293	6125	7049	8195	9121	9829
P75	660	1115	1560	2275	3074	4338	5745	6083	6388	6672
P50	626	1042	1462	2133	2881	4124	5463	5765	5985	6214
P25	586	989	1394	2041	2767	4002	5265	5539	5734	5927
P5	542	913	1309	1936	2645	3849	5085	5309	5423	5556



13.14 No harvest and Alt 2B

Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	36	23	39	116	217	341	525	787	1116	1478
P75	26	11	18	71	152	268	428	647	928	1234
P50	18	0	−1	43	116	218	355	541	783	1015
P25	8	−33	−33	3	61	138	236	374	573	746
P5	−40	−61	−62	−47	−23	16	88	169	298	399



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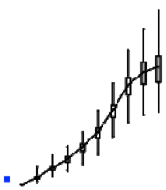
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−60	157	285	400	575	834	1177	1575	1845	2068
P75	−63	26	154	271	428	620	909	1244	1434	1510
P50	−65	16	133	243	396	574	844	1149	1312	1380
P25	−69	4	107	207	343	509	757	1029	1164	1188
P5	−80	−33	32	95	181	297	519	699	784	822



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Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1681	2035	2328	3447	4484	5928	8081	8686	10946	11441
P75	657	1108	1556	2251	3075	4368	5787	6294	6636	7166
P50	620	1039	1461	2121	2881	4171	5521	5894	6172	6504
P25	579	987	1396	2036	2770	4017	5346	5643	5880	6106
P5	535	904	1309	1929	2649	3853	5121	5370	5502	5715

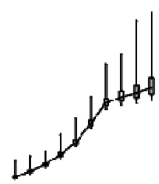
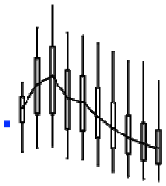


Figure 14 . Virginia

14.1 Alternative 1, 20% harvest

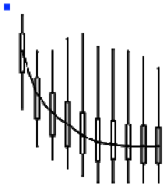
Market

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	64	147	181	140	135	123	111	96	94	65
P75	42	100	118	83	73	56	33	14	1	−9
P50	24	61	73	40	34	11	−6	−21	−30	−37
P25	2	16	16	−7	−10	−21	−36	−46	−55	−62
P5	−43	−37	−33	−52	−54	−64	−73	−80	−85	−87



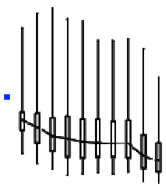
Small

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	−4	−24	−24	−17	−14	−21	−23	−24	−27	−33
P75	−14	−38	−46	−51	−57	−60	−61	−63	−64	−65
P50	−24	−47	−57	−63	−69	−73	−74	−75	−75	−75
P25	−35	−60	−69	−75	−79	−83	−82	−82	−84	−84
P5	−55	−75	−82	−87	−91	−94	−94	−94	−94	−94



Spat

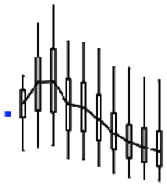
Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	64	78	83	73	71	52	52	55	45	18
P75	−14	−15	−20	−19	−21	−21	−23	−22	−36	−43
P50	−22	−28	−37	−39	−42	−43	−44	−44	−55	−60
P25	−32	−43	−51	−56	−57	−56	−56	−57	−67	−70
P5	−53	−63	−67	−74	−72	−71	−72	−70	−79	−80



14.2 Alternative 1, 40% harvest

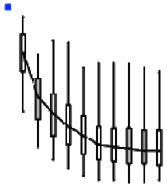
Market

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	50	121	144	97	94	86	62	61	48	45
P75	31	75	86	46	42	25	1	−15	−19	−23
P50	14	42	43	12	8	−8	−27	−38	−45	−51
P25	−5	4	2	−22	−23	−36	−48	−59	−65	−71
P5	−50	−44	−42	−59	−61	−70	−79	−85	−88	−90



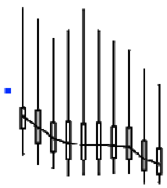
Small

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	−5	−26	−18	−19	−33	−30	−30	−31	−33	−35
P75	−15	−39	−47	−53	−59	−65	−66	−66	−67	−67
P50	−25	−49	−58	−65	−70	−75	−76	−77	−78	−78
P25	−35	−61	−70	−75	−80	−83	−84	−85	−85	−86
P5	−57	−76	−83	−88	−92	−94	−94	−95	−95	−94



Spat

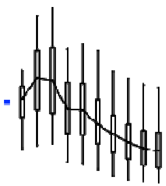
Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	73	63	46	53	71	53	43	36	18	5
P75	−15	−17	−28	−27	−29	−28	−31	−32	−44	−51
P50	−23	−32	−42	−46	−48	−48	−49	−50	−60	−65
P25	−33	−46	−54	−60	−61	−60	−59	−60	−70	−73
P5	−56	−65	−68	−75	−73	−73	−72	−72	−81	−81



14.3 Alternative 1, 60% harvest

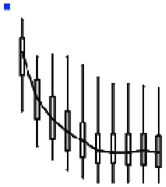
Market

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	36	97	106	60	66	58	35	26	20	17
P75	18	58	61	22	21	3	−15	−25	−32	−34
P50	4	27	24	−8	−9	−25	−36	−45	−52	−55
P25	−17	−9	−13	−35	−37	−47	−57	−64	−71	−74
P5	−52	−49	−47	−67	−69	−76	−83	−88	−89	−91



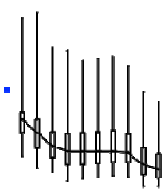
Small

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	−7	−27	−26	−27	−32	−38	−42	−42	−43	−44
P75	−17	−40	−49	−57	−63	−69	−69	−69	−69	−70
P50	−25	−50	−61	−68	−73	−78	−79	−79	−78	−79
P25	−37	−61	−72	−78	−82	−85	−85	−86	−86	−87
P5	−57	−76	−83	−89	−93	−95	−95	−95	−95	−95



Spat

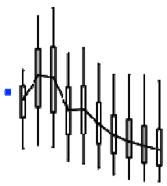
Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	60	65	35	33	24	26	28	20	−2	−10
P75	−19	−25	−35	−37	−36	−35	−34	−37	−49	−54
P50	−25	−36	−47	−52	−52	−52	−52	−53	−63	−67
P25	−36	−49	−57	−63	−63	−62	−61	−61	−71	−74
P5	−56	−66	−69	−77	−75	−74	−72	−73	−81	−81



14.4 Alternative 1, 80% harvest

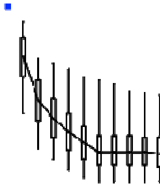
Market

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	23	77	86	40	45	29	18	18	17	12
P75	7	44	46	6	7	−10	−23	−28	−34	−37
P50	−7	17	15	−18	−17	−32	−44	−50	−54	−58
P25	−25	−15	−20	−43	−42	−52	−62	−66	−71	−75
P5	−57	−53	−55	−69	−72	−77	−83	−87	−90	−91



Small

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	−8	−28	−31	−34	−38	−40	−42	−46	−47	−48
P75	−17	−40	−50	−58	−65	−70	−70	−70	−71	−71
P50	−27	−51	−61	−68	−74	−79	−79	−79	−79	−80
P25	−38	−62	−71	−78	−83	−86	−86	−86	−86	−87
P5	−58	−77	−83	−89	−93	−95	−95	−95	−95	−95



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
	Year									
P95	34	48	36	31	22	12	9	7	7	−7
P75	−21	−28	−38	−39	−39	−40	−41	−41	−48	−54
P50	−28	−39	−48	−53	−54	−54	−54	−53	−62	−67
P25	−38	−51	−59	−65	−65	−63	−63	−61	−70	−74
P5	−58	−67	−69	−77	−75	−74	−73	−72	−81	−81

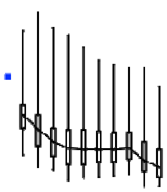
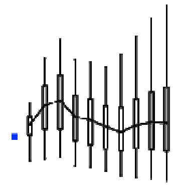


Figure 14 . Virginia (continued)

14.5 Alternative 2A, 20% harvest

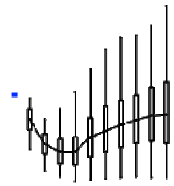
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	64	147	181	143	138	130	154	187	219	243
P75	39	96	114	77	71	57	55	71	83	92
P50	23	58	68	38	31	20	10	22	27	26
P25	3	15	15	−7	−14	−22	−26	−21	−23	−26
P5	−43	−40	−36	−54	−56	−63	−71	−75	−77	−81



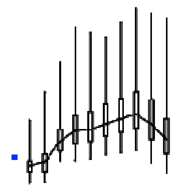
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	−4	−24	−15	3	25	44	56	58	68	87
P75	−15	−39	−44	−42	−23	−11	−6	−1	7	12
P50	−24	−49	−56	−56	−42	−36	−30	−25	−21	−20
P25	−35	−59	−68	−69	−62	−56	−52	−48	−46	−48
P5	−54	−76	−81	−85	−84	−83	−82	−81	−82	−82



Spat

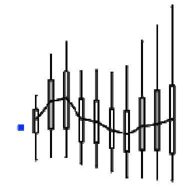
Percentile	1	2	3	4	5	6	7	8	9	10
P95	70	124	181	247	238	230	259	285	274	265
P75	−9	6	53	79	87	101	112	125	110	73
P50	−17	−10	30	50	53	63	73	82	63	34
P25	−28	−28	12	26	30	40	47	55	34	7
P5	−49	−48	−8	−8	−3	5	9	13	−11	−29



14.6 Alternative 2A, 40% harvest

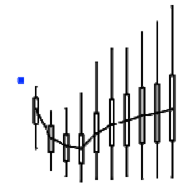
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	51	116	136	90	91	87	97	138	162	193
P75	28	75	89	46	43	29	26	47	58	67
P50	13	42	47	13	8	−4	−11	2	5	12
P25	−9	−2	−1	−23	−24	−32	−39	−37	−37	−42
P5	−51	−47	−47	−59	−63	−70	−79	−80	−83	−85



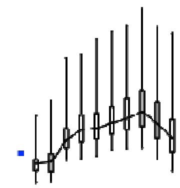
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	−5	−27	−24	−10	16	27	28	42	50	64
P75	−15	−39	−46	−46	−28	−16	−12	−6	−3	5
P50	−25	−50	−56	−58	−45	−38	−34	−30	−28	−25
P25	−37	−61	−69	−71	−61	−56	−55	−54	−53	−52
P5	−58	−77	−82	−86	−84	−84	−82	−84	−83	−83



Spat

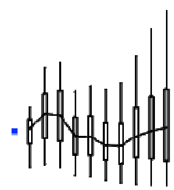
Percentile	1	2	3	4	5	6	7	8	9	10
P95	67	95	169	175	202	217	226	258	224	214
P75	−11	−1	44	68	71	83	99	111	90	60
P50	−18	−15	24	42	45	54	62	74	53	27
P25	−30	−32	9	21	26	34	42	48	27	2
P5	−52	−50	−12	−9	−5	5	8	9	−11	−31



14.7 Alternative 2A, 60% harvest

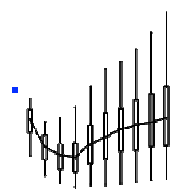
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	36	96	105	61	68	64	73	114	155	182
P75	18	56	62	21	23	12	11	35	52	64
P50	4	26	24	−7	−9	−21	−22	−8	0	5
P25	−19	−11	−15	−36	−37	−44	−49	−40	−42	−45
P5	−54	−50	−54	−67	−69	−74	−79	−81	−82	−83



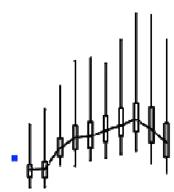
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	−7	−28	−25	−15	3	19	26	37	52	70
P75	−17	−40	−48	−47	−31	−20	−16	−9	−3	3
P50	−26	−51	−58	−60	−48	−42	−35	−31	−29	−25
P25	−38	−62	−71	−73	−66	−61	−55	−54	−51	−50
P5	−59	−77	−83	−87	−85	−85	−84	−82	−81	−80



Spat

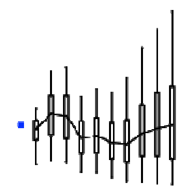
Percentile	1	2	3	4	5	6	7	8	9	10
P95	60	87	129	173	180	169	212	259	255	212
P75	−13	−6	35	58	64	76	89	99	90	62
P50	−21	−20	18	36	39	50	58	69	52	28
P25	−33	−34	3	15	19	29	39	48	28	2
P5	−53	−52	−13	−15	−4	0	7	12	−8	−26



14.8 Alternative 2A, 80% harvest

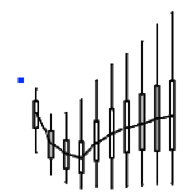
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	24	80	85	42	54	49	69	113	141	168
P75	7	43	43	6	11	3	8	30	47	57
P50	−6	17	13	−19	−16	−26	−28	−12	−5	0
P25	−22	−14	−20	−42	−41	−50	−54	−46	−46	−50
P5	−57	−51	−54	−69	−70	−77	−82	−84	−86	−88



Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	−7	−28	−26	−16	0	13	21	31	44	54
P75	−17	−41	−48	−49	−33	−23	−17	−11	−5	0
P50	−26	−51	−59	−62	−50	−43	−38	−35	−31	−29
P25	−38	−62	−71	−74	−65	−62	−58	−56	−57	−56
P5	−58	−76	−82	−86	−85	−86	−85	−84	−83	−83



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	55	76	114	140	140	173	200	227	238	213
P75	−15	−6	30	51	59	70	85	98	84	57
P50	−23	−22	16	30	36	46	55	68	49	23
P25	−33	−34	2	14	20	27	36	43	25	0
P5	−53	−50	−12	−14	−6	0	5	11	−13	−31

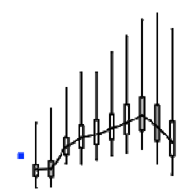
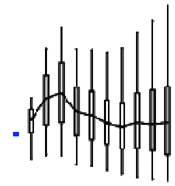


Figure 14 . Virginia (continued)

14.9 Alternative 2B, 20% harvest

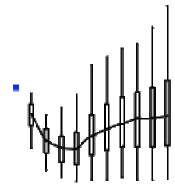
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	62	146	182	146	144	140	147	174	195	220
P75	42	100	122	80	73	58	53	70	75	81
P50	24	61	70	38	32	18	12	19	16	19
P25	2	15	19	−3	−10	−18	−26	−25	−29	−36
P5	−43	−37	−37	−54	−56	−63	−69	−74	−79	−81



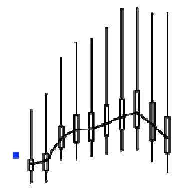
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−5	−25	−18	−7	20	28	35	40	55	74
P75	−15	−38	−44	−41	−25	−15	−9	−4	0	6
P50	−24	−49	−55	−56	−44	−38	−33	−28	−28	−26
P25	−35	−60	−68	−70	−62	−57	−54	−54	−54	−53
P5	−55	−76	−82	−85	−84	−84	−82	−84	−84	−83



Spat

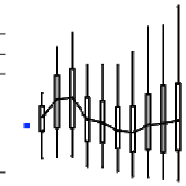
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	80	111	174	203	209	229	263	266	255	256
P75	−9	2	52	71	77	89	101	115	94	68
P50	−17	−12	30	45	47	57	68	77	55	30
P25	−28	−28	12	23	26	35	46	50	27	4
P5	−50	−48	−9	−9	−2	3	8	10	−12	−29



14.10 Alternative 2B, 40% harvest

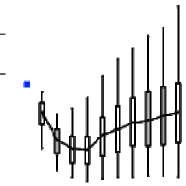
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	49	117	139	91	92	91	111	149	151	180
P75	29	75	86	43	38	28	29	47	61	64
P50	13	40	42	9	4	−7	−10	1	3	7
P25	−8	−3	−3	−24	−25	−34	−40	−37	−41	−38
P5	−49	−47	−46	−62	−63	−69	−76	−77	−80	−83



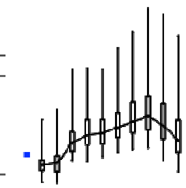
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−6	−27	−22	−12	8	23	32	43	51	70
P75	−16	−40	−46	−46	−29	−19	−12	−6	−2	1
P50	−25	−50	−57	−58	−45	−40	−34	−32	−28	−25
P25	−36	−62	−70	−71	−64	−60	−55	−55	−54	−52
P5	−57	−77	−83	−86	−84	−83	−83	−82	−82	−83



Spat

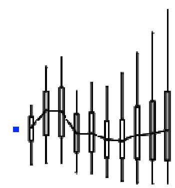
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	65	84	159	161	159	198	228	272	260	221
P75	−11	−2	42	65	65	78	97	109	94	64
P50	−19	−16	23	36	40	51	61	71	54	26
P25	−29	−31	6	18	21	32	40	46	29	4
P5	−51	−52	−12	−14	−4	4	9	12	−11	−31



14.11 Alternative 2B, 60% harvest

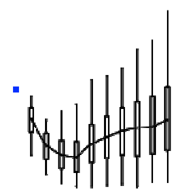
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	38	97	113	60	72	67	88	119	150	186
P75	20	59	66	24	26	13	16	35	44	58
P50	3	29	28	−6	−6	−16	−18	−9	−6	−1
P25	−18	−9	−12	−36	−36	−44	−45	−46	−47	−48
P5	−54	−52	−51	−67	−68	−74	−80	−84	−85	−84



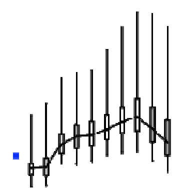
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−6	−27	−19	−13	9	12	19	36	43	69
P75	−16	−39	−45	−46	−31	−24	−16	−11	−6	2
P50	−26	−50	−58	−60	−48	−42	−37	−34	−33	−27
P25	−38	−62	−70	−73	−65	−61	−58	−59	−57	−54
P5	−58	−76	−83	−86	−86	−85	−84	−86	−82	−82



Spat

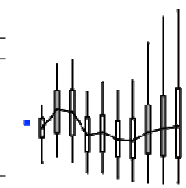
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	70	89	133	144	148	183	222	247	243	223
P75	−13	−4	37	53	59	71	83	99	83	61
P50	−21	−19	20	33	36	46	58	67	47	23
P25	−32	−33	4	13	18	28	39	43	24	1
P5	−53	−51	−13	−15	−9	1	5	7	−8	−27



14.12 Alternative 2B, 80% harvest

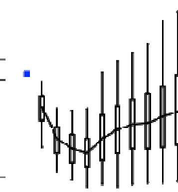
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	25	82	89	43	57	46	59	113	148	159
P75	7	46	47	8	11	2	7	25	38	49
P50	−7	19	15	−17	−13	−24	−25	−13	−8	−5
P25	−21	−14	−18	−41	−41	−48	−50	−44	−47	−49
P5	−56	−48	−54	−70	−70	−77	−82	−84	−86	−85



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−6	−27	−28	−27	1	10	16	23	41	48
P75	−17	−41	−47	−50	−32	−25	−20	−15	−10	−1
P50	−26	−50	−58	−61	−50	−43	−39	−38	−33	−29
P25	−36	−61	−69	−72	−67	−61	−58	−58	−57	−55
P5	−57	−75	−82	−87	−85	−87	−85	−84	−84	−83



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	45	56	119	126	131	153	183	216	238	211
P75	−16	−11	30	47	51	66	79	92	80	55
P50	−22	−22	15	28	33	44	55	63	48	22
P25	−32	−34	4	13	18	27	36	44	23	1
P5	−53	−52	−14	−14	−9	−2	8	10	−13	−32

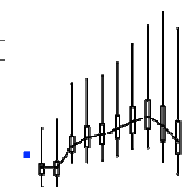
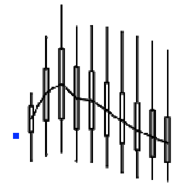


Figure 14 . Virginia (continued)

14.13 Alternative 3 (no harvest)

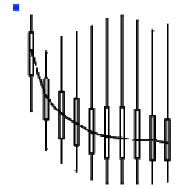
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	76	178	233	196	198	196	186	178	170	153
P75	53	121	156	124	116	96	77	60	46	34
P50	32	77	94	68	64	46	27	11	–2	–12
P25	8	27	30	13	13	0	–13	–26	–37	–46
P5	–43	–34	–29	–44	–47	–55	–65	–73	–77	–80



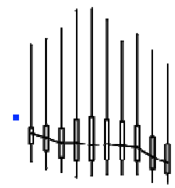
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	–4	–24	–16	–13	–10	–6	–4	–7	–12	–9
P75	–13	–38	–45	–49	–54	–53	–53	–55	–58	–60
P50	–23	–46	–57	–62	–67	–69	–70	–71	–71	–73
P25	–36	–60	–70	–74	–78	–81	–81	–81	–82	–82
P5	–56	–76	–83	–88	–92	–94	–94	–94	–94	–93



Spat

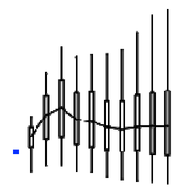
Percentile	1	2	3	4	5	6	7	8	9	10
P95	89	96	108	131	134	120	93	102	82	65
P75	–12	–10	–13	–3	0	–3	–5	–10	–24	–33
P50	–20	–25	–31	–31	–34	–33	–35	–37	–48	–56
P25	–32	–41	–49	–53	–53	–52	–52	–54	–63	–68
P5	–55	–63	–66	–74	–72	–70	–71	–70	–79	–80



14.14 No harvest and Alt 2B

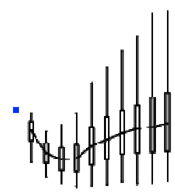
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	76	174	229	210	214	215	224	261	301	312
P75	54	123	157	129	132	112	112	125	129	134
P50	34	80	96	71	66	55	50	55	56	56
P25	10	27	31	16	10	5	1	3	–6	–8
P5	–44	–31	–28	–42	–45	–55	–60	–63	–67	–71



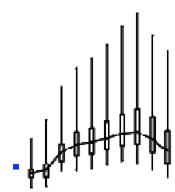
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	–3	–24	–17	–4	29	48	66	82	107	109
P75	–13	–37	–42	–39	–19	–8	0	5	14	19
P50	–23	–48	–55	–54	–40	–33	–26	–21	–19	–15
P25	–34	–59	–67	–68	–61	–55	–49	–48	–47	–46
P5	–58	–75	–81	–85	–84	–83	–80	–82	–81	–79



Spat

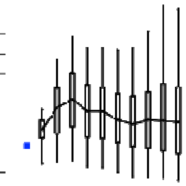
Percentile	1	2	3	4	5	6	7	8	9	10
P95	69	119	202	250	272	307	356	388	332	292
P75	–7	8	58	89	98	114	133	146	127	92
P50	–15	–7	37	57	63	72	85	89	70	41
P25	–25	–24	15	29	33	43	54	58	36	10
P5	–52	–49	–8	–8	–3	6	16	12	–6	–23



14.14 No harvest and Alt 2A

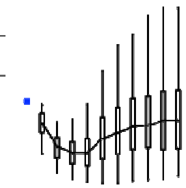
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	76	180	229	205	205	201	205	240	294	289
P75	52	120	151	128	122	109	104	112	130	123
P50	33	80	97	72	72	53	45	53	51	49
P25	15	25	39	17	14	6	–2	–5	–12	–18
P5	–40	–34	–31	–46	–48	–57	–66	–69	–70	–75



Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	–3	–22	–19	–3	32	60	70	91	99	99
P75	–13	–38	–43	–39	–17	–6	3	5	11	12
P50	–23	–48	–54	–54	–39	–33	–27	–25	–20	–20
P25	–33	–60	–66	–68	–61	–56	–51	–49	–51	–50
P5	–55	–76	–82	–85	–86	–86	–84	–83	–82	–79



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	74	128	234	316	328	366	328	353	324	289
P75	–6	11	65	99	107	117	134	136	120	85
P50	–15	–5	38	62	67	72	84	88	68	35
P25	–24	–25	18	32	35	41	53	57	31	6
P5	–50	–48	–10	–7	–3	0	10	14	–8	–27

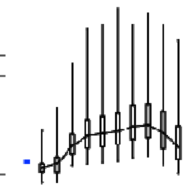
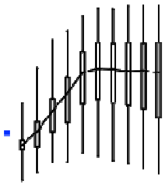


Figure 15 . Low Salinity

15.1 Alternative 1, 20% harvest

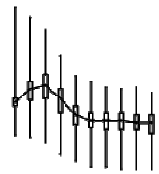
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	43	93	133	146	166	178	177	181	181	181
P75	−10	16	49	79	116	129	127	129	127	129
P50	−17	2	31	57	86	92	91	88	89	86
P25	−24	−19	2	15	41	48	43	39	34	22
P5	−68	−56	−42	−41	−29	−33	−39	−44	−50	−57



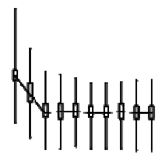
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−7	−12	−19	−33	−44	−47	−50	−51	−50	−53
P75	−56	−47	−43	−51	−60	−64	−64	−64	−65	−65
P50	−58	−51	−49	−56	−65	−68	−68	−68	−69	−69
P25	−60	−57	−56	−64	−70	−72	−73	−73	−73	−75
P5	−76	−77	−80	−86	−90	−93	−93	−94	−94	−94



Spat

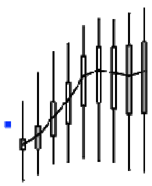
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−18	−39	−52	−53	−55	−58	−58	−57	−56	−56
P75	−51	−58	−69	−69	−69	−70	−70	−69	−70	−70
P50	−54	−64	−74	−73	−73	−74	−74	−73	−74	−74
P25	−56	−66	−76	−77	−76	−76	−76	−77	−77	−77
P5	−79	−87	−93	−93	−92	−93	−93	−93	−94	−94



15.2 Alternative 1, 40% harvest

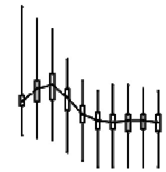
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	29	65	93	103	126	135	134	142	149	152
P75	−19	−2	29	54	88	99	99	101	106	106
P50	−25	−14	10	32	62	70	66	62	68	67
P25	−32	−31	−15	1	24	28	20	14	15	6
P5	−72	−63	−50	−48	−42	−46	−49	−58	−60	−62



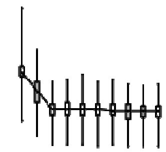
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−8	−15	−20	−36	−48	−53	−50	−50	−52	−53
P75	−56	−48	−44	−52	−61	−65	−66	−66	−66	−66
P50	−59	−52	−50	−57	−66	−69	−70	−69	−69	−70
P25	−61	−59	−58	−64	−70	−74	−74	−75	−74	−75
P5	−77	−79	−80	−86	−91	−94	−94	−94	−94	−94



Spat

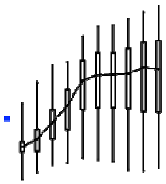
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−19	−42	−59	−58	−55	−59	−58	−60	−61	−60
P75	−51	−59	−71	−70	−71	−71	−71	−71	−72	−72
P50	−54	−64	−74	−74	−74	−74	−75	−75	−75	−75
P25	−56	−70	−77	−77	−77	−77	−77	−79	−78	−78
P5	−80	−88	−93	−93	−93	−94	−93	−94	−94	−94



15.3 Alternative 1, 60% harvest

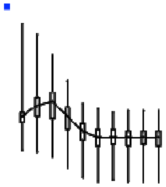
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	18	45	66	69	101	112	115	122	130	138
P75	−28	−13	11	35	71	81	81	86	93	96
P50	−34	−25	−5	16	47	53	54	55	63	61
P25	−41	−40	−25	−13	11	13	13	12	9	8
P5	−75	−66	−57	−55	−48	−50	−52	−63	−64	−60



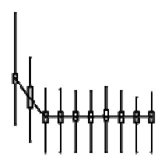
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−9	−15	−26	−40	−52	−55	−57	−56	−56	−56
P75	−57	−49	−46	−54	−63	−66	−66	−67	−67	−67
P50	−59	−53	−51	−59	−67	−70	−70	−70	−70	−70
P25	−62	−59	−60	−66	−72	−75	−74	−75	−74	−75
P5	−77	−78	−81	−87	−92	−94	−93	−94	−94	−94



Spat

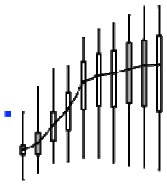
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−19	−43	−60	−60	−61	−61	−59	−61	−64	−62
P75	−52	−59	−72	−72	−72	−72	−71	−72	−72	−72
P50	−54	−65	−75	−75	−75	−75	−75	−75	−75	−75
P25	−57	−70	−78	−78	−77	−78	−77	−78	−78	−78
P5	−79	−86	−94	−94	−94	−94	−94	−94	−94	−94



15.4 Alternative 1, 80% harvest

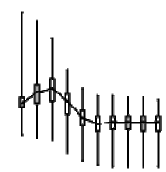
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	2	33	53	56	90	99	107	116	126	127
P75	−37	−23	2	25	61	71	75	83	87	92
P50	−43	−34	−13	6	38	45	48	53	57	58
P25	−48	−48	−32	−19	5	9	8	12	9	3
P5	−78	−69	−58	−56	−51	−51	−58	−61	−63	−66



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−11	−16	−25	−42	−52	−56	−56	−57	−57	−58
P75	−57	−60	−47	−55	−61	−67	−67	−67	−67	−67
P50	−60	−54	−52	−59	−68	−71	−70	−70	−70	−70
P25	−62	−60	−59	−66	−72	−75	−74	−74	−75	−75
P5	−77	−79	−80	−87	−91	−93	−94	−94	−94	−94



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−21	−45	−58	−61	−61	−63	−63	−61	−59	−60
P75	−52	−60	−72	−72	−72	−73	−72	−73	−72	−72
P50	−55	−66	−75	−75	−75	−75	−75	−75	−75	−75
P25	−57	−70	−78	−78	−77	−78	−78	−77	−78	−78
P5	−79	−88	−94	−94	−94	−94	−94	−94	−94	−94

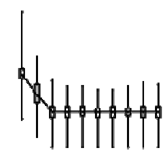
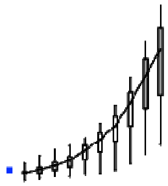


Figure 15 . Low Salinity (continued)

15.5 Alternative 2A, 20% harvest

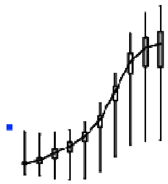
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	42	91	129	153	199	284	407	585	806	1039
P75	−11	16	48	85	154	233	338	493	701	897
P50	−17	2	27	60	123	191	278	421	593	762
P25	−23	−19	−2	19	65	113	180	277	389	474
P5	−67	−55	−43	−44	−31	−21	−1	40	102	158



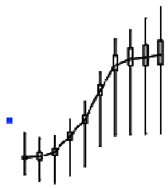
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−7	−12	−8	−4	7	39	87	150	184	195
P75	−56	−49	−36	−24	−8	19	66	119	144	153
P50	−58	−53	−42	−31	−15	12	57	105	127	133
P25	−61	−58	−50	−40	−23	0	43	86	98	97
P5	76	78	81	85	82	71	47	28	22	21



Spat

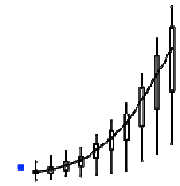
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−19	−26	−23	1	27	71	120	134	152	167
P75	−53	−47	−42	−18	7	52	96	108	112	118
P50	−56	−54	−47	−24	1	44	82	91	93	97
P25	−58	−59	−51	−28	−4	37	74	81	81	84
P5	−81	−89	−92	−82	−68	−39	−22	−21	−20	−19



15.6 Alternative 2A, 40% harvest

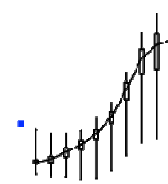
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	29	63	90	105	178	259	352	517	718	897
P75	−20	−1	26	58	126	199	296	440	616	777
P50	−26	−13	9	37	95	162	248	375	516	661
P25	−33	−33	−17	4	51	95	151	229	324	423
P5	−73	−63	−52	−54	−45	−32	−17	33	73	125



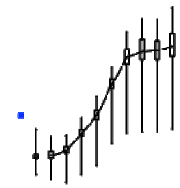
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−8	−15	−14	−10	10	32	79	139	168	181
P75	−56	−50	−37	−26	−9	18	64	114	138	149
P50	−59	−54	−43	−32	−15	11	54	101	121	130
P25	−61	−60	−51	−40	−24	1	37	77	84	101
P5	77	80	81	86	83	72	48	28	23	21



Spat

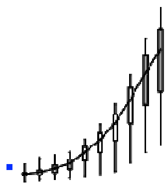
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−19	−29	−27	−3	26	66	116	134	133	149
P75	−53	−49	−43	−20	7	51	92	105	103	114
P50	−56	−55	−48	−25	0	43	81	88	90	96
P25	−59	−59	−51	−28	−5	38	72	78	78	82
P5	−82	−88	−92	−82	−69	−39	−24	−23	−22	−19



15.7 Alternative 2A, 60% harvest

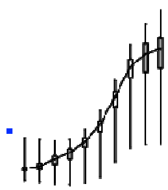
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	16	47	60	76	140	217	318	468	654	809
P75	−29	−14	9	38	103	173	267	403	566	698
P50	−34	−26	−7	18	76	138	223	341	476	596
P25	−43	−40	−28	−10	32	74	134	221	315	383
P5	−74	−65	−61	−58	−49	−41	−22	23	75	115



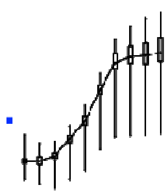
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−10	−14	−16	−13	2	32	79	135	167	188
P75	−57	−51	−39	−28	−11	16	62	112	137	145
P50	−59	−55	−44	−34	−17	10	53	100	120	128
P25	−62	−60	−52	−44	−25	−1	38	83	92	98
P5	−77	−79	−83	−85	−82	−72	−48	−26	−21	−20



Spat

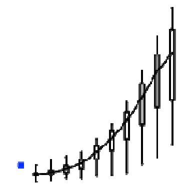
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−20	−31	−29	−7	21	65	112	130	142	149
P75	−53	−50	−45	−21	5	49	93	103	107	115
P50	−57	−56	−49	−25	−1	42	80	88	90	94
P25	−59	−61	−52	−30	−6	37	72	79	78	82
P5	−82	−88	−93	−82	−69	−40	−23	−21	−20	−18



15.8 Alternative 2A, 80% harvest

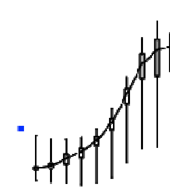
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1	27	42	63	125	194	298	444	610	745
P75	−37	−24	−2	27	92	160	254	385	523	641
P50	−43	−34	−16	9	64	128	213	323	446	531
P25	−48	−46	−35	−15	29	70	124	193	275	307
P5	−77	−69	−62	−63	−51	−48	−34	5	41	96



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−10	−17	−17	−13	−1	29	77	134	159	176
P75	−57	−52	−39	−29	−12	15	60	111	133	141
P50	−59	−55	−45	−34	−18	9	52	97	117	124
P25	−62	−60	−53	−44	−25	−2	37	74	79	86
P5	−77	−79	−82	−85	−82	−73	−50	−29	−27	−24



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−20	−32	−32	−7	18	64	114	135	132	146
P75	−53	−50	−46	−21	4	49	92	103	103	111
P50	−57	−56	−49	−26	−2	41	79	86	89	92
P25	−59	−60	−52	−30	−5	36	71	77	75	78
P5	−81	−88	−93	−82	−69	−40	−24	−24	−22	−19

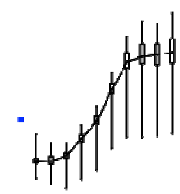
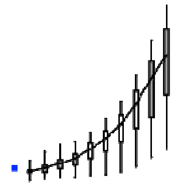


Figure 15 . Low Salinity (continued)

15.9 Alternative 2B, 20% harvest

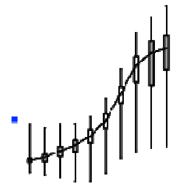
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	43	93	133	148	199	274	370	511	708	894
P75	−10	16	48	79	142	207	296	427	590	766
P50	−16	3	27	55	108	163	242	353	494	623
P25	−23	−20	−1	18	54	94	146	221	282	404
P5	−68	−56	−44	−47	−38	−34	−18	10	62	107



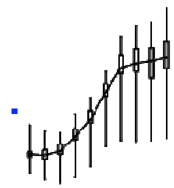
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−8	−12	−8	−7	4	29	71	123	143	160
P75	−56	−50	−39	−30	−15	8	46	89	111	118
P50	−58	−54	−45	−37	−24	−2	36	76	94	100
P25	−61	−60	−53	−46	−34	−13	23	52	48	70
P5	−76	−79	−82	−87	−87	−77	−55	−45	−40	−38



Spat

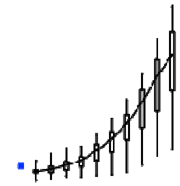
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−19	−27	−29	−4	17	51	97	110	116	134
P75	−54	−51	−44	−24	0	35	72	81	82	90
P50	−57	−58	−53	−34	−12	24	56	62	65	69
P25	−60	−63	−57	−38	−16	19	49	51	43	55
P5	−81	−90	−94	−87	−73	−47	−39	−40	−39	−36



15.10 Alternative 2B, 40% harvest

Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	28	61	91	100	156	238	331	458	634	797
P75	−20	−2	23	48	109	172	257	379	529	668
P50	−25	−14	6	29	79	136	215	320	449	557
P25	−32	−32	−18	−2	30	69	131	192	275	375
P5	−72	−63	−50	−54	−46	−42	−28	5	54	84



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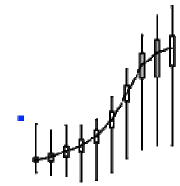
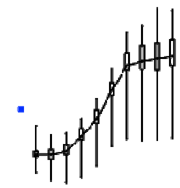
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−9	−18	−11	−11	−2	29	68	115	143	156
P75	−56	−51	−40	−31	−17	8	45	90	109	114
P50	−59	−55	−46	−39	−25	−3	35	74	91	98
P25	−61	−61	−55	−47	−35	−14	23	55	57	72
P5	−77	−80	−81	−88	−87	−77	−57	−43	−38	−39



Spat

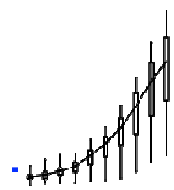
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−21	−33	−31	−13	14	52	98	106	129	126
P75	−54	−52	−46	−25	−1	34	72	81	84	88
P50	−58	−58	−54	−35	−13	24	56	61	64	67
P25	−60	−64	−58	−39	−18	18	49	51	49	56
P5	−81	−91	−94	−88	−73	−48	−38	−40	−39	−37



15.11 Alternative 2B, 60% harvest

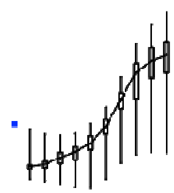
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	17	47	67	75	134	194	291	417	579	722
P75	−28	−12	8	33	89	151	236	348	485	602
P50	−34	−26	−7	15	63	118	191	285	400	491
P25	−41	−41	−27	−12	24	57	111	160	244	315
P5	−74	−65	−58	−60	−53	−51	−40	−11	35	67



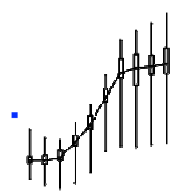
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−8	−14	−16	−13	1	23	65	111	137	154
P75	−57	−52	−40	−32	−17	6	43	84	106	113
P50	−59	−56	−47	−39	−27	−4	33	71	87	95
P25	−62	−61	−55	−50	−36	−14	21	34	64	71
P5	−77	−80	−83	−87	−88	−77	−54	−43	−39	−40



Spat

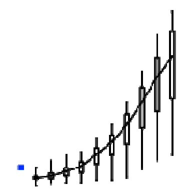
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−19	−30	−33	−11	13	50	96	107	117	130
P75	−54	−52	−46	−26	−1	33	71	78	76	85
P50	−58	−58	−55	−35	−13	22	54	60	62	65
P25	−61	−63	−58	−39	−18	17	47	38	51	53
P5	−82	−90	−94	−88	−74	−47	−40	−41	−38	−36



15.12 Alternative 2B, 80% harvest

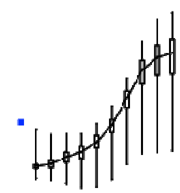
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	2	27	49	64	123	178	271	398	550	650
P75	−37	−23	−2	23	81	135	221	332	457	566
P50	−43	−34	−16	6	55	106	179	274	378	463
P25	−47	−46	−34	−21	14	52	96	164	233	287
P5	−77	−68	−62	−63	−53	−52	−41	−6	30	52



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−10	−17	−16	−16	−2	21	59	108	138	147
P75	−57	−52	−41	−33	−18	3	42	83	103	111
P50	−59	−56	−47	−40	−27	−4	33	70	87	93
P25	−62	−61	−54	−49	−35	−14	19	51	63	65
P5	−77	−79	−83	−88	−87	−78	−57	−42	−41	−39



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−21	−35	−34	−12	11	47	94	103	115	124
P75	−55	−53	−48	−26	−2	31	69	74	78	84
P50	−58	−59	−55	−36	−14	22	54	59	61	64
P25	−60	−63	−58	−39	−18	17	47	50	51	53
P5	−81	−90	−94	−88	−74	−48	−41	−41	−39	−37

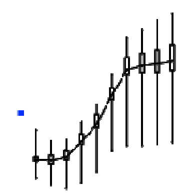
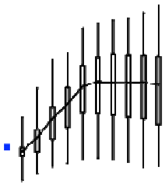


Figure 15 . Low Salinity (continued)

15.13 Alternative 3 (no harvest)

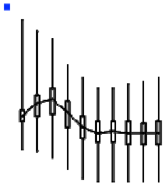
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	58	116	171	186	233	244	250	253	263	278
P75	−1	35	79	117	161	176	182	180	179	177
P50	−8	19	56	85	119	129	127	127	128	123
P25	−16	−9	16	40	69	67	63	59	56	45
P5	−65	−51	−37	−32	−24	−20	−24	−29	−38	−36



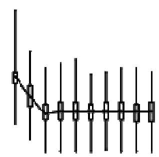
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−7	−13	−17	−31	−38	−43	−43	−41	−40	−38
P75	−55	−47	−43	−50	−58	−61	−61	−61	−62	−61
P50	−58	−51	−49	−56	−64	−67	−66	−67	−67	−67
P25	−61	−58	−57	−64	−70	−72	−72	−73	−73	−73
P5	76	77	80	86	91	93	93	93	93	93



Spat

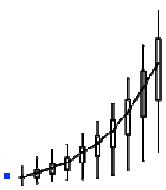
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−18	−40	−49	−46	−44	−52	−51	−49	−49	−51
P75	−51	−58	−68	−67	−67	−68	−67	−67	−68	−67
P50	−53	−64	−73	−72	−72	−72	−72	−72	−72	−72
P25	−57	−69	−76	−76	−76	−76	−76	−76	−77	−77
P5	−79	−87	−93	−93	−93	−93	−92	−93	−93	−93



15.14 No harvest and Alt 2B

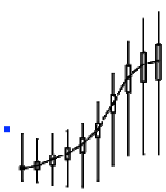
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	57	120	179	212	281	363	480	649	869	1104
P75	−1	36	76	120	194	266	369	513	703	919
P50	−7	19	52	89	154	217	303	424	586	753
P25	−14	−7	15	39	86	132	194	270	396	511
P5	−65	−52	−37	−34	−28	−13	5	40	101	159



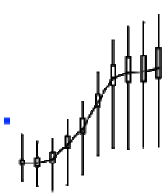
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−6	−13	−6	−2	10	41	85	132	167	176
P75	−55	−49	−38	−28	−12	10	51	96	115	128
P50	−58	−54	−45	−36	−22	0	39	79	98	104
P25	−60	−59	−53	−45	−34	−11	25	57	71	75
P5	−77	−79	−83	−86	−87	−77	−53	−39	−36	−37



Spat

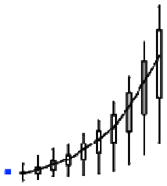
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−19	−28	−25	1	27	66	111	130	136	145
P75	−53	−50	−43	−21	4	37	77	87	90	100
P50	−57	−57	−52	−32	−10	26	59	66	68	73
P25	−59	−62	−57	−37	−17	20	50	54	55	59
P5	−82	−89	−94	−87	−73	−47	−37	−39	−36	−35



15.14 No harvest and Alt 2A

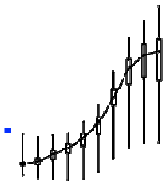
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	57	121	166	193	273	374	506	694	945	1217
P75	−2	34	77	124	207	296	413	580	811	1038
P50	−8	19	55	93	166	237	329	478	664	844
P25	−14	−9	17	48	90	139	213	291	422	545
P5	−63	−52	−35	−32	−24	−13	12	56	130	208



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−5	−11	−9	−4	14	46	101	158	186	213
P75	−55	−48	−35	−23	−5	22	69	121	146	156
P50	−58	−53	−41	−30	−13	13	57	106	129	135
P25	−60	−59	−49	−39	−26	−7	43	79	90	85
P5	76	80	81	85	83	71	48	28	21	21



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	−17	−26	−17	5	33	79	133	136	154	176
P75	−52	−47	−40	−16	10	55	98	107	116	118
P50	−56	−53	−46	−22	2	45	84	91	96	101
P25	−58	−60	−50	−27	−4	35	75	79	79	82
P5	−81	−89	−91	−81	−68	−40	−22	−23	−19	−17

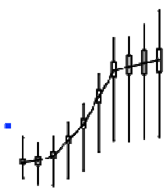
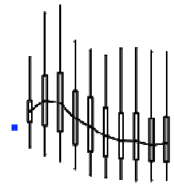


Figure 16 . Medium Salinity

16.1 Alternative 1, 20% harvest

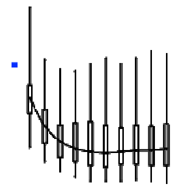
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	113	181	193	138	123	115	125	126	121	120
P75	43	82	86	57	48	31	23	23	14	17
P50	25	43	39	14	1	−14	−21	−22	−28	−25
P25	8	3	−6	−27	−39	−46	−49	−51	−53	−54
P5	−31	−44	−53	−66	−76	−80	−82	−85	−85	−84



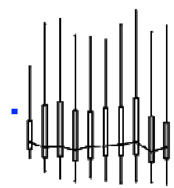
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	44	4	−4	−5	1	5	1	5	10	8
P75	−16	−35	−47	−45	−44	−47	−49	−47	−48	−46
P50	−26	−46	−60	−65	−67	−68	−67	−66	−66	−65
P25	−38	−61	−72	−75	−78	−79	−77	−77	−78	−78
P5	−64	−75	−83	−87	−90	−90	−90	−89	−90	−91



Spat

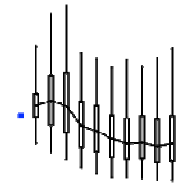
Percentile	1	2	3	4	5	6	7	8	9	10
P95	52	102	107	88	86	83	101	117	92	100
P75	−11	7	11	1	0	4	5	16	−6	−13
P50	−35	−42	−41	−45	−41	−40	−38	−35	−47	−42
P25	−44	−53	−52	−57	−54	−51	−51	−50	−59	−54
P5	−53	−69	−76	−81	−77	−80	−83	−81	−82	−84



16.2 Alternative 1, 40% harvest

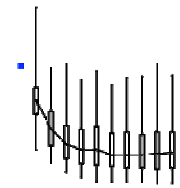
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	96	140	152	87	78	67	77	68	79	93
P75	30	55	59	20	14	[illegible]	−3	0	−5	0
P50	14	21	13	−14	−21	−32	−38	−37	−42	−38
P25	−2	−13	−23	−43	−50	−57	−60	−59	−64	−62
P5	−38	−51	−60	−72	−80	−85	−86	−87	−89	−90



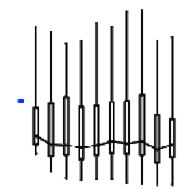
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	46	−2	2	−10	−4	−15	−9	−8	1	−7
P75	−17	−36	−47	−50	−48	−53	−52	−54	−52	−52
P50	−27	−50	−62	−66	−66	−70	−70	−70	−69	−68
P25	−38	−63	−73	−77	−78	−79	−80	−80	−81	−80
P5	−66	−76	−84	−88	−91	−91	−91	−91	−92	−92



Spat

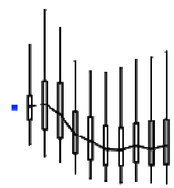
Percentile	1	2	3	4	5	6	7	8	9	10
P95	76	70	58	61	79	75	90	92	60	65
P75	−7	−3	4	−6	−5	−1	0	6	−14	−19
P50	−36	−44	−45	−48	−45	−41	−43	−41	−50	−44
P25	−44	−56	−55	−59	−55	−53	−54	−55	−63	−57
P5	−54	−71	−79	−81	−80	−80	−83	−84	−85	−85



16.3 Alternative 1, 60% harvest

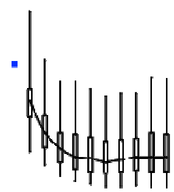
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	75	116	95	55	43	42	47	57	60	66
P75	14	31	29	−5	−11	−22	−24	−19	−16	−14
P50	1	4	−8	−32	−40	−49	−50	−45	−49	−45
P25	−14	−26	−37	−55	−62	−68	−69	−65	−68	−67
P5	−44	−56	−64	−78	−84	−87	−90	−88	−89	−91



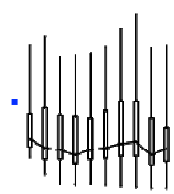
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	39	3	−13	−13	−19	−24	−22	−22	−10	−11
P75	−19	−39	−52	−53	−55	−58	−57	−56	−52	−53
P50	−28	−52	−64	−70	−71	−74	−72	−70	−70	−70
P25	−40	−63	−74	−79	−81	−82	−81	−80	−81	−81
P5	−66	−76	−84	−88	−90	−92	−92	−91	−92	−92



Spat

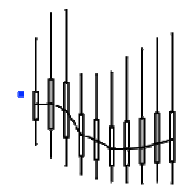
Percentile	1	2	3	4	5	6	7	8	9	10
P95	56	65	45	46	48	54	73	87	53	55
P75	−12	−6	−13	−14	−16	−9	1	1	−16	−26
P50	−37	−46	−48	−53	−48	−46	−42	−40	−53	−47
P25	−45	−57	−57	−61	−57	−56	−54	−54	−63	−59
P5	−55	−72	−82	−83	−82	−83	−84	−85	−86	−86



16.4 Alternative 1, 80% harvest

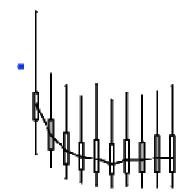
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	57	83	86	21	21	23	38	46	57	62
P75	3	15	12	−20	−25	−33	−28	−24	−19	−18
P50	−10	−9	−17	−41	−47	−55	−55	−54	−50	−46
P25	−25	−35	−44	−63	−66	−72	−72	−70	−69	−68
P5	−51	−64	−72	−81	−85	−89	−90	−91	−89	−91



Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	42	−6	−15	−23	−14	−26	−20	−22	−19	−15
P75	−20	−41	−51	−58	−56	−60	−56	−58	−53	−53
P50	−29	−53	−65	−69	−71	−75	−72	−72	−70	−70
P25	−41	−64	−75	−79	−81	−83	−82	−81	−81	−81
P5	−67	−77	−86	−89	−91	−92	−91	−92	−92	−92



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	46	47	90	47	42	46	60	73	74	68
P75	−14	−9	−2	−19	−16	−12	−1	−1	−12	−22
P50	−39	−48	−49	−53	−49	−47	−45	−41	−51	−46
P25	−46	−58	−57	−62	−58	−57	−56	−53	−63	−59
P5	−57	−73	−83	−84	−85	−86	−86	−86	−86	−86

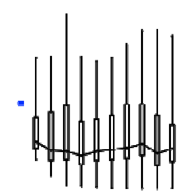
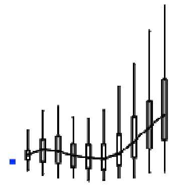


Figure 16 . Medium Salinity (continued)

16.5 Alternative 2A, 20% harvest

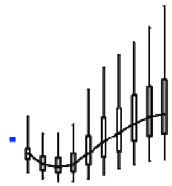
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	115	184	198	162	156	186	273	353	472	563
P75	39	80	91	64	63	64	97	165	220	297
P50	25	43	37	22	16	12	28	72	124	170
P25	8	1	−6	−20	−25	−29	−15	16	47	79
P5	−31	−45	−54	−60	−69	−68	−60	−54	−38	−35



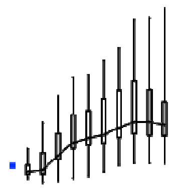
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	44	11	11	27	96	136	161	185	214	254
P75	−17	−33	−35	−28	7	42	60	84	101	113
P50	−27	−47	−52	−48	−27	−5	12	29	43	48
P25	−38	−60	−64	−62	−48	−34	−22	−4	7	11
P5	−64	−74	−78	−79	−75	−67	−57	−48	−41	−38



Spat

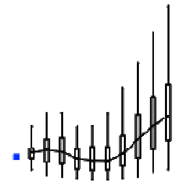
Percentile	1	2	3	4	5	6	7	8	9	10
P95	65	166	269	341	350	404	453	562	569	606
P75	3	49	123	195	211	258	289	327	291	243
P50	−22	−16	39	88	106	118	146	168	168	158
P25	−32	−30	25	66	79	87	108	123	116	115
P5	−52	−65	−60	−51	−43	−22	2	10	9	8



16.6 Alternative 2A, 40% harvest

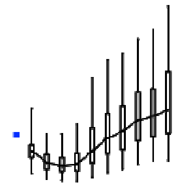
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	95	134	136	94	95	135	211	290	384	467
P75	26	54	58	25	31	31	65	131	185	225
P50	13	21	15	−5	−11	−12	9	55	96	128
P25	−5	−17	−23	−38	−42	−41	−29	−3	24	50
P5	−41	−56	−60	−68	−73	−73	−68	−60	−47	−40



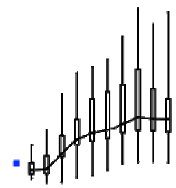
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	45	1	1	17	98	130	140	165	182	222
P75	−18	−35	−40	−33	11	36	50	74	79	109
P50	−28	−49	−54	−51	−28	−6	6	25	32	42
P25	−40	−61	−65	−64	−49	−34	−26	−11	−3	2
P5	−68	−76	−79	−80	−74	−67	−61	−52	−45	−45



Spat

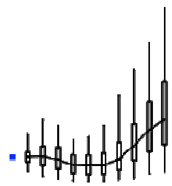
Percentile	1	2	3	4	5	6	7	8	9	10
P95	61	114	236	307	329	354	433	528	475	514
P75	0	27	94	150	220	244	268	319	253	221
P50	−22	−19	35	83	103	113	135	156	151	150
P25	−34	−33	24	63	77	86	103	111	110	106
P5	−54	−65	−64	−50	−43	−22	−2	3	4	1



16.7 Alternative 2A, 60% harvest

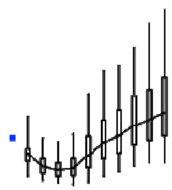
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	73	115	98	53	62	97	192	272	357	464
P75	15	33	30	6	6	12	45	102	173	234
P50	1	2	−8	−25	−26	−26	−7	35	84	115
P25	−15	−28	−37	−51	−55	−54	−41	−11	16	38
P5	−44	−60	−66	−76	−78	−77	−72	−65	−52	−46



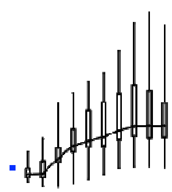
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	37	0	−8	7	77	117	128	159	200	224
P75	−19	−37	−44	−37	3	31	49	74	84	107
P50	−28	−50	−56	−53	−31	−9	4	21	31	43
P25	−41	−63	−68	−67	−52	−37	−27	−13	−4	4
P5	−68	−75	−79	−82	−78	−68	−60	−50	−43	−43



Spat

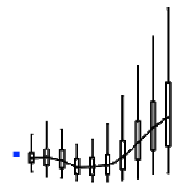
Percentile	1	2	3	4	5	6	7	8	9	10
P95	58	107	239	274	317	346	430	533	572	524
P75	−3	25	72	143	211	241	272	305	282	239
P50	−24	−22	32	81	98	113	138	153	154	154
P25	−35	−35	20	58	76	81	103	115	108	111
P5	−55	−68	−68	−57	−45	−24	−3	3	4	0



16.8 Alternative 2A, 80% harvest

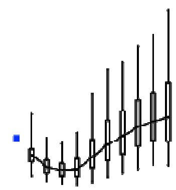
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	58	94	75	30	44	89	172	261	346	431
P75	4	16	12	−12	−9	−1	40	97	156	211
P50	−10	−8	−17	−39	−37	−33	−8	34	79	110
P25	−22	−33	−41	−57	−60	−58	−45	−14	11	25
P5	−50	−63	−67	−78	−81	−80	−76	−69	−57	−54



Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	42	0	−9	9	78	119	133	161	181	223
P75	−19	−38	−44	−36	−3	31	48	66	79	96
P50	−29	−51	−56	−54	−33	−11	3	20	29	36
P25	−41	−62	−67	−68	−52	−39	−28	−14	−4	−6
P5	−67	−75	−79	−81	−77	−69	−62	−54	−46	−48



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	60	91	204	270	293	342	397	521	560	539
P75	−3	17	67	127	183	248	271	301	258	226
P50	−25	−22	30	79	98	109	133	148	150	148
P25	−35	−33	20	58	76	80	98	110	105	101
P5	−54	−66	−67	−56	−47	−26	−3	2	−1	−3

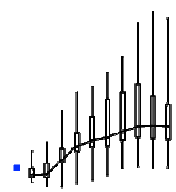
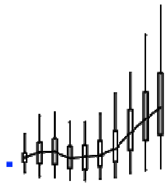


Figure 16 . Medium Salinity (continued)

16.9 Alternative 2B, 20% harvest

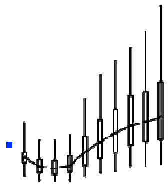
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	112	184	194	157	156	189	265	343	483	590
P75	41	82	95	68	72	87	126	203	268	338
P50	26	43	45	23	28	32	57	116	167	211
P25	8	0	−3	−16	−20	−10	10	50	89	108
P5	−31	−45	−51	−60	−62	−57	−51	−33	−23	−16



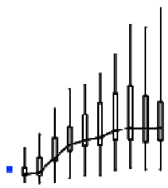
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	46	8	7	20	94	146	176	202	237	290
P75	−16	−31	−33	−24	18	52	73	102	111	130
P50	−26	−46	−50	−44	−16	5	25	39	48	58
P25	−38	−59	−62	−57	−43	−29	−17	−2	6	10
P5	−65	−74	−75	−74	−66	−59	−56	−44	−43	−40



Spat

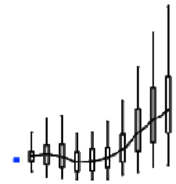
Percentile	1	2	3	4	5	6	7	8	9	10
P95	86	143	251	333	350	395	481	600	589	670
P75	6	50	130	177	227	274	316	345	306	277
P50	−19	−13	47	101	122	132	158	173	170	174
P25	−29	−27	33	76	95	99	123	124	115	121
P5	−53	−56	−54	−39	−29	−28	−3	5	−1	−1



16.10 Alternative 2B, 40% harvest

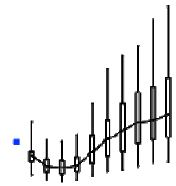
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	96	143	153	91	97	130	203	317	434	525
P75	27	52	55	26	36	44	87	173	244	283
P50	14	20	12	−7	−3	8	35	93	136	170
P25	−3	−16	−25	−38	−36	−26	−7	29	61	92
P5	−39	−55	−62	−68	−69	−67	−49	−41	−24	−20



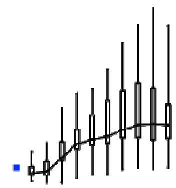
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	43	4	1	15	79	148	175	196	247	275
P75	−18	−35	−37	−31	14	45	79	101	112	129
P50	−28	−48	−52	−47	−19	6	24	40	45	56
P25	−39	−61	−65	−60	−42	−29	−18	−3	5	10
P5	−67	−75	−78	−76	−68	−60	−57	−48	−41	−40



Spat

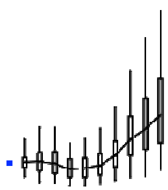
Percentile	1	2	3	4	5	6	7	8	9	10
P95	66	102	244	306	324	402	513	590	656	582
P75	3	25	107	158	217	275	316	349	325	259
P50	−21	−15	43	98	117	129	156	176	179	176
P25	−30	−30	30	75	93	102	123	125	115	121
P5	−54	−60	−61	−44	−31	−29	−7	0	−6	0



16.11 Alternative 2B, 60% harvest

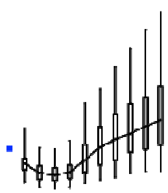
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	75	114	112	61	76	109	178	294	398	486
P75	17	34	36	12	15	28	69	149	206	269
P50	2	5	−2	−20	−17	−8	23	74	108	153
P25	−15	−26	−34	−46	−46	−38	−13	23	43	63
P5	−45	−61	−66	−74	−74	−68	−56	−46	−42	−22



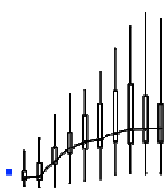
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	41	2	0	16	91	119	165	201	238	272
P75	−19	−34	−38	−32	9	44	69	90	103	124
P50	−29	−48	−53	−47	−22	3	19	30	45	57
P25	−42	−62	−64	−60	−47	−32	−23	−7	−1	8
P5	−67	−76	−77	−76	−69	−63	−58	−49	−45	−44



Spat

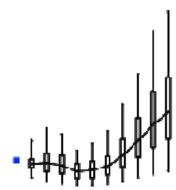
Percentile	1	2	3	4	5	6	7	8	9	10
P95	79	131	223	301	316	388	478	567	618	595
P75	3	35	97	154	222	264	313	342	294	261
P50	−22	−17	40	92	116	126	152	167	168	169
P25	−33	−32	29	71	89	98	117	111	116	116
P5	−56	−61	−58	−47	−37	−30	−9	−4	−7	−6



16.12 Alternative 2B, 80% harvest

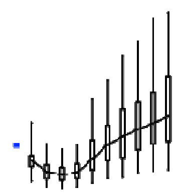
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	58	94	77	29	49	86	165	254	379	437
P75	3	20	14	−9	−3	12	62	124	202	244
P50	−10	−7	−15	−33	−28	−17	14	57	105	141
P25	−22	−33	−39	−53	−52	−42	−19	9	38	62
P5	−51	−61	−69	−74	−75	−70	−61	−51	−41	−32



Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	41	2	−8	1	83	119	162	188	231	241
P75	−19	−36	−41	−34	9	36	66	78	96	125
P50	−28	−49	−54	−50	−25	1	16	29	40	52
P25	−39	−61	−64	−61	−45	−29	−23	−9	2	7
P5	−66	−75	−77	−76	−69	−61	−59	−50	−47	−45



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	55	86	217	298	307	364	459	483	624	587
P75	−1	26	75	150	216	246	302	316	303	256
P50	−23	−19	38	90	116	122	148	165	169	165
P25	−33	−30	29	70	94	96	116	117	115	109
P5	−55	−59	−61	−46	−37	−33	−8	−5	−9	−10

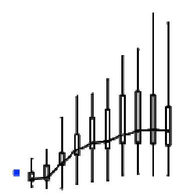
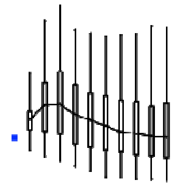


Figure 16 . Medium Salinity (continued)

16.13 Alternative 3 (no harvest)

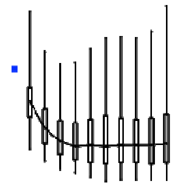
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	128	233	262	214	207	202	204	206	223	219
P75	53	110	132	106	89	84	75	72	62	68
P50	37	65	66	47	35	24	12	9	3	2
P25	16	13	8	−12	−17	−25	−28	−34	−36	−39
P5	−26	−37	−45	−57	−66	−77	−80	−82	−83	−85



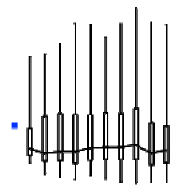
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	47	14	4	5	16	25	26	25	31	51
P75	−15	−33	−42	−44	−41	−38	−40	−41	−40	−37
P50	−26	−46	−59	−63	−62	−63	−62	−62	−62	−61
P25	−39	−61	−70	−74	−76	−77	−76	−76	−77	−76
P5	−65	−75	−82	−85	−88	−91	−90	−90	−90	−90



Spat

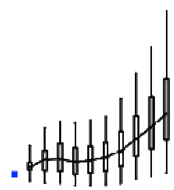
Percentile	1	2	3	4	5	6	7	8	9	10
P95	97	101	115	146	144	126	145	167	147	143
P75	−4	12	17	15	15	18	17	24	3	−1
P50	−34	−40	−38	−38	−33	−32	−32	−29	−40	−36
P25	−43	−52	−51	−55	−50	−48	−49	−48	−57	−54
P5	−54	−69	−74	−78	−73	−77	−81	−82	−81	−81



16.14 No harvest and Alt 2B

Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	132	212	242	236	247	263	346	461	582	745
P75	56	109	141	123	129	146	197	267	352	434
P50	37	67	71	57	65	77	108	160	216	277
P25	20	16	13	1	6	14	40	82	117	157
P5	−28	−36	−42	−51	−52	−49	−43	−18	−8	7



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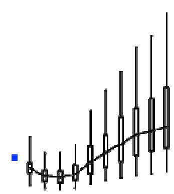
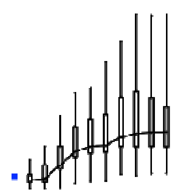
Percentile	1	2	3	4	5	6	7	8	9	10
P95	48	10	10	30	110	158	202	261	289	340
P75	−15	−31	−32	−19	25	52	94	116	139	164
P50	−25	−45	−48	−41	−12	11	31	53	61	73
P25	−37	−58	−61	−55	−39	−24	−12	4	14	21
P5	−67	−73	−74	−73	−64	−56	−50	−44	−39	−33



Spat

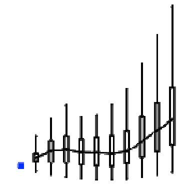
Percentile	1	2	3	4	5	6	7	8	9	10
P95	73	132	266	365	389	501	593	709	703	711
P75	7	51	132	216	253	272	346	371	344	303
P50	−18	−10	49	107	132	137	170	189	194	195
P25	−28	−26	34	84	100	105	131	130	132	130
P5	−54	−53	−50	−33	−25	−22	8	4	12	13



16.14 No harvest and Alt 2A

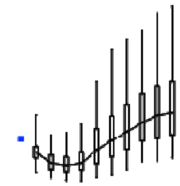
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	130	207	265	215	223	267	334	446	570	697
P75	54	110	129	117	124	131	155	218	273	340
P50	37	66	70	59	58	54	64	108	156	201
P25	22	16	15	5	1	−2	11	40	63	93
P5	−23	−36	−46	−54	−62	−61	−58	−51	−37	−26



Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	45	7	11	27	107	167	187	204	236	249
P75	−15	−31	−34	−25	18	43	65	84	99	107
P50	−26	−46	−50	−46	−21	−3	13	30	44	49
P25	−36	−59	−63	−60	−47	−34	−20	−4	1	7
P5	−64	−73	−78	−79	−73	−68	−59	−43	−42	−36



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	103	152	295	335	413	469	523	560	633	663
P75	5	49	157	184	231	267	293	322	302	238
P50	−21	−13	43	93	110	119	149	163	168	160
P25	−29	−29	28	70	79	82	110	121	114	114
P5	−52	−62	−62	−50	−40	−21	8	17	10	15

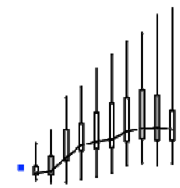
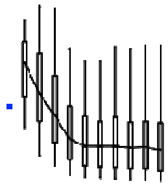


Figure 17 . High Salinity

17.1 Alternative 1, 20% harvest

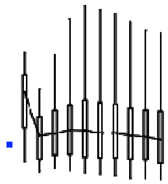
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	114	133	128	76	60	60	78	76	80	80
P75	85	69	40	0	−13	−20	−14	−21	−20	−22
P50	58	17	−12	−43	−53	−53	−53	−55	−54	−58
P25	13	−20	−48	−70	−79	−80	−81	−82	−82	−85
P5	−28	−65	−79	−91	−94	−95	−96	−97	−97	−98



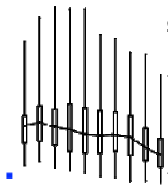
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	238	142	232	325	359	349	341	317	295	287
P75	179	71	88	100	115	109	104	93	88	85
P50	135	21	27	37	36	29	29	22	19	11
P25	43	−39	−29	−27	−34	−36	−36	−39	−39	−49
P5	46	71	62	68	74	77	82	87	87	93



Spat

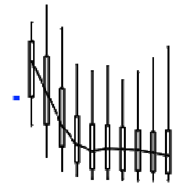
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1640	1939	2053	2036	2036	1720	1674	1502	1484	1235
P75	733	857	821	876	834	791	777	732	581	458
P50	616	654	598	565	509	495	504	477	346	263
P25	398	425	372	306	283	281	306	256	184	113
P5	128	174	102	64	35	−8	−23	−62	−61	−77



17.2 Alternative 1, 40% harvest

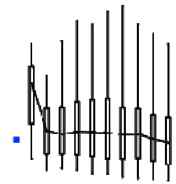
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	91	110	83	40	32	39	22	31	47	61
P75	67	49	11	−22	−31	−32	−34	−39	−41	−39
P50	44	6	−33	−56	−63	−60	−61	−62	−65	−68
P25	2	−31	−58	−77	−84	−84	−85	−86	−87	−89
P5	−32	−69	−86	−93	−96	−96	−97	−98	−98	−98



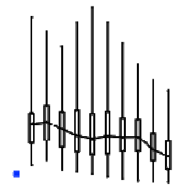
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	227	149	233	278	270	301	313	271	247	224
P75	172	74	75	90	94	97	75	73	59	54
P50	132	21	13	19	18	16	12	13	1	−6
P25	37	−34	−34	−36	−39	−44	−45	−43	−49	−58
P5	44	70	67	71	79	80	86	89	91	96



Spat

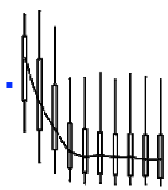
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1838	1675	1494	1768	1942	1771	1533	1287	1103	980
P75	704	803	720	741	698	724	656	639	475	388
P50	587	608	523	452	419	448	435	436	298	210
P25	364	398	319	266	236	242	274	275	156	66
P5	108	162	61	27	1	−32	−52	−72	−77	−88



17.3 Alternative 1, 60% harvest

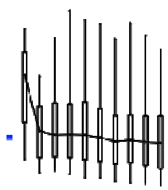
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	69	73	57	6	7	12	5	11	8	5
P75	48	25	0	−38	−43	−46	−49	−48	−50	−50
P50	27	−18	−43	−66	−71	−69	−71	−71	−73	−73
P25	−15	−44	−64	−82	−86	−87	−88	−89	−89	−91
P5	−45	−76	−86	−95	−97	−97	−98	−98	−98	−99



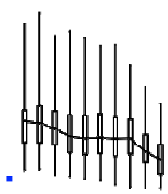
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	219	124	199	255	235	228	198	229	204	175
P75	171	63	69	67	71	58	44	45	43	43
P50	126	13	5	6	5	0	−9	−6	−10	−12
P25	31	−42	−40	−42	−46	−49	−53	−51	−56	−63
P5	−45	−72	−68	−74	−81	−82	−88	−91	−94	−97



Spat

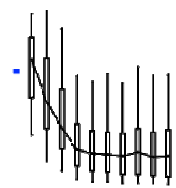
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1487	1590	1369	1416	1356	1273	1283	1088	873	719
P75	657	697	649	609	607	623	585	568	418	327
P50	550	533	483	403	366	391	380	386	260	185
P25	344	343	323	249	232	239	215	235	151	46
P5	79	87	38	12	−8	−21	−59	−83	−83	−90



17.4 Alternative 1, 80% harvest

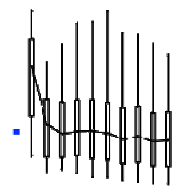
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	50	53	37	−4	−9	−2	−10	4	−4	−3
P75	30	11	−16	−46	−52	−53	−54	−50	−53	−51
P50	10	−27	−50	−69	−72	−73	−74	−71	−75	−74
P25	−23	−50	−68	−83	−87	−88	−90	−90	−91	−92
P5	−56	−78	−87	−95	−97	−97	−98	−98	−98	−99



Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	219	124	158	196	198	218	179	175	159	139
P75	167	58	53	57	57	52	43	46	33	35
P50	118	12	−4	0	1	−3	−14	−9	−18	−16
P25	28	−46	−47	−44	−49	−51	−58	−55	−62	−63
P5	−45	−74	−70	−76	−82	−83	−88	−92	−95	−96



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1297	1494	1245	1403	1305	1165	1073	990	878	774
P75	610	645	583	583	546	564	532	514	398	329
P50	508	491	437	391	365	384	349	369	256	181
P25	303	325	279	230	199	226	188	213	132	52
P5	60	66	25	7	−25	−33	−63	−83	−88	−91

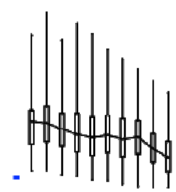
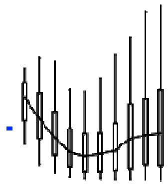


Figure 17 . High Salinity (continued)

17.5 Alternative 2A, 20% harvest

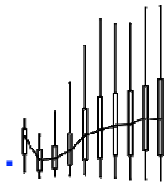
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	110	131	124	72	68	93	136	170	216	228
P75	85	66	31	−1	−10	−9	10	45	54	71
P50	58	18	−17	−44	−51	−47	−41	−19	−13	−10
P25	14	−19	−49	−71	−80	−80	−78	−75	−68	−70
P5	−30	−68	−81	−91	−94	−94	−95	−95	−95	−96



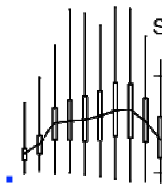
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	227	143	261	409	594	730	708	709	792	798
P75	176	70	90	150	277	337	355	366	395	426
P50	136	20	25	63	141	171	192	198	228	222
P25	47	−38	−27	−8	20	28	41	40	66	41
P5	43	70	61	60	56	67	70	77	78	88



Spat

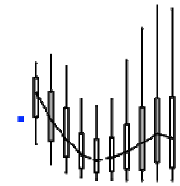
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1873	2484	3271	4140	4052	3750	4180	4146	3478	2899
P75	760	1073	1747	1921	2010	2155	2340	2318	1966	1522
P50	647	859	1383	1430	1452	1539	1657	1696	1420	974
P25	464	631	976	963	914	947	1057	1015	900	520
P5	141	204	139	153	106	63	12	−40	−37	−59



17.6 Alternative 2A, 40% harvest

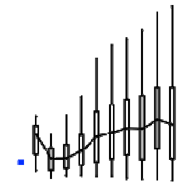
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	89	101	84	33	21	32	93	143	179	174
P75	66	44	18	−22	−31	−28	−7	19	33	36
P50	42	−1	−32	−55	−65	−59	−51	−37	−23	−29
P25	3	−34	−58	−77	−83	−81	−78	−79	−68	−76
P5	−40	−71	−83	−92	−95	−95	−96	−96	−96	−96



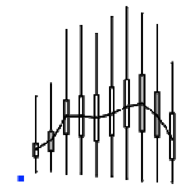
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	223	135	226	316	501	561	595	635	721	752
P75	175	69	84	130	243	279	303	319	362	363
P50	133	18	19	54	122	143	164	161	202	181
P25	37	−39	−31	−15	1	15	34	12	67	16
P5	43	72	65	64	67	67	76	81	82	90



Spat

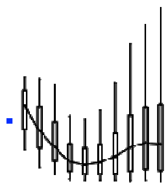
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1719	1974	3121	3202	3057	3406	3585	3477	3219	2440
P75	723	981	1638	1720	1754	1914	2077	2180	1816	1359
P50	613	802	1307	1308	1275	1346	1517	1571	1311	845
P25	447	583	933	891	773	907	1069	986	885	400
P5	123	153	96	94	50	37	−8	−45	−54	−71



17.7 Alternative 2A, 60% harvest

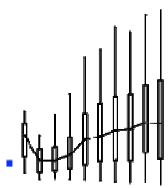
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	71	68	57	7	2	18	62	124	156	183
P75	49	23	−2	−37	−44	−38	−20	8	22	26
P50	25	−16	−42	−66	−71	−67	−57	−43	−35	−37
P25	−13	−44	−65	−81	−86	−86	−85	−81	−78	−80
P5	−47	−75	−86	−95	−96	−96	−96	−97	−96	−98



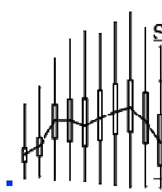
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	224	120	212	300	463	494	596	575	651	668
P75	171	61	70	113	214	260	290	298	340	360
P50	120	11	10	33	102	116	142	149	176	172
P25	26	−43	−37	−29	−7	7	11	9	46	17
P5	−45	−71	−67	−71	−73	−78	−81	−88	−87	−95



Spat

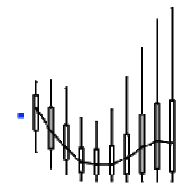
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1558	1897	2461	2835	3008	2966	3199	3376	3072	2708
P75	684	900	1549	1670	1686	1838	1968	2048	1799	1367
P50	573	724	1243	1240	1145	1280	1418	1493	1229	810
P25	409	545	890	836	722	851	969	1008	802	348
P5	91	122	69	68	32	−12	−33	−69	−62	−85



17.8 Alternative 2A, 80% harvest

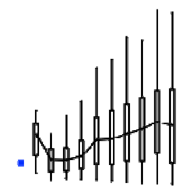
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	50	52	40	−4	−9	9	56	99	140	158
P75	30	12	−14	−48	−50	−45	−28	1	17	21
P50	11	−24	−48	−69	−72	−72	−62	−47	−37	−40
P25	−22	−49	−65	−83	−87	−87	−86	−84	−78	−82
P5	−54	−77	−86	−95	−95	−96	−97	−97	−97	−97



Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	221	122	199	262	403	442	534	522	649	641
P75	165	59	63	94	194	222	251	276	309	315
P50	121	13	11	28	96	101	125	145	174	160
P25	30	−39	−37	−28	−4	−6	7	7	40	0
P5	−45	−72	−67	−71	−72	−77	−85	−88	−88	−93



Spat

Percentile	1	2	3	4	5	6	7	8	9	10
P95	1491	1757	2409	2385	2489	2887	3141	3175	2921	2523
P75	648	854	1526	1541	1586	1763	1911	2015	1725	1316
P50	533	696	1171	1147	1090	1225	1345	1493	1225	760
P25	370	525	879	780	772	817	957	990	824	384
P5	67	87	65	54	19	−10	−45	−60	−67	−82

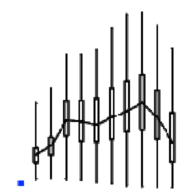
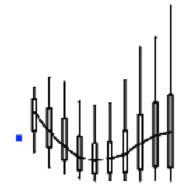


Figure 17 . High Salinity (continued)

17.9 Alternative 2B, 20% harvest

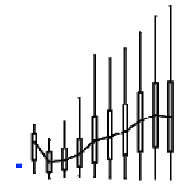
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	110	133	123	79	71	76	128	199	222	291
P75	84	65	42	3	−12	−8	15	50	77	95
P50	57	15	−19	−43	−50	−45	−36	−13	5	11
P25	14	−22	−50	−71	−78	−76	−75	−69	−63	−65
P5	−32	−65	−79	−89	−94	−94	−94	−94	−93	−94



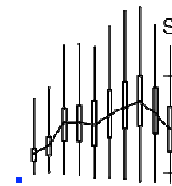
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	227	145	242	380	622	596	656	746	837	897
P75	176	74	95	147	276	309	345	410	464	470
P50	134	22	30	62	139	159	190	248	283	273
P25	32	−39	−26	−9	18	36	58	76	105	76
P5	43	71	62	60	63	67	71	81	78	82



Spat

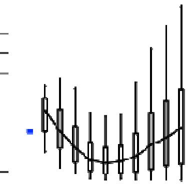
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1964	2242	3259	3305	3227	3722	4101	4178	3754	3247
P75	759	1048	1737	1808	1909	2185	2368	2534	2233	1789
P50	648	835	1398	1400	1333	1572	1763	1903	1615	1222
P25	446	594	936	919	[illegible]	1036	1234	1311	1119	686
P5	139	179	132	110	41	52	12	−25	−27	−51



17.10 Alternative 2B, 40% harvest

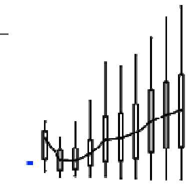
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	89	103	84	36	29	34	97	163	200	247
P75	65	43	10	−22	−32	−29	−5	36	59	82
P50	40	−1	−33	−57	−63	−59	−49	−27	−13	7
P25	−1	−33	−61	−78	−84	−82	−80	−75	−68	−65
P5	−41	−72	−84	−93	−95	−94	−95	−95	−95	−96



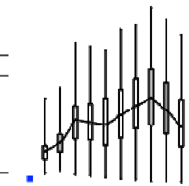
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	221	132	214	334	533	515	577	668	772	836
P75	171	68	79	123	251	267	316	386	431	468
P50	130	19	16	50	124	133	161	221	258	281
P25	23	−39	−33	−16	11	14	25	56	79	87
P5	44	70	66	69	68	78	81	87	87	89



Spat

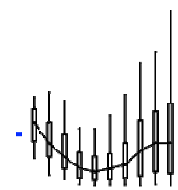
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1766	2006	3000	2922	2843	3307	3396	3779	3535	3178
P75	721	986	1606	1653	1764	1969	2224	2416	2115	1742
P50	608	792	1303	1244	1191	1407	1611	1775	1518	1143
P25	427	597	899	868	734	916	1116	1191	1004	707
P5	112	168	91	61	27	0	−16	−54	−53	−68



17.11 Alternative 2B, 60% harvest

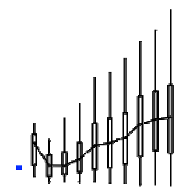
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	69	78	63	11	10	36	74	133	154	231
P75	48	22	−1	−34	−41	−36	−16	25	43	58
P50	22	−17	−42	−63	−70	−64	−57	−32	−16	−16
P25	−13	−42	−64	−82	−86	−85	−82	−78	−70	−73
P5	−45	−76	−85	−94	−96	−95	−95	−96	−94	−95



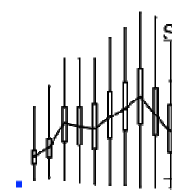
Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	220	136	248	323	455	480	550	636	694	792
P75	169	62	78	125	225	251	276	359	387	415
P50	123	13	12	42	111	122	152	218	245	254
P25	15	−44	−34	−24	−11	−1	19	55	88	72
P5	−45	−71	−68	−71	−69	−78	−81	−89	−84	−90



Spat

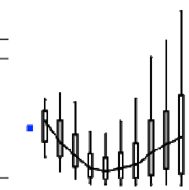
Percentile	1	2	3	4	5	6	7	8	9	10
P95	1564	1987	2546	2560	2549	2995	3176	3469	3408	2880
P75	680	925	1566	1565	1635	1884	2084	2361	1948	1609
P50	574	738	1247	1179	1134	1302	1532	1767	1417	1072
P25	406	547	865	800	710	936	1081	1227	995	645
P5	86	114	78	41	−2	−13	−17	−56	−56	−68



17.12 Alternative 2B, 80% harvest

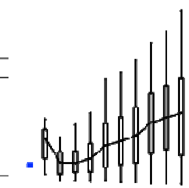
Market

Percentile	1	2	3	4	5	6	7	8	9	10
P95	49	58	44	−6	−9	11	50	120	147	197
P75	29	12	−12	−43	−50	−42	−25	12	28	55
P50	11	−24	−47	−68	−73	−68	−62	−42	−27	−16
P25	−23	−48	−66	−82	−86	−85	−84	−79	−69	−77
P5	−49	−73	−86	−94	−95	−96	−96	−96	−95	−97



Small

Percentile	1	2	3	4	5	6	7	8	9	10
P95	217	131	190	245	401	435	495	574	630	725
P75	167	63	65	101	197	225	272	334	371	406
P50	126	12	10	31	93	112	139	200	223	244
P25	31	−42	−34	−33	−12	3	10	54	74	45
P5	−44	−71	−71	−73	−71	−77	−83	−87	−86	−91



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Percentile	1	2	3	4	5	6	7	8	9	10
P95	1451	1633	2377	2240	2264	2610	3011	3229	3164	2642
P75	644	836	1504	1513	1553	1797	2043	2264	1904	1513
P50	544	688	1158	1074	1026	1305	1463	1660	1404	1039
P25	392	500	894	784	674	965	1072	1240	1005	629
P5	69	83	50	25	−4	−1	−40	−57	−48	−75

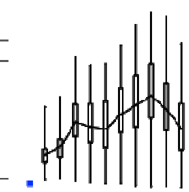
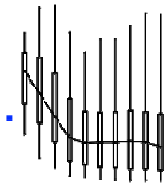


Figure 17 . High Salinity (continued)

17.13 Alternative 3 (no harvest)

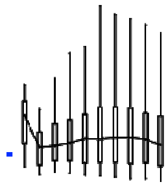
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	131	171	173	132	101	122	122	142	161	159
P75	101	93	69	30	10	8	9	12	9	6
P50	73	38	3	−31	−38	−37	−37	−36	−37	−44
P25	21	−8	−37	−66	−73	−76	−77	−79	−79	−81
P5	−26	−62	−77	−89	−93	−94	−96	−97	−97	−97



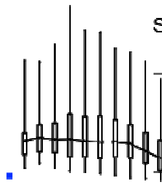
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	238	153	258	347	371	508	481	463	444	413
P75	182	75	103	118	137	161	162	159	141	131
P50	133	24	29	37	51	50	55	56	49	31
P25	35	−37	−22	−22	−30	−28	−28	−33	−29	−40
P5	−45	−71	−61	−66	−72	−75	−78	−84	−84	−90



Spat

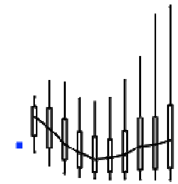
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	2089	2068	2374	3065	2628	2595	2306	2233	2067	1747
P75	775	933	957	1109	1072	1081	1015	935	780	648
P50	640	696	664	669	535	615	619	577	460	333
P25	395	444	426	349	348	324	345	327	231	108
P5	146	225	150	99	65	37	6	−35	−49	−71



17.14 No harvest and Alt 2A

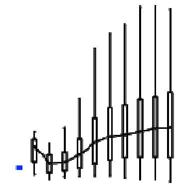
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	131	173	169	127	117	129	176	240	351	377
P75	103	99	69	37	22	15	39	74	76	107
P50	76	44	2	−22	−38	−34	−26	−3	1	13
P25	24	−8	−39	−62	−73	−72	−73	−67	−65	−63
P5	−21	−57	−77	−89	−92	−94	−93	−95	−94	−96



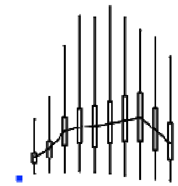
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	230	153	254	443	762	853	913	1026	1031	1014
P75	179	81	100	182	318	385	405	436	451	484
P50	137	30	35	84	162	201	214	231	252	255
P25	37	−32	−21	0	28	48	64	65	67	64
P5	−43	−71	−60	−57	−53	−52	−63	−69	−71	−85



Spat

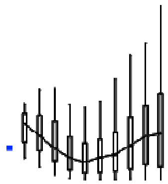
Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1866	2559	4152	5081	5038	5385	5033	4649	4382	3798
P75	798	1180	1908	2196	2280	2401	2601	2686	2209	1746
P50	678	948	1482	1610	1649	1726	1814	1904	1520	1104
P25	490	654	1028	1107	985	1102	1176	1181	888	582
P5	146	235	185	245	223	139	82	6	−15	−58



17.14 No harvest and Alt 2B

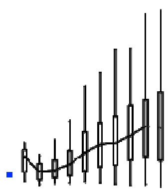
Market

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	127	169	171	126	118	134	200	271	304	413
P75	101	96	77	33	14	26	45	88	122	158
P50	71	36	−1	−28	−41	−27	−19	7	34	41
P25	17	−8	−37	−63	−72	−71	−67	−61	−49	−55
P5	−29	−55	−77	−89	−92	−93	−93	−92	−92	−92



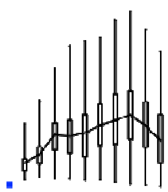
Small

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	233	143	250	387	629	729	899	904	1149	1170
P75	179	78	103	171	306	371	415	496	533	592
P50	130	23	34	73	160	213	228	280	343	339
P25	20	−35	−20	−5	27	56	69	104	132	103
P5	−46	−70	−58	−58	−50	−56	−64	−72	−68	−78



Spat

Percentile	Year 1	2	3	4	5	6	7	8	9	10
P95	1856	2580	3568	4230	4393	4505	5022	5266	4724	4072
P75	797	1163	1873	1960	2147	2453	2758	2856	2525	2143
P50	677	927	1518	1475	1585	1812	1954	2133	1808	1357
P25	429	641	1052	957	858	1208	1237	1382	1147	663
P5	148	218	181	174	136	136	72	28	−3	−41



Attachment 1

Development of Habitat Layer (Greenhawk 2005)

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Development of a
Potential Habitat Layer for Chesapeake Bay Oyster Bottom

Prepared by Kelly Greenhawk
Maryland Department of Natural Resources, Fisheries Division

December 2005

The dataset described in this document was created for use by scientists, managers, and modelers involved in work related to the preparation of an environmental impact statement entitled “Development of an Environmental Impact Statement for Introducing Non-Native Oyster Species into the Chesapeake Bay, Including an Evaluation of Native Oyster Restoration Alternatives”. The dataset (filename "Chesapeake Bay habitat v1.shp") is in the ESRI shapefile format, and is a spatial representation of the locations and extent of oyster habitat (including leased bottom) for both the Maryland and Virginia portions of the Chesapeake Bay. The file will be used as input for modeling efforts related to the EIS referenced above, and in the generation of spatial products related to this project such as report figures. The creation of this file was necessitated by of the lack of a recent comprehensive oyster bar survey in either Maryland or Virginia and an awareness that significant oyster habitat loss has occurred in recent years. The approach in developing these data sets involved adjusting the area and the habitat quality of oyster bars throughout Chesapeake Bay as determined in historical surveys to account for this loss of habitat. For Maryland, the area and habitat quality of each oyster bar determined in a comprehensive field survey carried out in the mid 1970s through early 1980s was adjusted by the results of a 1999 – 2000 survey of the size and habitat quality of a small subset of these bars. In Virginia, adjustments to a comprehensive historical oyster bar survey were made based on recent experience in the field. The dataset described in this document was developed as input to model the distribution and abundance of oysters in Chesapeake Bay. While this data set will provide the resolution needed to model the oyster population, a re-survey of oyster habitat in Maryland and Virginia is needed prior to initiation of any site specific or regional management activities requiring accurate delineation of Chesapeake Bay oyster bars.

Created using ESRI's ArcGIS product, the file was derived from the following spatial data layers created and maintained by the Maryland Department of Natural Resources, the Virginia Institute of Marine Sciences, and the Virginia Marine Resources Commission:

Maryland datasets:

- ESRI shapefile which delineates results from the Maryland Bay Bottom Survey, an acoustic and patent tong survey conducted by the Department from 1978 to 1983 (survey will be referred to as the "MBBS" onward in this document). The results of the survey categorize Maryland's Bay bottom into seven classifications: cultch, mud with cultch, sand with cultch, mud, sand, hard bottom and leased bottom. Based upon review of recent acoustic survey work and the collective knowledge of the Department's Shellfish Program, it was determined that areas classified as mixed cultch by the MBBS ("mud with cultch" and "sand with cultch") had likely degraded to non-cultch bottom. For this reason, only areas classified as "cultch" bottom type have been included in this data product. (file name "BBSurvey.shp")
- ESRI shapefile which delineates oyster bar boundaries charted by C.C. Yates 1906-1911. Yates boundaries were only used in limited sections of the Eastern Bay, Broad Creek and Harris Creek, where data from the Maryland BBS is missing. (file name "Yatesbrs.shp")
- ESRI shapefile which delineates oyster repletion activities undertaken by the Department's Shellfish Program (file name "DNRRepletion.shp")
- ESRI shapefile which delineates oyster repletion activities undertaken by the Department and other groups within Maryland's oyster sanctuaries and reserves (file name "MdSancRes.shp")
- Dxf file prepared by the Natural Resources Police containing linear boundaries for current Maryland oyster leases
(file name "Lselines.dxf")
- Dbase file prepared by the Natural Resources Police containing corner coordinates for current (2004) Maryland oyster leases (file name "Lease91.dbf")

Virginia datasets:

- ESRI shapefile which delineates potential oyster restoration sites the Virginia portion of the Chesapeake Bay. (filename "Potential.shp")
- ESRI shapefile representation of Virginia's lease boundaries (based on 2002 lease boundaries) prepared by staff at VIMS (filename "Privlease.shp)

  Metadata for the source datasets can be found in Attachment 1.

Detailed Process Step:

Data was processed using a combination of the following software packages: ArcGIS software versions 9.0 and 9.1, XTools Pro version 2.0.0, MapInfo Professional versions 7.0 and 7.5, MapBasic version 7.5, Excel 2002, and Multi-Edit version 7.11. Footnotes throughout this document indicate the specific software package used for a particular process step.

Development of the Maryland habitat

1.) Polygons not classified as "cultch" in the Maryland Bay Bottom Survey dataset were removed from the MBBS shapefile. [1]

2.) Because chart # 9 was never located when the MBBS was digitized, data is missing from the source file for parts of the Eastern Bay, Harris Creek and Broad Creek. Consequently, oyster bar boundaries from the Yates survey were used for habitat definitions in these areas. A total of 59 Yates bar boundaries were appended to the file. [1]

3.) During the MBBS, areas of Rangia clam shells in the Magothy River were mapped as cultch. Based on the collective knowledge of and recent observations by Shellfish Program biologists, *today* that area is mud bottom. For this reason, "cultch" polygons in this tributary (totaling 1,963 acres) were removed from the file [1]

4.) Based on longevity studies of shell plantings conducted using underwater video and acoustic survey gear, and consultation with Shellfish Program staff, a conservative estimate of planting longevity is five years. The five year time span is an average and was used in order to provide the best estimate of habitat for the file. Polygons representing oyster repletion efforts undertaken by Maryland DNR and other entities between 1999 and 2003 were appended to the file. (files "DNRRepletion.shp" and "MdSancRes.shp") Plantings older than 5 years were not used. [1]

5.) In order to calculate acreages for all the polygons, the file was projected to US State Plane projection and acreages were calculated. The file was then un-projected to a geographic coordinate system (WGS84). [1 2]

6.) File was translated to MapInfo for further processing. [3]

7.) Overlapping planting polygons were combined in MapInfo to ensure that habitat (hence acreages) were not duplicated[3]. Figure 1 show how a pair of overlapping planting polygons looked before and after the combine operation.

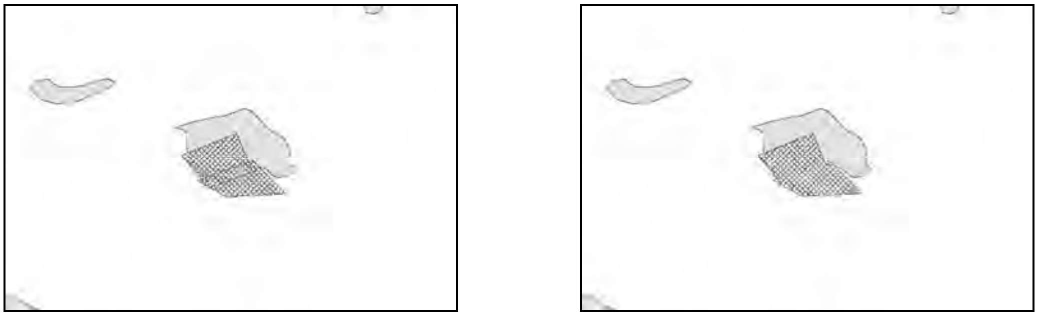

Figure 1. The two plantings in the figure on the left (hatched objects), were combined to create one polygon, shown on the right.

8.) Due to the contiguous nature of the bars charted by Yates, those that shared a boundary were treated as one large oyster bar, and adjacent bars were combined before being reduced. To facilitate this task, MapInfo's "Combine" operation was applied.[3] Figure 2 illustrates how one cluster of Yates bars looked before and after the combine operation.

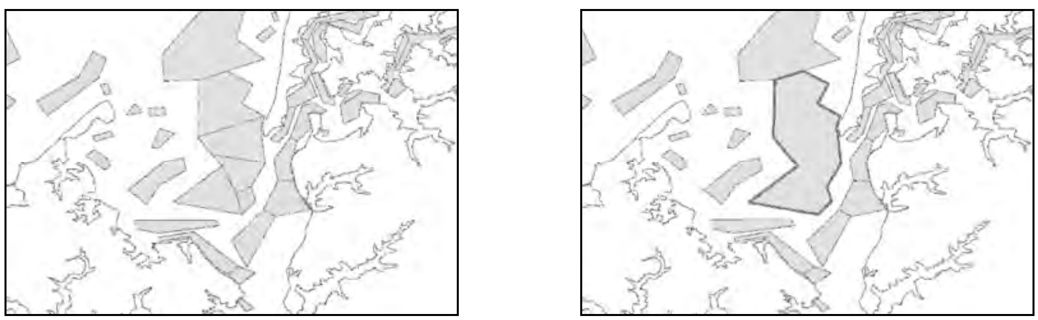

Figure 2. Five polygons in the map on the left were combined to create one large polygon shown on the right (dark outline).

9.) MapInfo file was translated back to a shapefile for continued work in ArcMap.[3]

10.) Concurrent with well-documented evidence that the Bay's oyster habitat has degraded over time, it was determined that adjustments to the dataset were necessary to make the layer more accurately reflect the state of today's oyster habitat. In order to account for the age of the data (The MBBS was conducted between 1978 and 1984.), reduction factors for habitat defined by the MBBS and the Yates survey were identified, based on the results of acoustic surveys performed between 1999 and 2003 by MDNR.[7] Attachment 2 shows the summary table from which the reduction factors were taken. The summary table was extracted from the paper "Assessment of Recent Habitat Conditions of Eastern Oyster *Crassostrea virginica* Bars in Mesohaline Chesapeake Bay" (Smith et al., North American Journal of Fisheries Management 25:1569-1590, 2005). Attachment 3 contains underwater images from visual ground truth operations for the various bottom classifications used in Attachment 2. The reduction factors used were as follows:

- MBBS cultch polygons - reduction factor equal to 29.17%

  This adjustment factor will result in a polygon that is 29.17% of its original area after the scale operation is applied. This value was obtained by summing the frequencies for the four acoustic survey categories "heavily sedimented shell with mud", "heavily sedimented shell with sand", "lightly sedimented shell with sand", and "clean shell" in the column labeled "Inside MBBS Bottom" (21.64 + 5.16 + 1.21 + 1.16 = 29.17%).

- Yates polygons - reduction factor equal to 12.24%

This value was obtained by summing the frequencies for the same four acoustic survey categories in the column labeled "Inside Yates Bars". (8.33 + 2.96 + .33 + .62 = 12.24%)

- Plantings deployed within the last 5 years (1999 through 2003) were not reduced.

11.) Scale factors were calculated for a.) the Maryland BBS polygons and b.) the Yates polygons, and Visual Basic code obtained from ESRI was used to "scale" or shrink the polygons.[1]
The formula used to calculate the scale factor is

$$S = \sqrt{(a_d / a_o)}$$

whereby S = scale factor, a_d = desired area, and a_o = original area.

The program used to perform this task is detailed in Attachment 4. Figure 3 illustrates the result of the scale operation on a cluster of habitat polygons.

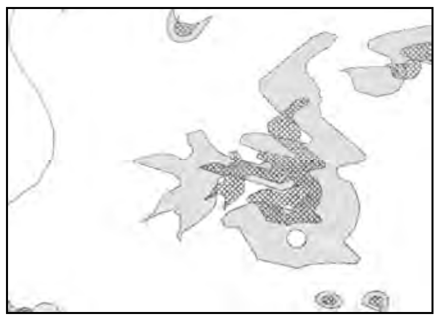

Figure 3. Figure showing the effect of the scale operation. Scaled polygons (dark gray) are shown overlaying the original (MBBS) habitat polygons (light gray). Polygons resulting from the scale operation (dark gray) in this step represent areas of low *and* high quality habitat, specifically as follows:

Maryland BBS polygons -------> 26.8% of resulting polygons represent "low quality" cultch (21.64% + 5.16% from Attachment 2) and

2.37% of resulting polygons represent "high quality" cultch (1.21% + 1.16% from Attachment 2).

Therefore, it follows that 91.9 % of the MBBS polygons resulting from the scale operation can be designated low quality cultch

calculated .268 /.2917 = .918753 = .919 = 91.9 % and

8.1% of the MBBS polygons resulting from the scale operation can be designated high quality cultch

calculated .0237/.2917 = .081248 = .081 = 8.1 %.

Yates polygons ---------------> 11.29% of resulting polygons represent "low quality" cultch (8.33% + 2.96% from Attachment 2) and

.95% of resulting polygons represent "high quality" cultch (.33% + .62% from Attachment 2).

Therefore, 92.2 % of the Yates polygons resulting from the scale operation can be designated low quality cultch

calculated .1129/.1224 = .922386 = .922 = 92.2 % and

7.8 % of the Yates polygons resulting from the scale operation can designated high quality cultch

calculated .0095 / .1224 = .077615 = .078 = 7.8%.

The concept of "low quality" and "high quality" cultch was derived from work performed under the interstate research project entitled "Oyster Population Estimation in Support of the Ten-year Goal for Oyster Restoration in the Chesapeake Bay Fishery". More information about the oyster population estimation work can be found on the project's website. (http://www.vims.edu/mollusc/cbope/overview.htm)

12.) New acreage values were calculated for the dataset, in order to confirm the reduced areas.[1]

13.) File was translated back to a MapInfo format for further processing.[3]

14.) Overlapping polygons of different types were addressed as follows:

- In areas where planting polygons (considered "high quality" habitat) overlapped polygons from the MBBS or Yates survey, the area of overlap was "erased" from the low quality habitat to ensure that habitat was not duplicated.[3]
- There were no areas of overlap involving Maryland BBS polygons and Yates boundaries, since the Yates boundaries were only used in the area encompassed by chart number 9 of the MBBS.

Figure 4 shows overlapping habitat polygons before and after the erase tool was used.

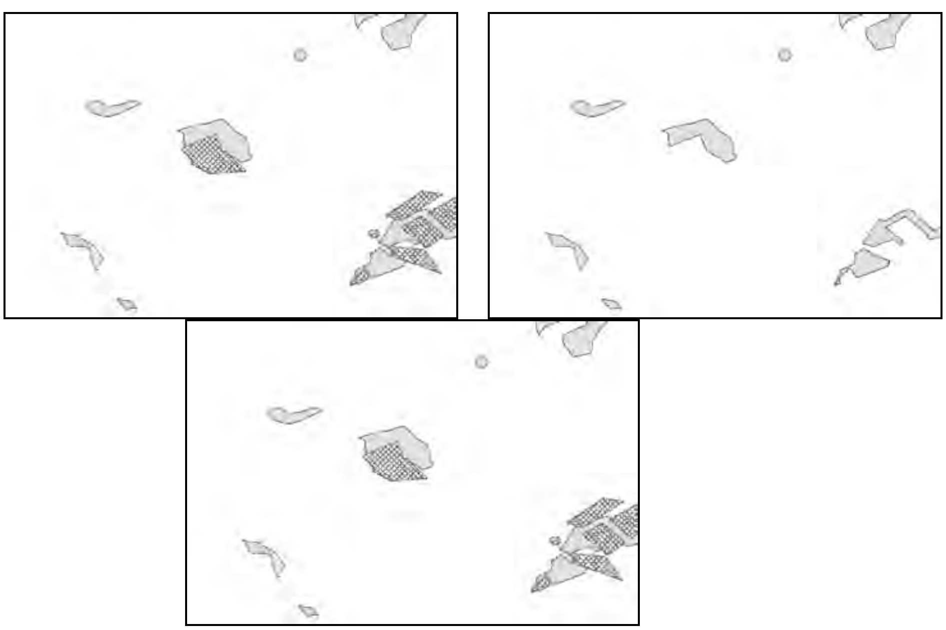

Figure 4. The image on the left shows a planting (gray hatched polygon) that overlaps a Maryland BBS cultch polygon (gray). The image in the center shows the cultch polygon after the erase operation. (For illustration purposes the planting polygon has been omitted.) The right-most image shows both polygons after the erase operation, with the cultch polygon surrounding three sides of the planting, but not overlapping the planting.

15.) Dataset was mapped with layers representing NOAA's inshore water body areas and basins from the Chesapeake Bay Oyster Population Estimation (CBOPE) project (Harding 2005). Fields were added to accommodate region codes and basin names, then updated with these values.[3]

16.) Dataset was plotted for QA/QC operations.[3]

Summary statistics for Maryland habitat records / polygons:

- 2,115 polygons
  - 1,949 polygons were derived from the Maryland Bay Bottom Survey
  - 123 polygons were derived from shell plantings
  - 43 polygons were derived from the Yates bars dataset
- Acres of Maryland habitat, not including leased bottom sum of field "A" = 36,144.49 (sum of field "A" acres of Maryland habitat, not including leased bottom)

Development of the Maryland leased bottom

Maryland's official lease delineations are maintained by DNR's Natural Resources Police in Autocad format. For this reason, considerable effort was required to transform the lease lines into a GIS-compatible format. The process of translating the data to a shapefile format began with the acquisition of the following datasets from NRP:

- lselines.dxf - linear delineation of Maryland's oyster leases, stored in Autocad format
- lease91.dbf - dBase file; records for 780 locations; each record representing the location of the first corner of each lease

In addition, Maryland lease charts (prepared by MDNR, Natural Resources Police, dated 7-17-2001) were used for QA/QC operations. (Leases located in Maryland's coastal bays are not included in this file.)

1.) Coordinate information in the Dbase file was used to create a shapefile in ArcGIS 9. (point feature type) [1]

2.) Dxf file was imported into TNT MIPS software by Kevin Boone (MDNR, Watershed Services Division), where various processes were applied in order to convert lines in the DXF file to a polygon shapefile.

3.) The 2 files resulting from the above processes were converted to MapInfo format then overlaid in MapInfo for verification and editing purposes. [3]

4.) Polygons present in the file generated by MIPS without corresponding point objects in the file of corner coordinates were deleted since they could not be verified by the NRP Dbase file. (per instructions from Williams, NRP) [3]

5.) Polygons that overlapped the shoreline were shaped to the shoreline. [3]

6.) Once all edits were applied, a series of charts were printed on transparent film and overlaid onto copies of the official charts, obtained from NRP. The leases on each film were compared to lease outlines on corresponding charts to verify lease shape, size, and relationship to the shoreline. [3]

7.) A field was added to hold a calculated acreage value for each lease. Acreages were calculated in MapInfo. [3]

It should be stressed that this dataset was created solely for use on this project, and should not be used for any other purposes. For legal definitions of Maryland's leased bottom, contact the Natural Resources Police.

Summary statistics for Maryland leased bottom records / polygons:

- 767 lease polygons (File does not contain leased bottom for Maryland's coastal bays)
- Total lease acreage = 7,747.81 (sum of field "A")

Although the Maryland lease boundaries are included in this habitat layer, because leased bottom is considered potential habitat only for aquaculture purposes, the Maryland leases were not used in subsequent modeling operations. (Only potential habitat currently available for larval settlement was used in the modeling scenarios.)

Development of the Virginia habitat

1.) The source dataset for non-lease habitat in the Virginia portion of the Bay is the shapefile "Potential.shp", which is a collection of polygons representing suitable oyster restoration sites. Obtained from the Virginia Institute of Marine Sciences, the file contains 2,711 polygon regions, totaling 12,290.32 acres of potential oyster habitat. The file was generated by staff at VIMS and VMRC and complements the "Virginia Oyster Reef Restoration Map Atlas", published by VIMS in 2002.

2.) Habitat polygons in the coastal bays were removed from the file. (1,063 polygons removed) [1]

3.) Polygons in the file without attribute data were determined to represent holes in oyster habitat (personal communication with VIMS staff). A hole is a hole in a habitat polygon; an area of non-oyster habitat that is completely surrounded by habitat. These polygons were removed from the file and saved as a separate layer, for erase operations. [1]

4.) Habitat polygons were erased using the holes layer. [3]

5.) A series of maps were plotted similar in scale to those found in the map atlas and each map was compared to its corresponding map in the map atlas. [1]

6.) Overlapping polygons were merged into one polygon using the dissolve operation. [1]

7.) Using the file of NOAA water body regions, each habitat polygon was assigned a region code. [1]

8.) Using the CBOPE basin layer, each polygon was assigned a basin name. Pursuant to instructions from Versar modelers, Virginia polygons which fell outside of the CBOPE basins (Harding 2005) were assigned to the closest basin. [1]

Summary statistics for Virginia habitat records / polygons:

- 769 polygons
- total acreage = 11,355.13 acres (sum of field "A")

Development of the Virginia leased bottom

The source file for the Virginia leases ("Privlease.shp") is a polygon delineation of leased shellfish bottom prepared by VIMS and based on VMRC lease records.

1.) Shapefile converted to MapInfo format for processing in MapInfo. [3]

2.) Lease polygons in the Virginia coastal bays were removed from the file, leaving 5,142 records. [3]

3.) Each of 48 multi-polygon lease polygons in the file was located, and nested polygons were combined. This operation was necessary to prepare for the scale operation to follow. [3]

4.) File was translated to a shapefile for further processing in Arcmap [3]

5.) A scale factor was calculated for the reduction process as follows:

$$S = \sqrt{(a_d / a_o)}$$

whereby S = scale factor, a_d = desired area, and a_o = original area.

6.) Visual Basic code (Attachment 4) was used to "scale" or shrink the polygons to 30% of their original area. This 30% value was provided by scientific staff at VMRC, based on recent field experience and is considered the best available estimate of current habitat.[1]

7.) Results of scale operation were again visually inspected for accuracy. During this inspection, it was discovered that nested leases (a lease sharing 2 or more sides with another lease) did not shift in tangent with outer leases. An example of the resulting inconsistencies is shown in the following figures.

Figure 5. Nested lease polygons before (left) and after (right) the scale operation.

8.) File was translated file to Mapinfo for combine operations. [3]

9.) Nested polygons were located and the combine operation was performed. [3]

10.) File was translated back to Arcview format. [3]

11.) In order to confirm reduced areas, the file was projected to US State Plane projection (Maryland, NAD 83, meters), and acreage values were calculated for the dataset.[1 2]

12.) Leases smaller than 0.1 acre were identified, and if determined to be sliver polygons, were deleted. [1]

13.) File was un-projected back to a geographic coordinate system (WGS84). [1]

14.) Dataset was again visually inspected for QA/QC purposes. [1] Attempts to obtain hardcopy charts of Virginia's oyster lease boundaries from VMRC for QA/QC purposes failed.

Summary statistics for Virginia leased bottom records / polygons:

- 4,829 polygons
- total acreage = 20,782.80 acres (sum of field "A")

Compilation of master habitat file

1.) A master habitat file was created by merging the 4 datasets described above into one shapefile.[1]

2.) MapInfo split tool was applied to polygons which fell on the border of two basins. [3]

3.) MapInfo "check regions" feature was used to detect self-intersections, overlaps and gaps. This operation returned a table of 269 problem areas. [3]

4.) Intersections, overlaps and gaps were corrected in the file using the following rules: [3]

The overlap between a Maryland habitat polygon and a Maryland lease polygon was corrected by allowing the habitat polygon to take precedence, so the intersection was erased from the lease.

5.) Fields were added to the master file to accommodate lease ids and EIS alternative numbers, then updated accordingly.

A total of 767 records (all Maryland leases) contain lease ids and 60 records contain data in the alternative field. [1]

[1] ArcGIS/ArcMap version 9.0
[2] XTools Pro version 2.0.0
[3] MapInfo Professional versions 7.0 and 7.5
[4] MapBasic version 7.5
[5] Excel 2002
[6] Multi-Edit version 7.11
[7] Acoustic surveys were conducted by MDNR using a seabed classification system produced by Questar Tangent. See http://marine.questertangent.com for more information on the system used.

Attribute names, field types and definitions:

FID - ESRI internal feature identifier

Shape - (type of object); ESRI defined value (Value is "Polygon" in this file.)

ID - integer (9) unique numeric identifier; possible values 1 through 8,480

CX - Double (12) longitude value of the centroid, expressed in decimal degrees

CY - Double (12) latitude value of the centroid, expressed in decimal degrees

A - Double (19) area of habitat polygon, expressed in acres

B - String (1) Basin name from Chesapeake Bay Oyster Population Estimation project:

Maryland basins:	Virginia basins:
CHESTER	EASTERN SHORE / TANGIER
CHOPTANK	GREAT / LITTLE WICOMICO
EASTERN BAY	JAMES
LITTLE CHOPTANK	PIANKATANK
MD MAINSTEM	POQUOSON / BACK
MD POTOMAC	RAPPAHANNOCK
PATUXENT	VA MAINSTEM
TANGIER	VA POTOMAC
	YORK / MOBJACK

See http://www.vims.edu/mollusc/cbope/index.htm for details on the above basin designations.

N - String (3) numeric NOAA water body code; possible values are as follows:

212	239	268
217	243	270
218	245	271
220	246	273
224	248	276
225	249	278
226	251	279
228	252	301
230	253	306
231	254	307
232	257	308
235	258	309
236	259	311
237	267	313

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The shapefile used to assign the NOAA codes was obtained from the Chesapeake Bay Program office and is based on NOAA's water body codes, also known as "NEM" areas. "NEM" is an abbreviation for NEMFIS, which was the Northeast Marine Fisheries Information System, a State and Federal initiative to work together in collecting and managing commercial fisheries data.

S - String (2) source code for origin of habitat polygon; possible values are as follows:

MH = Maryland habitat
ML = Maryland lease
VH = Virginia habitat
VL = Virginia lease

HT - String (1) alphabetic code representing the habitat type for Maryland habitat polygons; possible values are as follows:

B = Maryland Bay Bottom Survey
P = planting
Y = Yates bar

Only Maryland habitat polygons will have a value in the HT field.

LID - String (15) lease identifier; 3 digit lease identifier (assigned by MDNR, NRP), followed by a dash, followed by an acreage value. LID field will be blank for Virginia leases.

ALT - String (2) EIS alternative number for which lease will be used; possible values are as follows:

4 - EIS alternative number 4
5 - EIS alternative number 5
45 - EIS alternative numbers 4 and 5

Sixty Maryland leases have a value in the ALT field. The remaining records are blank.

CLOS_STAT - String (50) closure status; possible values for Maryland records are "SANCTUARY", "RESTRICTED" or blank; possible values for Virginia records are "CONDEMNED", "PROHIBITED", "PROHIBITED NON-PRODUCTIVE", "CONDEMNED AND PROHIBITED" or blank.

Note: Only polygons with greater than 50% area inside a closure were flagged using this field.

CLOS_NAME - String (50) name of closure assigned by either the Maryland Department of the Environment or the Virginia Department of Health

Summary statistics for file Chesapeake Bay Habitat v1.shp:

- shapefile contains 8,480 polygons / records
  - 2,115 polygons define Maryland habitat
  - 767 polygons define Maryland leases
  - 769 polygons represent Virginia habitat
  - 4,829 polygons represent Virginia leases

- sum of acreage = 76,030.23, specifically as follows:
  - 36,144.49 acres of Maryland habitat
  - 7,747.81 acres of Maryland leases
  - 11,355.13 acres of Virginia habitat
  - 20,782.80 acres of Virginia leases

References

Harding, J.. (2005). Chesapeake Bay Oyster Population Estimation (CBOPE). Available: http://www.vims.edu/mollusc/cbope/overview.htm. Last accessed April 5, 2007.

Attachment 1.

Metadata for source datasets.

"BBSurvey.shp"

Identification_Information:
  Citation:
    Citation_Information:
      Originator: Maryland Department of Natural Resources
      Publication_Date: 20030204
      Publication_Time: Unknown
      Title: **BBSURVEY**
      Geospatial_Data_Presentation_Form: vector digital data
      Series_Information:
      Publication_Information:
      Online_Linkage: http://dnrweb.dnr.state.md.us/gis/data/index.html
  Description:
    Abstract: Polygon dataset characterizing bottom type designations determined by MDNR's Acoustic Bay Bottom Survey conducted from 1974 to 1983. Bottom type designations include cultch, mud, sand, leased bottom, hard bottom, mud with cultch and sand with cultch. Note: The data in this file is up to 30 years old and areas designated as "cultch bottom" when this survey was conducted have likely degraded. For this reason, it is very likely that many of the areas shown as cultch in the dataset are no longer valid. The data in this file should only be used as a guide to the location of oyster bars in the mid to late 1970's and early 1980's.

    Purpose:
      This file was created for Maryland DNR planning purposes, specifically for the purpose of managing Maryland's oyster resource. This file is the result of the digitization of the 37 mylars of the Md Bay Bottom Survey.
    Supplemental_Information: Digitization was performed using MapInfo software (version 3x) between May of 1994 and May of 1996 at the Oxford Laboratory. All mylars were digitized with the exception of mylar # 9, which could not be located. Mylar # 9 covers the southern portion of the Eastern Bay.
  Time_Period_of_Content:
    Time_Period_Information:
      Range_of_Dates/Times:
        Beginning_Date: 1974
        Beginning_Time: unknown
        Ending_Date: 1983
        Ending_Time: unknown
    Currentness_Reference: ground condition
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: None planned
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -77.049563
      East_Bounding_Coordinate: -75.669141
      North_Bounding_Coordinate: 39.312854
      South_Bounding_Coordinate: 37.903566
  Keywords:
    Theme:
      Theme_Keyword_Thesaurus: none
      Theme_Keyword: sediment
      Theme_Keyword: bars
      Theme_Keyword: mud
      Theme_Keyword: sand
      Theme_Keyword: cultch

Theme_Keyword: leased
Theme_Keyword: hard bottom
Place:
Place_Keyword_Thesaurus: none
Place_Keyword: Maryland
Stratum:
Stratum_Keyword_Thesaurus: none
Stratum_Keyword: Chesapeake Bay seafloor
Temporal:
Temporal_Keyword_Thesaurus: none
Temporal_Keyword: 1970's
Access_Constraints: none
Use_Constraints: The Department of Natural Resources makes no warranty, expressed or implied, as to the use or appropriateness of Spatial Data, and there are no warranties of merchantability or fitness for a particular purpose or use. The information contained in Spatial Data is from publicly available sources, but no representation is made as to the accuracy or completeness of Spatial Data. The Department of Natural Resources shall not be subject to liability for human error, error due to software conversion, defect, or failure of machines, or any material used in the connection with the machines, including tapes, disks, CD-ROM's or DVD-ROM's and energy. The Department of Natural Resources shall not be liable for any lost profits, consequential damages, or claims against the Department of Natural Resources by third parties. The liability of the Department of Natural Resources for damage regardless of the form of the action shall not exceed any distribution fees that may have been paid in obtaining Spatial Data.
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:
Address_Type: mailing address
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0830 - 1700 (EST)
Data_Set_Credit: Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory
Security_Information:
Security_Classification_System: none
Security_Classification: Unclassified
Security_Handling_Description: none
Native_Data_Set_Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.1.0.722
Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report: Dataset was digitized from mylars of the survey which were generated by the Department's Hydrographic Operations Division. Scale of mylars is 1:20,000.
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report: ************
Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report: ***************
Lineage:

Process_Step:
Process_Description: Before digitization, mylars were registered in US State Plane 1927 feet. Original MapInfo file created took on the MapInfo proprietary coordinate system and projection, Lat / Long with a proprietary datum comparable to NAD 83.
Process_Date: Unknown
Process_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer Analyst
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0800 - 1630 EST
Process_Step:
Process_Description: Metadata imported.
Source_Used_Citation_Abbreviation: C:\arcgis\arcexe82\Metadata\Stylesheets\DNRTemplate.xml
Process_Step:
Process_Description: Metadata imported.
Source_Used_Citation_Abbreviation: Z:\All\SCOLdata\Outgoing\Shapefiles\Mdoysbrs.shp.xml
Process_Step:
Process_Description: Metadata imported.
Source_Used_Citation_Abbreviation: Z:\All\SCOLdata\Metadata\BBSURVEY.shp.xml
Process_Step:
Process_Description: Dataset copied.
Source_Used_Citation_Abbreviation:
Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: G-polygon
Point_and_Vector_Object_Count: 7556
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 1900
Lambert_Conformal_Conic:
Standard_Parallel: 38.300000
Standard_Parallel: 39.450000
Longitude_of_Central_Meridian: -77.000000
Latitude_of_Projection_Origin: 37.666667
False_Easting: 400000.000000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 0.000256
Ordinate_Resolution: 0.000256
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983

Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222
Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: BBSURVEY
Attribute:
Attribute_Label: FID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: BOT_TYPE
Attribute_Definition: Numeric bottom type code, 1 through 7 as follows: 1 = mud; 2 = sand; 3 = sand with cultch; 4 = mud with cultch; 5 = cultch; 6 = hard bottom; 7 = leased bottom (leased bottom was not surveyed, only charted.)
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: BOTTOM
Attribute_Definition: Textual description of bottom type as follows: "MUD", "SAND", "MUD WITH CULTCH", "SAND WITH CULTCH", "CULTCH", "HARD BOTTOM", AND "LEASED"
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: BORDER
Attribute_Definition: Field contains "I" for "incomplete" if any part of the polygon's border overlaps the mylar's border.
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: HOLES
Attribute_Definition: Number of "holes" in the polygon object. Holes are either caused by physical features such as islands, where the surveyors could not work, or other bottom types.
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: Acres
Overview_Description:
Entity_and_Attribute_Detail_Citation: *************
Distribution_Information:
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Transfer_Size: 3.140
Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:

Address_Type: mailing and physical address
Address: Sarbanes Cooperative Oxford Laboratory
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0800 - 1700
Distribution_Liability: This data represents the results of data generated for a specific Maryland Department of Natural Resources management activity. As such, they are only valid for their intended use, content, time, and accuracy specifications. The user is responsible for any application of the data for other than it's intended purpose.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name: ARCE shapefile
Format_Information_Content: Data is normally distributed as a statewide dataset - Md State Plane NAD 83 meters
File_Decompression_Technique: no compression applied
Transfer_Size: 3.140
Digital_Transfer_Option:
Online_Option:
Online_Computer_and_Operating_System: http://dnrweb.dnr.state.md.us/gis/data/index.html
Metadata_Reference_Information:
Metadata_Date: 20050629
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:
Address_Type: mailing and physical address
Address: Sarbanes Cooperative Oxford Laboratory
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0830 - 1700 (EST)
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Security_Information:
Metadata_Security_Classification: Unclassified
Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html
Profile_Name: ESRI Metadata Profile

"Yatesbrs.shp"

Identification_Information:
  Citation:
    Citation_Information:
      Originator: Maryland Department of Natural Resources, Fisheries Service, Sarbanes Cooperative Oxford Laboratory
      Publication_Date: 1911
      Publication_Time: Unknown
      Title: **Yatesbrs**
      Geospatial_Data_Presentation_Form: vector digital data
      Series_Information:
      Publication_Information:
      Online_Linkage: http://dnrweb.dnr.state.md.us/gis/data/index.html
  Description:
    Abstract: Polygon delineation of Maryland oyster bottom as surveyed by C.C. Yates, circa 1906.
    Purpose:
      This file was created for Maryland DNR planning purposes, specifically for the purpose of managing Maryland's oyster resource.
    Supplemental_Information: Boundaries were generated using Dbase III+ and MapInfo software based on coordinate information found in publications by the Department of Commerce and Labor, Bureau of the Coast & Geodetic Survey and Bureau of Fisheries.
  Time_Period_of_Content:
    Time_Period_Information:
      Range_of_Dates/Times:
        Beginning_Date: 01/01/1906
        Beginning_Time: unknown
        Ending_Date: 12/31/1911
        Ending_Time: unknown
    Currentness_Reference: publication date
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: None planned
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -76.863501
      East_Bounding_Coordinate: -75.186116
      North_Bounding_Coordinate: 39.295060
      South_Bounding_Coordinate: 37.898347
  Keywords:
    Theme:
      Theme_Keyword_Thesaurus: none
      Theme_Keyword: oysters
      Theme_Keyword: oyster bars
    Place:
      Place_Keyword_Thesaurus: none
      Place_Keyword: Maryland
    Stratum:
      Stratum_Keyword: Chesapeake Bay seafloor
    Temporal:
      Temporal_Keyword: early 1900's
      Temporal_Keyword: 1906
  Access_Constraints: none
  Use_Constraints: The Department of Natural Resources makes no warranty, expressed or implied, as to the use or appropriateness of Spatial Data, and there are no warranties of merchantability or fitness for a particular purpose or use.

The information contained in Spatial Data is from publicly available sources, but no representation is made as to the accuracy or completeness of Spatial Data. The Department of Natural Resources shall not be subject to liability for human error, error due to software conversion, defect, or failure of machines, or any material used in the connection with the machines, including tapes, disks, CD-ROM's or DVD-ROM's and energy. The Department of Natural Resources shall not be liable for any lost profits, consequential damages, or claims against the Department of Natural Resources by third parties. The liability of the Department of Natural Resources for damage regardless of the form of the action shall not exceed any distribution fees that may have been paid in obtaining Spatial Data.
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:
Address_Type: mailing address
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0830 - 1700 (EST)
Data_Set_Credit: Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory
Security_Information:
Security_Classification_System: none
Security_Classification: Unclassified
Security_Handling_Description: none
Native_Data_Set_Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.1.0.722
Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report: Dataset was derived from coordinate information in Department of Commerce & Labor publication entitled "Survey of Maryland Oyster Bars, 1906 - 1912", Parts I and II
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report: ************
Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report: ***************
Lineage:
Process_Step:
Process_Description:
The spatial layer that this dataset is derived from was originally in the form of a MapInfo file, and consisted of a series of polylines (shoreline) and polygons (islands). MapInfo was used to join adjacent polylines until the entire
Chesapeake Bay was represented by one large "donut-polygon". Islands in this secondary file were represented by holes. (DNR filename "Baygon"). MapInfo's Universal Translator was used to convert the file "Baygon" to an ArcView shapefile. A copy of the shapefile was then made in ArcMap and used as the base file. The polygons in this dataset (COMPRegions.shp) were created by using the Geoprocessing Wizard in ArcMap version 8.2. Specifically, each polygon was created by clipping a copy of the original (baywide) polygons in a temporary dataset with hand-drawn polygons.
Process_Step:
Process_Description: Metadata imported.
Source_Used_Citation_Abbreviation: C:\arcgis\arcexe82\Metadata\Stylesheets\DNRTemplate.xml
Process_Step:
Process_Description: Metadata imported.

Source_Used_Citation_Abbreviation: Z:\All\SCOLdata\Metadata\yatesbrs.shp.xml
Process_Step:
Process_Description: Dataset copied.
Source_Used_Citation_Abbreviation:
Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: G-polygon
Point_and_Vector_Object_Count: 769
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 1900
Lambert_Conformal_Conic:
Standard_Parallel: 38.300000
Standard_Parallel: 39.450000
Longitude_of_Central_Meridian: -77.000000
Latitude_of_Projection_Origin: 37.666667
False_Easting: 400000.000000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 0.000256
Ordinate_Resolution: 0.000256
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222
Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: yatesbrs
Attribute:
Attribute_Label: FID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: YATESBRS_I
Attribute_Definition: Name given to oyster bar by Yates.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:

Attribute_Label: YATESNAME
Attribute_Definition: Number of corner coordinates published for oyster bar.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: NUMCORNS
Attribute_Definition: Reference code - Volume number and page number coordinates were taken from
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: REFCODE
Attribute_Definition: Two letter code for county within which oyster bar lies
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: COUNTY
Attribute_Definition: Longitude of centroid value, expressed in negative decimal degrees and calculated from MapInfo
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: SQACRES
Attribute_Definition: Latitude of centroid value, expressed in negative decimal degrees and calculated from MapInfo
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CENTROIDX
Attribute_Definition: Size of oyster bar, in acres, calculated in MapInfo
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CENTROIDY
Attribute:
Attribute_Label: SQMETERS
Attribute:
Attribute_Label: CALCDACRES

Overview_Description:
Entity_and_Attribute_Detail_Citation: *************
Distribution_Information:
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Transfer_Size: 0.112
Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:
Address_Type: mailing and physical address
Address: Sarbanes Cooperative Oxford Laboratory
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120

Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0800 - 1700
Distribution_Liability: This data represents the results of data generated for a specific Maryland Department of Natural Resources management activity. As such, they are only valid for their intended use, content, time, and accuracy specifications. The user is responsible for any application of the data for other than it's intended purpose.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name: ARCE shapefile
Format_Information_Content: Data is normally distributed as a statewide dataset - Md State Plane NAD 83 meters
File_Decompression_Technique: no compression applied
Transfer_Size: 0.112
Digital_Transfer_Option:
Online_Option:
Online_Computer_and_Operating_System: http://dnrweb.dnr.state.md.us/gis/data/index.html
Metadata_Reference_Information:
Metadata_Date: 20050629
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:
Address_Type: mailing and physical address
Address: Sarbanes Cooperative Oxford Laboratory
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0830 - 1700 (EST)
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Security_Information:
Metadata_Security_Classification: Unclassified
Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html
Profile_Name: ESRI Metadata Profile

"DNRRepletion.shp"

Identification_Information:
Citation:
Citation_Information:
Originator: Maryland Department of Natural Resources, Fisheries Service, Cooperative Oxford Laboratory
Publication_Date: 20030409
Publication_Time: Unknown

Title: **DNR Repletion**
Geospatial_Data_Presentation_Form: vector digital data
Series_Information:
Publication_Information:
Publication_Place: Oxford, Maryland
Publisher: Maryland Department of Natural Resources
Online_Linkage: http://dnrweb.dnr.state.md.us/gis/data/index.html
Larger_Work_Citation:
Citation_Information:
Originator: John Hess, MDNR Shellfish Program, Deale Island Hatchery, Deale Island, Md
Publication_Date: Unpublished Material
Title: DNR Shellfish Oyster Propagation Activity summary reports
Description:
Abstract: Polygon delineation of annual oyster repletion activities undertaken by the Maryland Department of Natural Resources, Shellfish Program.
Purpose: This file was created for MDNR planning purposes, specifically for the purpose of tracking the activities of the Department's Shellfish Repletion Program.
Supplemental_Information: Boundaries were generated using MapInfo software (version 5) from coordinates taken from planting forms completed by the Department's Shellfish Program. The file was later migrated to Arcview.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: 04/10/2000
Beginning_Time: unknown
Ending_Date: changes annually
Currentness_Reference: publication date
Status:
Progress: In work
Maintenance_and_Update_Frequency: As needed
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -76.977947
East_Bounding_Coordinate: -75.860381
North_Bounding_Coordinate: 39.189665
South_Bounding_Coordinate: 37.958141
Keywords:
Theme:
Theme_Keyword_Thesaurus: none
Theme_Keyword: oyster repletion
Theme_Keyword: dredged shell
Theme_Keyword: seed
Theme_Keyword: oyster propagation
Place:
Place_Keyword_Thesaurus: none
Place_Keyword: Maryland
Stratum:
Stratum_Keyword: Chesapeake Bay
Temporal:
Access_Constraints: none
Use_Constraints: The Department of Natural Resources makes no warranty, expressed or implied, as to the use or appropriateness of Spatial Data, and there are no warranties of merchantability or fitness for a particular purpose or use. The information contained in Spatial Data is from publicly available sources, but no representation is made as to the accuracy or completeness of Spatial Data. The Department of Natural Resources shall not be subject to liability for human error, error due to software conversion, defect, or failure of machines, or any material used in the connection with the machines, including tapes, disks, CD-ROM's or DVD-ROM's and energy. The Department of Natural Resources shall not be liable for any lost profits, consequential damages, or claims against the Department of Natural Resources by third

parties. The liability of the Department of Natural Resources for damage regardless of the form of the action shall not exceed any distribution fees that may have been paid in obtaining Spatial Data.
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:
Address_Type: mailing address
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0830 - 1700 (EST)
Data_Set_Credit: Data set was produced by MDNR, Fisheries Service staff at the Oxford Laboratory, Oxford, Maryland.
Security_Information:
Security_Classification_System: none
Security_Classification: Unclassified
Security_Handling_Description: none
Native_Data_Set_Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.1.0.722
Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report: Dataset was derived from coordinates collected by MDNR's Shellfish Program personnel in the field as material was deployed. Beginning in 1999, coordinates were taken from DGPS (Northstar DGPS model 951XD) ; prior to 1999, coordinates were taken from Loran.
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report: No report available.
Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report: No report available.
Lineage:
Source_Information:
Type_of_Source_Media: planting form completed in the form
Process_Step:
Process_Description: This spatial layer was created using MapInfo software (version 5x). MapInfo's Universal Translator was then used to convert the file to an ArcView shapefile.
Process_Step:
Process_Description: Metadata imported.
Source_Used_Citation_Abbreviation: C:\DOCUME~1\KGREEN~1\LOCALS~1\Temp\xml6D.tmp
Process_Step:
Process_Description: Metadata imported.
Source_Used_Citation_Abbreviation: C:\DOCUME~1\KGREEN~1\LOCALS~1\Temp\xml86.tmp
Process_Step:
Process_Description: Metadata imported.
Source_Used_Citation_Abbreviation: Z:\KGreenhawk\Metadata from SCOLdata\DNRRepletion.shp.xml
Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:

SDTS_Point_and_Vector_Object_Type: G-polygon
Point_and_Vector_Object_Count: 181
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 1900
Lambert_Conformal_Conic:
Standard_Parallel: 38.300000
Standard_Parallel: 39.450000
Longitude_of_Central_Meridian: -77.000000
Latitude_of_Projection_Origin: 37.666667
False_Easting: 400000.000000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 0.000256
Ordinate_Resolution: 0.000256
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222
Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: DNRRepletion
Attribute:
Attribute_Label: FID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: DATE_
Attribute_Definition: Date of repletion activity; if seed planting, may be the date buoys were deployed
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: OPERATORS
Attribute_Definition: From fieldsheet, names of staff operating vessel
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: NAME
Attribute_Definition: From fieldsheet, code assigned to bar by Shellfish Program staff, usually taken from Maryland Oyster Bars publication (file mdoysbrs)
Attribute_Definition_Source: Maryland Department of Natural Resources

Attribute:
Attribute_Label: NOB
Attribute_Definition: From fieldsheet, NOB number within which activity falls
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: ACCURACY
Attribute_Definition: From fieldsheet, estimated accuracy of GPS
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DESC_
Attribute_Definition: From fieldsheet, description of repletion activity; usually bar name, current year and code for material deployed
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: ACRES
Attribute_Definition: From fieldsheet, estimated number of acres covered by deployed material
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DEPTH
Attribute_Definition: From fieldsheet, depth range in feet at planting location
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: BOTTOM
Attribute_Definition: From fieldsheet, bottom type(s) of are where material was deployed; codes are comma delimited and are as follows: SH = shell; M or MD mud; S = sand; CL = clay
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: COMMENTS
Attribute_Definition: From fieldsheet, comments recorded by field staff (eg. funding agency) or comments from data producer (eg. incomplete coordinates on fieldsheet)
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: NUMCOORDS
Attribute_Definition: Number of coordinates provided on fieldsheet
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT1
Attribute_Definition: From fieldsheet, latitude of first corner; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG1
Attribute_Definition: From fieldsheet, longitude of first corner; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT2
Attribute_Definition: From fieldsheet, latitude of second corner; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG2
Attribute_Definition: From fieldsheet, longitude of second corner; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT3

Attribute_Definition: From fieldsheet, latitude of third corner; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG3
Attribute_Definition: From fieldsheet, longitude of third corner; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT4
Attribute_Definition: From fieldsheet, latitude of fourth corner; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG4
Attribute_Definition: From fieldsheet, longitude of fourth corner; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT5
Attribute_Definition: From fieldsheet, latitude of center coordinate; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG5
Attribute_Definition: From fieldsheet, longitude of center coodinate; expressed in degrees and decimal minutes to three places
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: YEAR
Attribute_Definition: Four digit year, derived from field DATE_
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: RECTYPE
Attribute_Definition: Record type; "SHELL" for dredged shell or fresh shell planting; "SEED" for seed plant; OTHER for other types of material
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: ACCESS
Attribute_Definition: Accession number; internal tracking number used by data producer; first two characters represent 2 digit year; Characters 3 through 5 are alphabetic and are a code for group responsible for planting activity ("DNR" denotes Md Department of Natural Resouces in this dataset); Characters 6 through 11 are the oyster bar code for the oyster bar within which the activity falls (from MDNR - Maryland Oyster Bar publication); Characters 12 through 14 denote type of material deployded (DSH = dredged shell; FSH = fresh shell; SSE = seed from state seed area; HSE = hatchery seed; characters 15-18 represent month and day of planting; the last character is intended to avoid duplicate accession / tracking numbers. Value will be the letter "A" if the activity on this bar was the only one of its kind that day, but will be assigned a "B", "C" , etc. for additional activities. Duplication will only occur if the same group plants the same material on different locations on the same bar during the same day.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: TRIB
Attribute_Definition: Tributary name within which activity falls, derived from barcode
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: BARNAME
Attribute_Definition: Barname within which activity falls or intersects

Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: BARCODE
Attribute_Definition: Six character barcode, derived from MdOysBrs file
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: MATERIAL
Attribute_Definition: Material code for type of material deployed; DSH = dredged shell; FSH = fresh shell; SSE = seed from state seed area; HSE = hatchery seed
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: MATSOURCE
Attribute_Definition: From summary report, source of material deployed; Prior to 2002 code is a 2-4 character alphabetic code. Definitions for 2000 are as follows: BEA = Bald Eagle Addition #2; B = Bugby SSA; WCT = Wild Cherry Tree SSA; GM = Great Marsh; OC = Oyster Creek SSA; BC-N = Back Cove SSA; HSB = Horse Shoe Bend; GR = Gravelly Run; Definitions for 2001 are as follows: B = Bugby SSA; BN = Bugby North SSA; WCT = Wild Cherry Tree SSA; BC = Back Cove SSA (63 acres); Beginning in 2002, Shellfish staff used 6 character code from MdOysBrs file
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: BUSHELS
Attribute_Definition: From summary report, number of bushels of material deployed; A negative 8 in this field denotes data that is missing at publication time, but will be updated in the near future.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: X1
Attribute_Definition: Calculated field, derived from Long1 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: Y1
Attribute_Definition: Calculated field, derived from Lat1 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: X2
Attribute_Definition: Calculated field, derived from Long2 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: Y2
Attribute_Definition: Calculated field, derived from Lat2 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: X3
Attribute_Definition: Calculated field, derived from Long3 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: Y3
Attribute_Definition: Calculated field, derived from Lat3 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: X4

Attribute_Definition: Calculated field, derived from Long4 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: Y4
Attribute_Definition: Calculated field, derived from Lat4 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: X5
Attribute_Definition: Calculated field, derived from Long5 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: Y5
Attribute_Definition: Calculated field, derived from Lat5 (decimal degree equivalent) and used to generate polygon in MapInfo software
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: PAGE
Attribute_Definition: From summary report, page number where plant can be referenced
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LOCDETAILS
Attribute_Definition: From summary report, details regarding location of plant on oyster bar
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CATEGORY
Attribute_Definition: From summary report, activity purpose / category; Categories are as follows: "SEED TRANSPLANTED FOR NOB IMPROVEMENT BY DNR", "DSH FOR SEED OYSTER PRODUCTION BY DNR", "DSH FOR NOB IMPROVEMENT BY DNR", "DSH FOR CO SEED OYSTER PRODUCTION AND/OR GROWOUT, FSH FOR NOB IMPROVEMENT BY DNR; NOT LISTED (planting not found in summary report)
Attribute_Definition_Source: Maryland Department of Natural Resources
Overview_Description:
Entity_and_Attribute_Detail_Citation: *************
Distribution_Information:
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Transfer_Size: 0.175
Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:
Address_Type: mailing and physical address
Address: Sarbanes Cooperative Oxford Laboratory
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA

Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: *******
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0800 - 1700
Distribution_Liability: This data represents the results of data generated for specific Maryland Department of Natural Resources management activity. As such, they are only valid for their intended use, content, time, and accuracy specifications. The user is responsible for any application of the data for other than it's intended purpose.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name: ARCE shapefile
Format_Information_Content: Data is normally distributed as a statewide dataset - Md State Plane NAD 83 meters
File_Decompression_Technique: no compression applied
Transfer_Size: 0.175
Digital_Transfer_Option:
Online_Option:
Online_Computer_and_Operating_System: http://dnrweb.dnr.state.md.us/gis/data/index.html
Metadata_Reference_Information:
Metadata_Date: 20050629
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly Greenhawk
Contact_Organization: Maryland Department of Natural Resources
Contact_Position: DP Programmer / Analyst
Contact_Address:
Address_Type: mailing and physical address
Address: Sarbanes Cooperative Oxford Laboratory
Address: 904 South Morris Street
City: Oxford
State_or_Province: Maryland
Postal_Code: 21654
Country: USA
Contact_Voice_Telephone: 410-226-0078
Contact_TDD/TTY_Telephone: none
Contact_Facsimile_Telephone: 410-226-0120
Contact_Electronic_Mail_Address: kgreenhawk@dnr.state.md.us
Hours_of_Service: Monday through Friday 0830 - 1700 (EST)
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html
Profile_Name: ESRI Metadata Profile
Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html
Profile_Name: ESRI Metadata Profile

"MdSancRes.shp"

Identification_Information:
Citation:
Citation_Information:

Originator: Kelly Greenhawk, MDNR, Fisheries Service
Publication_Date: Unpublished Material
Title: **MdSancRes**
Geospatial_Data_Presentation_Form: vector digital data
Online_Linkage: \\OX0057178\C$\Documents and Settings\kgreenhawk\My Documents\ArcData\Bndfile\Oysbound\mdsancres.shp
Description:
Abstract: Polygon representation of oyster recovery activities undertaken in Maryland's oyster sanctuaries and reserves.
Purpose: File was created for the purpose of tracking oyster recovery efforts in Maryland's oyster sanctuaries and reserves.
Supplemental_Information:
File was created by Kelly Greenhawk, MDNR, Fisheries Service, Cooperative Oxford Laboratory but is maintained and distributed by Eric Campbell, MDNR, Fisheries Service, Shellfish Program. File is updated on a continual basis, as planting forms are submitted by the various Maryland partners. Due to the occasional receipt of incomplete forms, some fields in this file may be missing data, or may contain incomplete information. Records are flagged as suspect in this instance, in either the field COMMENTS or in the field OBJCOMM.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: 1997
Ending_Date: unknown
Currentness_Reference: ground condition
Status:
Progress: In work
Maintenance_and_Update_Frequency: Continually
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -76.979840
East_Bounding_Coordinate: 2.567953
North_Bounding_Coordinate: 39.216303
South_Bounding_Coordinate: -0.000001
Keywords:
Theme:
Theme_Keyword_Thesaurus: none
Theme_Keyword: oysters
Theme_Keyword: sanctuary
Theme_Keyword: reserve
Theme_Keyword: restoration
Theme_Keyword: recovery
Place:
Place_Keyword_Thesaurus: none
Place_Keyword: Maryland
Place_Keyword: Chesapeake Bay
Stratum:
Stratum_Keyword_Thesaurus: none
Stratum_Keyword: estuary floor
Use_Constraints: The Department of Natural Resources makes no warranty, expressed or implied, as to the use or appropriateness of Spatial Data, and there are no warranties of merchantability or fitness for a particular purpose or use. The information contained in Spatial Data is from publicly available sources, but no representation is made as to the accuracy or completeness of Spatial Data. The Department of Natural Resources shall not be subject to liability for human error, error due to software conversion, defect, or failure of machines, or any material used in the connection with the machines, including tapes, disks, CD-ROM's or DVD-ROM's and energy. The Department of Natural Resources shall not be liable for any lost profits, consequential damages, or claims against the Department of Natural Resources by third parties. The liability of the Department of Natural Resources for damage regardless of the form of the action shall not exceed any distribution fees that may have been paid in obtaining Spatial Data.

Point_of_Contact:
  Contact_Information:
    Contact_Person_Primary:
      Contact_Person: Eric Campbell
      Contact_Organization: MDNR, Fisheries Service, Shellfish Program
    Contact_Position: Biologist
    Contact_Address:
      Address_Type: mailing and physical address
      Address: Maryland Department of Natural Resources
      Address: Tawes State Office Building
      Address: 580 Taylor Avenue
      City: Annapolis
      State_or_Province: MD
      Postal_Code: 21401
      Country: USA
    Contact_Voice_Telephone: 410-260-8344
    Contact_Facsimile_Telephone: 410-260-8279
    Contact_Electronic_Mail_Address: ecampbell@dnr.state.md.us
 Data_Set_Credit: MDNR, Fisheries Service
 Native_Data_Set_Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.1.0.722
Data_Quality_Information:
 Completeness_Report: Records from forms that were submitted to MDNR with only one set of coordinates (as opposed to 4 sets of corner coordinates) are represented with a circlular object, as opposed to a polygon object. These objects were created by using the buffer feature of ArcView 8x in conjunction with the centroid coordinate values.
 Lineage:
  Source_Information:
    Type_of_Source_Media: paper forms, designed by MDNR's Shellfish Program
    Source_Time_Period_of_Content:
      Time_Period_Information:
        Range_of_Dates/Times:
          Beginning_Date: 1997
          Ending_Date: 2002
      Source_Currentness_Reference: ground condition
  Process_Step:
    Source_Used_Citation_Abbreviation: C:\DOCUME~1\KGREEN~1\LOCALS~1\Temp\xml15.tmp
  Process_Step:
    Process_Description: Metadata imported.
    Source_Used_Citation_Abbreviation: J:\DATA\OysterData\MdSancRes.shp.xml
  Process_Step:
    Process_Description: Dataset copied.
    Source_Used_Citation_Abbreviation:
  Process_Step:
    Process_Description: Dataset copied.
    Source_Used_Citation_Abbreviation: C:\Documents and Settings\kgreenhawk\My Documents\ArcData\Help Campbell with Mdsancres updates (Geo coordsys)\MdSRsp83m
  Process_Step:
    Process_Description: Dataset moved.
    Source_Used_Citation_Abbreviation: C:\Documents and Settings\kgreenhawk\My Documents\ArcData\Metadata templates\MdSR83mBKUP
  Process_Step:
    Process_Description: Metadata imported.
    Source_Used_Citation_Abbreviation: C:\Documents and Settings\kgreenhawk\My Documents\ArcData\Help Campbell with Mdsancres updates (Geo coordsys)\MdSR83mBKUP.shp.xml
Spatial_Data_Organization_Information:
 Direct_Spatial_Reference_Method: Vector

Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: G-polygon
Point_and_Vector_Object_Count: 158
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 1900
Lambert_Conformal_Conic:
Standard_Parallel: 38.300000
Standard_Parallel: 39.450000
Longitude_of_Central_Meridian: -77.000000
Latitude_of_Projection_Origin: 37.666667
False_Easting: 400000.000000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 0.016384
Ordinate_Resolution: 0.016384
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222
Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: mdsancres
Attribute:
Attribute_Label: FID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: RECTYPE
Attribute_Definition: Type of record - SEED, SHELL or MULTI; object represents the boundaries of a seed planting activity, or deployment of shell or other material used as substrate for oysters
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: GROUP
Attribute_Definition: Three character code for the name of the group which served as project leader for the activity; ANS = Academy of Natural Sciences; CBF = Chesapeake Bay Foundation; ORP = Oyster Recovery Partnership; DNR = Md. Department of Natural Resources; SRF = South River Federation; PRF = Potomac River Fisheries Commission; LCF = Living Classrooms Foundation; COE = Army Corps of Engineers

Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: ORP
Enumerated_Domain_Value_Definition: Oyster Recovery Partnership
Enumerated_Domain:
Enumerated_Domain_Value: CBF
Enumerated_Domain_Value_Definition: Chesapeake Bay Foundation
Enumerated_Domain:
Enumerated_Domain_Value: DNR
Enumerated_Domain_Value_Definition: Maryland Department of Natural Resources
Enumerated_Domain:
Enumerated_Domain_Value: COE
Enumerated_Domain_Value_Definition: Army Corp of Engineers
Enumerated_Domain:
Enumerated_Domain_Value: ANS
Enumerated_Domain_Value_Definition: Academy of Natural Science
Enumerated_Domain:
Enumerated_Domain_Value: LCF
Enumerated_Domain_Value_Definition: Living Classroom Foundation
Enumerated_Domain:
Enumerated_Domain_Value: PRF
Enumerated_Domain_Value_Definition: Potomac River Fisheries Commission
Enumerated_Domain:
Enumerated_Domain_Value: SRF
Enumerated_Domain_Value_Definition: South River Federation
Enumerated_Domain:
Enumerated_Domain_Value: MRA
Enumerated_Domain_Value_Definition: Magothy River Association
Attribute:
Attribute_Label: ACCESS
Attribute_Definition: Internal DNR tracking / accession number to identify activity; For more information on coding scheme, see Entity and Attribute Overview under Overview Description
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: OTHGROUPS
Attribute_Definition: Listing of other groups involved in activity
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: FUNDSOURCE
Attribute_Definition: Funding source for activity
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: LOCATION
Attribute_Definition: Location of activity, usually tributary name.
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: BARNAME
Attribute_Definition: Barname of oyster bar where activity took place, from form; barname will not always match barcode from MdOysbrs file since this field is reserved for information on the form
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: BOTTYPE
Attribute_Definition: Bottom type at location; Codes are as follows: ND = no data provided; S = sand; SH = shell; M = mud; GR = gravel; ST = stone; BSH = broken shell; CL = clay
Attribute_Definition_Source: Maryland Department of Natural Resouces

Attribute:
Attribute_Label: DEPTH
Attribute_Definition: Depth or depth range in feet (minimum depth, followed by "-", followed by the maximum depth)
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: STARTDATE
Attribute_Definition: Date or beginning date of deployment if a range of dates is provided on form; when material was deployed
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: ENDDATE
Attribute_Definition: If a date range was provided, ending date of project. Field will be null if project was completed in one day or only start date was provided.
Attribute_Definition_Source: Maryland Department of Natural Resouces
Attribute:
Attribute_Label: SANCT
Attribute_Definition: Logical field indicating whether activity took place in a sanctuary ("Y" or "N")
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: RESERVE
Attribute_Definition: Logical field indicating whether activity took place in a reserve ("Y" or "N")
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: ORA
Attribute_Definition: Logical field indicating whether activity took place in a designated Oyster Recovery Area
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CLOSNAME
Attribute_Definition: Name of sanctuary or reserve / name of closure followed by a dash, then an "S" if the closure is a sanctuary or an "R" if the closure is a reserve; "NONE" is used for projects that do not fall within a designated sanctuary or reserve, once entered into the GIS.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LOCNOTES
Attribute_Definition: Notes on location of activity
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: MATERIAL1
Attribute_Definition: Material deployed; DSH = dredged shell; FSH = fresh shell; HSE = hatchery seed; USE = seed from unknown source; MUL = multiple materials; BBO = buy back oysters; CUL = cultchless oysters; 1YC = one year old cultch; SOS = spat on shell; STO = stone; UNK = material unknown; RUB = rubble; SLG = slag; SHL = shell of unknown type; RFB = reef ball(s); SPT = spat; OG1 = oyster gardeners' 1 year old oysters; FNS = fines; OTH = other material; If code OTH is used, see field OTHER for description of material. See Value Definition Source for more information.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value_Definition_Source:
The abundance of material codes used in this file stems from the fact that the various partners use a variety of terms to describe the material they have
deployed. Although a more streamlined coding system, with fewer material codes
may be desirable in the future, the dataset creator has chosen to retain a more
lengthy, specific coding system for now.

It is hoped that with the establishment of the Technical Committee called for in Maryland's Comprehensive Oyster Management Plan, data management guidelines can be written that will include a directive to the data producers
to utilitze a more streamlined coding system.

Attribute:
Attribute_Label: MATERIAL2
Attribute_Definition: Material deployed if more than one material was deployed; DSH = dredged shell; FSH = fresh shell; HSE = hatchery seed; USE = seed from unknown source; MUL = multiple materials; BBO = buy back oysters; CUL = cultchless oysters; 1YC = one year old cultch; SOS = spat on shell; STO = stone; UNK = material unknown; RUB = rubble; SLG = slag; SHL = shell of unknown type; RFB = reef ball(s); SPT = spat; OG1 = oyster gardeners' 1 year old oysters; FNS = fines; OTH = other material
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: MATERIAL3
Attribute_Definition: Material deployed if more than two different materials were deployed; DSH = dredged shell; FSH = fresh shell; HSE = hatchery seed; USE = seed from unknown source; MUL = multiple materials; BBO = buy back oysters; CUL = cultchless oysters; 1YC = one year old cultch; SOS = spat on shell; STO = stone; UNK = material unknown; RUB = rubble; SLG = slag; SHL = shell of unknown type; RFB = reef ball(s); SPT = spat; OG1 = oyster gardeners' 1 year old oysters; FNS = fines; OTH = other material
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: MATERIAL4
Attribute_Definition: Material deployed, if more than 3 types of material were deployed; DSH = dredged shell; FSH = fresh shell; HSE = hatchery seed; USE = seed from unknown source; MUL = multiple materials; BBO = buy back oysters; CUL = cultchless oysters; 1YC = one year old cultch; SOS = spat on shell; STO = stone; UNK = material unknown; RUB = rubble; SLG = slag; SHL = shell of unknown type; RFB = reef ball(s); SPT = spat; OG1 = oyster gardeners' 1 year old oysters; FNS = fines; OTH = other material
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: OTHER
Attribute_Definition: Additional description of material in MATERIAL1
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: AVGSIZE
Attribute_Definition: Average size of oysters, if seed was deployed, in centimeters. ND = no data provided
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: MATSOURCE
Attribute_Definition: Material source, i.e. hatchery name or vendor
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: BSTUSED
Attribute_Definition: Broodstock used, if applicable
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: TESTED
Attribute_Definition: Was the material, if seed material, tested for disease ? ("Y" or "N")
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DISEASE
Attribute_Definition: Was disease present ? If the value of TESTED is "Y", field can be "Y", "N" or blank. A blank in this field denotes seed / oysters were tested but results of test were not indicated on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAB_NAME
Attribute_Definition: Name of lab performing disease diagnosis
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DERMOPREV
Attribute_Definition: Percent of sample testing positive for Dermo

Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: MSXPREV
Attribute_Definition: Percent of sample testing positive for MSX
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CONTACT
Attribute_Definition: Contact name for laboratory
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CONTACTPH
Attribute_Definition: Contact phone number for laboratory
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: OYS
Attribute_Definition: Number of oysters deployed, if seed activity. Value will be a negative nine if number of oysters was not provided on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: BU
Attribute_Definition: Number of bushels of material deployed; Value will be a negative nine if number of bushels was not provided on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CUYDS
Attribute_Definition: Number of cubic yards of material deployed; Value will be a negative nine if number of cubic yards was not provided on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CONFIG
Attribute_Definition: Configuration of planting, if noted on form; flat, mound, etc.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: ATTACH
Attribute_Definition: Logical field reflecting whether an attachment describing configuration details was submitted with the form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: COMMENTS
Attribute_Definition: Additional information pertaining to activity.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: INCXY
Attribute_Definition: Logical field. Is coordinate information provided on form incomplete ? ("Y" or "N")
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: NUMCOORDS
Attribute_Definition: Number of corner coordinates provided on form
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: PRJORIGIN
Attribute_Definition: Project origin; Field will contain "ND" for no data for activities where project origin was not reported on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: PURP1

Attribute_Definition: Project purpose (text field 1 of 2 due to ESRI text field limitations). Field will contain "ND" for no data for activities where project purpose was not reported on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: PURP2
Attribute_Definition: Project purpose (text field 2 of 2). Field will contain "ND" for no data for activities where project origin was not reported on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: EXPRESULTS
Attribute_Definition: Expected results. Field will contain "ND" for no data for activities where expected results were not reported on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDY1
Attribute_Definition: Decimal equivalent of corresponding LAT field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDX1
Attribute_Definition: Decimal equivalent of corresponding LONG field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDY2
Attribute_Definition: Decimal equivalent of corresponding LAT field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDX2
Attribute_Definition: Decimal equivalent of corresponding LONG field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDY3
Attribute_Definition: Decimal equivalent of corresponding LAT field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDX3
Attribute_Definition: Decimal equivalent of corresponding LONG field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDY4
Attribute_Definition: Decimal equivalent of corresponding LAT field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDX4
Attribute_Definition: Decimal equivalent of corresponding LONG field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDY5
Attribute_Definition: Decimal equivalent of corresponding LAT field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDX5
Attribute_Definition: Decimal equivalent of corresponding LONG field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDY6
Attribute_Definition: Decimal equivalent of corresponding LAT field

Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: DDX6
Attribute_Definition: Decimal equivalent of corresponding LONG field
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: OBJECTCOMM
Attribute_Definition: Comments pertaining to spatial object location or shape, from database manager.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: ACRES
Attribute_Definition: Area of object in acres, calculated in GIS.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: SQMETERS
Attribute_Definition: Area of object in square meters, calculated in GIS
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT1
Attribute_Definition: Latitude value of first corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG1
Attribute_Definition: Longitude value of first corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT2
Attribute_Definition: Latitude value of second corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG2
Attribute_Definition: Longitude value of second corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT3
Attribute_Definition: Latitude value of third corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG3
Attribute_Definition: Longitude value of third corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT4
Attribute_Definition: Latitude value of fourth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG4
Attribute_Definition: Longitude value of fourth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.

Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT5
Attribute_Definition: Latitude value of fifth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG5
Attribute_Definition: Longitude value of fifth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LAT6
Attribute_Definition: Latitude value of sixth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: LONG6
Attribute_Definition: Longitude value of sixth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: PRJPREP
Attribute_Definition: Description of preparations undertaken to ready site for deployment.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CENTROIDX
Attribute_Definition: X value of centroid coordinate, expressed in meters. Field is calculated in GIS and used to center polygon objects for records where only one coordinate is provided.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: CENTROIDY
Attribute_Definition: Y value of centroid coordinate, expressed in meters. Field is calculated in GIS and used to center polygon objects for records where only one coordinate is provided.
Attribute_Definition_Source: Maryland Department of Natural Resources
Attribute:
Attribute_Label: TONS
Attribute_Definition: Amount of material deployed, expressed in tons. Value will be a negative nine if number of tons was not provided on form.
Attribute_Definition_Source: Maryland Department of Natural Resources
Overview_Description:
Entity_and_Attribute_Overview:
characters 1-2 represent year activity took place;
characters 3 through 5 represent project leader (see GROUP for more info);
characters 6 through 11 represent barcode from MdOysBrs file/publication;
characters12-14 represent type of material deployed (see MATERIAL fields for more info)
characters 15-18 represent month and day of activity (MMDD);
character 19 is used to avoid duplicate accession / tracking codes, when the same group
deploys the same material more than once on the same bar on the same date. The letter "A"
is used for the first planting, the letter "B" is used for the second planting, the letter "C" is used
for the third planting, etc..
Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Eric Campbell

Contact_Organization: MDNR, Fisheries Service, Shellfish Progam
Contact_Position: Biologist
Contact_Voice_Telephone: 410-260-8344
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Transfer_Size: 0.087
Metadata_Reference_Information:
Metadata_Date: 20050629
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Eric Campbell
Contact_Organization: MDNR, Fisheries Service, Shellfish Program
Contact_Position: Biologist
Contact_Address:
Address_Type: REQUIRED: The mailing and/or physical address for the organization or individual.
City: REQUIRED: The city of the address.
State_or_Province: REQUIRED: The state or province of the address.
Postal_Code: REQUIRED: The ZIP or other postal code of the address.
Contact_Voice_Telephone: 410-260-8344
Contact_Facsimile_Telephone: 410-260-8279
Contact_Electronic_Mail_Address: ecampbell@dnr.state.md.us
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html
Profile_Name: ESRI Metadata Profile

"Lselines.dxf" and "Lease91.dbf"

Required Disclaimer

Any documents, maps, data, or publications that use the Natural Oyster Bar/Lease lines/coordinates provided must also include the following disclaimer:

"The Natural Oyster Bar/lease lines shown are for oyster management purposes only. For the official boundary(ies) consult the current official Natural Oyster Bar Chart."

The oyster bars/leases in this product are part of the conversion of the present mylar based Natural Oyster Bar Charts to digital format. They are based on bars that were delineated by the Bay Bottom Survey from 1975-1985, and amendments, Potomac River Oyster Survey of 1928,and amendments, and the Potomac River Bottom Survey of 1994, and amendments. They may differ from the bars shown on the current official mylar based Natural Oyster Bar Charts. Leases are based on the conversion of the coordinates from the original lease documents. They are based on surveys dating from 1912 to the present. Coordinates based on early surveys were converted by NADCON to NAD 83-91 values. Surveys performed after 1995 were done by GPS in the same coordinates.

It is the responsibility of the licensee to verify that this data is current.
This office does not automatically notify licensees of changes/updates to this data.

Some leases have corner points that fall on the shoreline. In these instances this file may exhibit lines that cross the shoreline, or that connect from point to point over the water. In these cases the true extent of the lease should be verified from the lease document.

Any requests for all or part of this data must be referred to this office. The data is copyrighted by the State of Maryland, Department of Natural Resources.

The data is available only in DXF format, with coordinates in NAD 1983 (1991 adjustment) Maryland Zone 1900 State Plane coordinate Meters.

"Potential.shp"

Metadata was not available for the source file "Potential". See the document "Virginia Oyster Reef Restoration Map Atlas", dated August 2002 for more information on this dataset.

"Privlease.shp"

Identification_Information:
  Citation:
    Citation_Information:
      Originator:
      Comprehensive Coastal Inventory, Virginia Institute of Marine Science
      and Virginia Marine Resources Commission
      Publication_Date: 2002
      Title: Privateleases - coverage
      Geospatial_Data_Presentation_Form: vector digital data
      Publication_Information:
        Publication_Place: Gloucester Point, Virginia
        Publisher: Virginia Insititute of Marine Science
  Description:
    Abstract:
    This polygon coverage delineates general survey boundaries of private
    oyster ground leases in Virginia. The coverage was generated from data
    provided by the Virginia Marine Resources Commission; the state agency
    responsible for regulating private oyster ground leases in Virginia. Data
    was originally received in AutoCad. Considerable manipulation was required
    to make the conversion. While private lease boundaries are legally
    defined, this coverage does not meet legal survey standards.
    Purpose:
    The data conversion and subsequent development of the GIS coverage was
    necessary for an oyster reef restoration targeting model being developed
    at the Virginia Institute of Marine Science.
  Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 2002
    Currentness_Reference: Data layer accurate to 2002.

Status:
  Progress: Complete
  Maintenance_and_Update_Frequency:
  This coverage is not updated to reflect current status of private oyster ground leases in Virginia. The Virginia Marine Resources Commission does update their AutoCad system to reflect current standings, however, updates to the GIS record do not occur.
Spatial_Domain:
  Bounding_Coordinates:
    West_Bounding_Coordinate: -77.06352286
    East_Bounding_Coordinate: -75.25314337
    North_Bounding_Coordinate: 38.34948166
    South_Bounding_Coordinate: 36.77505899
Keywords:
  Theme:
    Theme_Keyword_Thesaurus: none
    Theme_Keyword: Private Oyster Ground Leases
  Place:
    Place_Keyword_Thesaurus: none
    Place_Keyword: Virginia's Waters
Access_Constraints: none
Use_Constraints:
Acknowledgement the Virginia Marine Resources Commission should be included in products derived from this data. While private lease boundaries are legally defined, this coverage does not meet legal survey standards.
Point_of_Contact:
  Contact_Information:
    Contact_Person_Primary:
      Contact_Person: Marcia Berman
      Contact_Organization: Virginia Institute of Marine Science (VIMS)
    Contact_Position: Director Comprehensive Coastal Inventory Program
    Contact_Address:
      Address_Type: mailing address
      Address: P.O. Box 1346
      City: Gloucester Point
      State_or_Province: Virginia
      Postal_Code: 23062
      Country: USA
    Contact_Voice_Telephone: (804) 684-7188
    Contact_Facsimile_Telephone: (804) 684-7179
    Contact_Electronic_Mail_Address: marcia@vims.edu
Data_Set_Credit:
The Virginia Marine Resources Commission is credited with origination of the database. The GIS coverage was generated by the Comprehensive Coastal Inventory Program at the Virginia Institute of Marine Science. The coverage was worked on by Sharon Killeen, Dan Schatt and Helen Woods.
Native_Data_Set_Environment:
SunOS, 5.7, sun4u UNIX ARC/INFO version 7.2.1
Cross_Reference:
  Citation_Information:
    Originator: The Virginia Marine Resources Commission
    Publication_Date: 2002
    Title: Virginia Private Oyster Leases
    Geospatial_Data_Presentation_Form: map
    Publication_Information:
      Publication_Place: Newport News, Va

Publisher: Virginia Marine Resources Commission

Data_Quality_Information:
Logical_Consistency_Report:
Polygon topology is present with all polygons closed and coded for private.
Completeness_Report:
The most current data available was used to create the coverage.
Lineage:
Source_Information:
Source_Citation:
Citation_Information:
Originator: Virginia Marine Resources Commission
Publication_Date: 2002
Title: Virginia Private Oyster Leases
Geospatial_Data_Presentation_Form: map
Publication_Information:
Publication_Place: Newport News, VA
Publisher: Virginia Marine Resources Commission
Type_of_Source_Media: AutoCAD file
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 2002
Source_Currentness_Reference: Data layer accurate to 2002
Source_Citation_Abbreviation: VMRC
Source_Contribution: location of private oyster leases
Process_Step:
Process_Description:
An autocad file (VMRC) was turned into a shapefile using ArcInfo the conversion tool and projected using ArcInfo projection tools.
Process_Date: 2002
Process_Step:
Process_Description:
The coverage was then cleaned of all dangles and all polygons were closed using ArcInfo Arcedit.
Process_Date: 2002

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: Point
Point_and_Vector_Object_Count: 5935
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: String
Point_and_Vector_Object_Count: 12508
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: GT-polygon composed of chains
Point_and_Vector_Object_Count: 5939

Spatial_Reference_Information:
  Horizontal_Coordinate_System_Definition:
    Planar:
      Grid_Coordinate_System:
        Grid_Coordinate_System_Name: Universal Transverse Mercator
        Universal_Transverse_Mercator:
          UTM_Zone_Number: 18
          Transverse_Mercator:
            Scale_Factor_at_Central_Meridian: 0.999600
            Longitude_of_Central_Meridian: -75.0000
            Latitude_of_Projection_Origin: 0.0000
            False_Easting: 500000
            False_Northing: 0.0000
      Planar_Coordinate_Information:
        Planar_Coordinate_Encoding_Method: coordinate pair
        Coordinate_Representation:
          Abscissa_Resolution: 0.84691375494
          Ordinate_Resolution: 0.84691375494
        Planar_Distance_Units: Meters
    Geodetic_Model:
      Horizontal_Datum_Name: North American Datum of 1983
      Ellipsoid_Name: GRS1980
      Semi-major_Axis: 6378206.4
      Denominator_of_Flattening_Ratio: 294.98

Entity_and_Attribute_Information:
  Overview_Description:
    Entity_and_Attribute_Overview:
    Each polygon in this coverage is a separate private lease polygon. Items listed in the .aat are from the autocad conversion.

PRILEASE83.PAT:

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	ALTERNATE NAME
1	AREA	4	12	F	3	
5	PERIMETER	4	12	F	3	
9	PRILEASE83#	4	5	B	-	
13	PRILEASE83-ID	4	5	B	-	
17	LEASE	8	8	C	-	

PRILEASE83.AAT:

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	ALTERNATE NAME
1	FNODE#	4	5	B	-	
5	TNODE#	4	5	B	-	
9	LPOLY#	4	5	B	-	
13	RPOLY#	4	5	B	-	
17	LENGTH	4	12	F	3	
21	PRILEASE83#	4	5	B	-	
25	PRILEASE83-ID	4	5	B	-	
29	ENTITY	14	14	C	-	
43	HANDLE	16	16	C	-	
59	LAYER	32	32	C	-	

91	ELEVATION	8	19	F	5
99	THICKNESS	8	19	F	5
107	COLOR	4	6	B	-
111	LINETYPE	32	32	C	-
143	LINEWIDTH	8	19	F	5
151	STYLE	32	32	C	-
183	TEXT	254	254	C	-

Entity_and_Attribute_Detail_Citation: none

Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Virginia Institute of Marine Science (VIMS)
Contact_Position: Director Comprehensive Coastal Inventory Program
Contact_Address:
Address_Type: mailing address
Address: P.O. Box 1346
City: Gloucester Point
State_or_Province: Virginia
Postal_Code: 23062
Country: USA
Contact_Voice_Telephone: (804) 684-7188
Contact_Instructions: Contact via email
Contact_Electronic_Mail_Address: marcia@vims.edu
Distribution_Liability:
The Comprehensive Coastal Inventory Program (CCI) at VIMS performs a service by distributing data generated by either CCI or public agencies which offer data without restriction or charge. CCI assumes no responsibility for data accuracy or precision, metadata completeness or correctness for digital information. CCI assumes no liability for misuse of any data which may arise as a result of any alteration, conversion, or combination with other data sources. As well, the timeliness and scale of these products must be considered when evaluating appropriate use.

Metadata_Reference_Information:
Metadata_Date: 20041103
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Virginia Institute of Marine Science (VIMS)
Contact_Person: Tamia Rudnicky
Contact_Position: GIS Programmer/Analyst
Contact_Address:
Address_Type: mailing address
Address: P.O. Box 1346
City: Gloucester Point
State_or_Province: Virginia
Postal_Code: 23062
Country: USA

Contact_Voice_Telephone: (804) 684-7181
Contact_Facsimile_Telephone: (804) 684-7179
Contact_Electronic_Mail_Address: tamia@vims.edu
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Access_Constraints: none
Metadata_Use_Constraints: none

Generated by mp version 2.5.4 on Mon Nov 22 12:14:01 2004

Attachment 2.

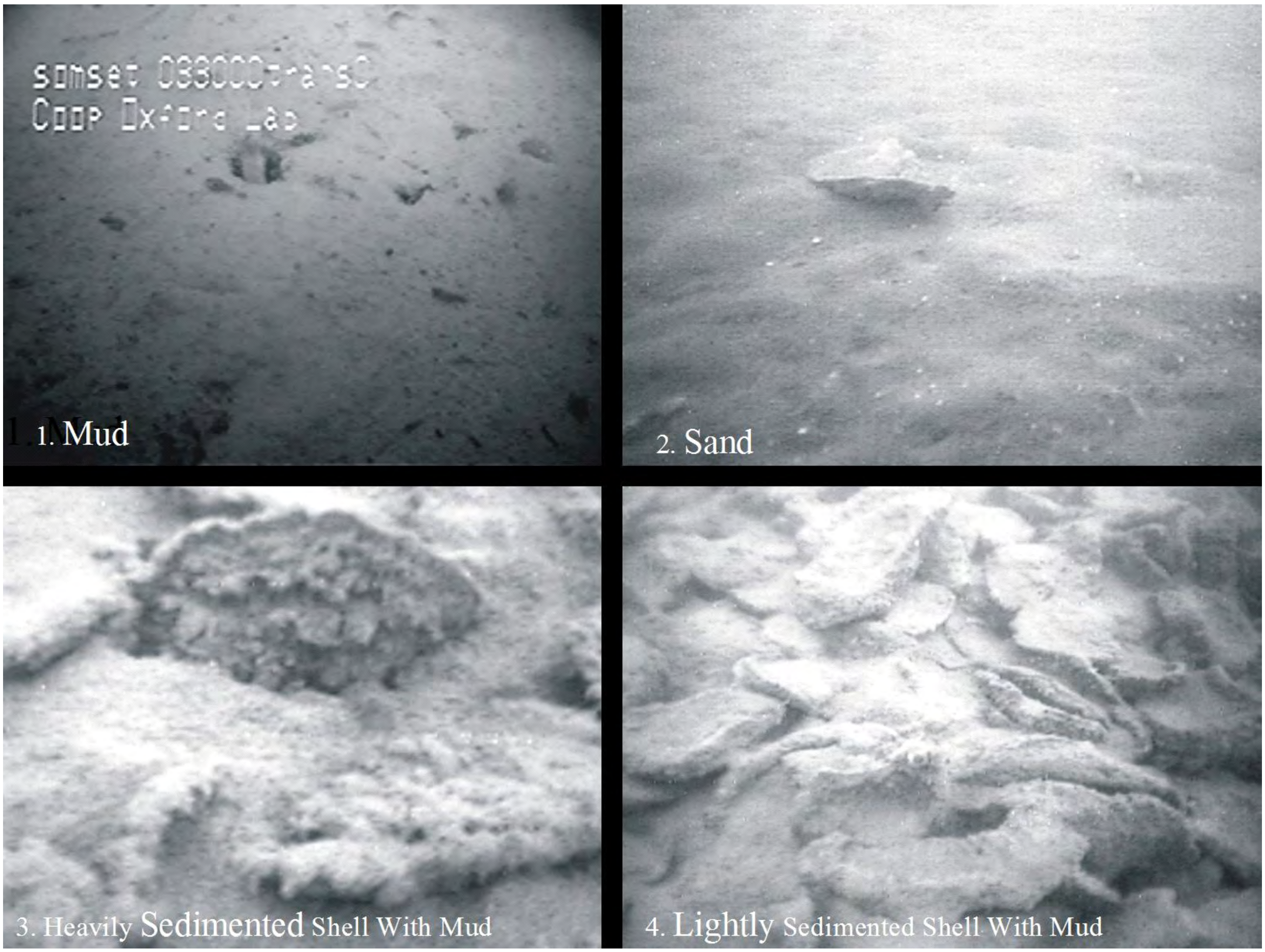
Frequency data used to establish polygon reduction rates for Maryland oyster habitat, derived from data collected by MDNR. The shaded areas of the table contain the specific frequencies used.

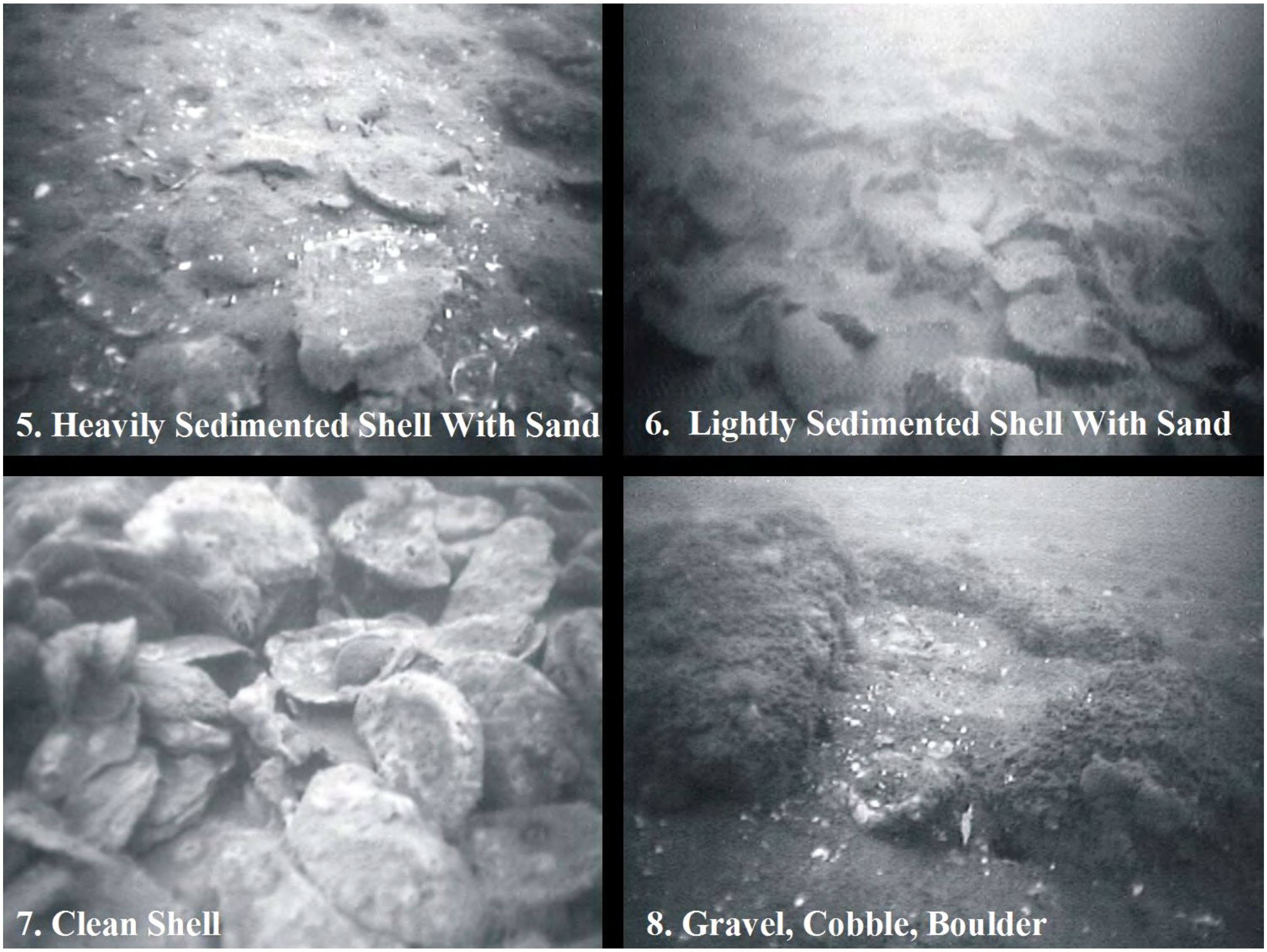
Table 2. Relative abundance of classed bottom interrogations from 15 pooled acoustic benthic habitat surveys. Distributions came from bottom interrogations 1) within Yates Oyster Bars, and 2) within Maryland Bay Bottom Survey (MBBS) shell bottom polygons within Yates Bars. Because the Terrapin Sands survey was not within Yates bar boundaries it was not included in this analysis.

	Inside Yates bars		MBBS shell bottom	
Bottom class	Frequency	Relative frequency (%)	Frequency	Relative frequency (%)
Clean shell	181	0.62	81	1.16
Mud	9,490	32.52	1,431	20.58
Sand	15,572	53.36	3,338	48.00
Heavily sedimented shell with mud	2,432	8.33	1,505	21.64
Heavily sedimented shell with sand	864	2.96	359	5.16
Lightly sedimented shell with sand	95	0.33	84	1.21
Gravel/cobble /boulder	310	1.06	95	1.37
Unidentified	239	0.82	61	0.88
Total	29,183	100	6,954	100

Attachment 3.

Images showing the various bottom classifications identified by the acoustic surveys referenced in Attachment 2.




5. Heavily Sedimented Shell With Sand
6. Lightly Sedimented Shell With Sand
7. Clean Shell
8. Gravel, Cobble, Boulder

Attachment 4.

VBA code used to scale habitat polygons.

Attachment 4. VBA code used to scale habitat polygons. The line that reads ".Scale pPoint, 0.349857, 0.349857" contains the scale factor needed to reduce the Yates bar polygons to 12.24% of their original acreage. The scale factor is the square root of the percent reduction in area desired. For the MBBS polygons, a scale factor of .540092 was used.

```
Sub Scale_polygon()

    Dim pMxDoc As IMxDocument
    Dim pMap As IMap
    Dim pTransform2D As ITransform2D
    Dim pEnumFeature As IEnumFeature
    Dim pFeature As IFeature
    Dim pArea As IArea
    Dim pPoint As IPoint
    Dim pPolygon As IPolygon

    Set pMxDoc = ThisDocument
    Set pEnumFeature = pMxDoc.FocusMap.FeatureSelection
    pEnumFeature.Reset
    Set pFeature = pEnumFeature.Next

    If pFeature.Shape.GeometryType = esriGeometryPolygon Then
      Set pArea = pFeature.Shape
    End If

    Do While Not pFeature Is Nothing

        Set pArea = pFeature.Shape
        Set pPoint = pArea.Centroid

        Set pTransform2D = pFeature.ShapeCopy
        With pTransform2D
            .Scale pPoint, 0.349857, 0.349857


        End With
        Set pFeature.Shape = pTransform2D
        pFeature.Store
        Set pFeature = pEnumFeature.Next
    Loop

    pMxDoc.ActiveView.Refresh

 End Sub
```

Attachment 2

Oyster Population Estimates for the Maryland Portion of Chesapeake Bay 1994 – 2006

(Greenhawk and O'Connell 2007)

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Oyster population estimates for the

Maryland Portion of Chesapeake Bay 1994 – 2006

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INTRODUCTION

The Chesapeake Bay 2000 Agreement established a goal of increasing the Chesapeake Bay oyster population 10-fold by 2010 from its 1994 level of abundance. Upon the adoption of this goal, the National Oceanic and Atmospheric Administration Chesapeake Bay Stock Assessment Committee and U.S. Environmental Protection Agency Chesapeake Bay Program jointly funded an interstate research project to estimate the 1994 baseline population of oysters and to develop a methodology for producing annual oyster population estimates that could be used to measure progress toward achieving the 10-fold goal. This collaborative project between the Maryland Department of Natural Resources (MD DNR) and Virginia Institute of Marine Sciences resulted in annual oyster population estimates of small and market size oysters (spat estimates were not included) for the period 1994-2002. Estimates of the oyster population in Virginia have been produced annually since 2002. Oyster population estimates in Maryland have not been updated since 2002 until now primarily because of a lack of documentation of the methodology used to compute the 1994-2002 estimates. This report provides documentation for the methodology used to estimate Maryland's oyster population from 1994 to 2002, presents the assumptions associated with the estimates, and provides estimates of abundance through 2006.

METHODS

Oyster abundance was based on estimates of suitable oyster habitat and estimates of oyster density in each of eight basins in the Maryland portion of Chesapeake Bay. The steps used to calculate the population estimates are presented as follows.

1.0 Step 1 - Delineation of Maryland Basins

The Maryland portion of the Chesapeake Bay was divided into eight basins. This was done in an attempt to account for the significant observed variation in oyster abundance among basins. The following eight basins were established: 1) Chester River; 2) Eastern Bay; 3) Choptank River; 4) Little Choptank River; 5) Tangier Sound; 6) Potomac River; 7) Patuxent River; and 8) Chesapeake Bay mainstem (Figure 1).

Step 2 - Calculation of Available Oyster Habitat in Maryland Basins

Maryland's oyster population estimates are based on multiplying the annual measured oyster density by the amount of available oyster habitat within each basin. The most recent comprehensive survey of available oyster habitat is the Maryland Bay Bottom Survey (MBBS), conducted between 1976 and 1983. (Note: A digital dataset of the MBBS is available from MD DNR.) It is widely accepted in the scientific community that the amount and quality of existing oyster habitat in Maryland has declined significantly since the MBBS survey was conducted. Because the oyster population estimates are based on the amount and quality of available habitat, changes in habitat availability and quality since the MBSS was completed needed to be taken into account in our study.

A survey was conducted by the MD DNR Cooperative Oxford Laboratory between 1999 and 2000 at 15 oyster bars located throughout the Maryland portion of the Chesapeake Bay (Smith et al. 2005). The objective of the 1999-2000 MD DNR survey was to assess the relative abundance of oyster habitat within the cultch bottom classifications of both the 1978-1983 MBBS and a survey conducted by C.C. Yates between 1906-1911. The 15 bars surveyed were believed to be a fair representation of bars typically found in the Chesapeake Bay based upon a similarity of bottom types found at each bar. The MBBS classified oyster habitat into the following seven bottom classes: cultch, mud with cultch, sand with cultch, mud, sand, hard bottom and leased bottom (Smith et al. 2001). Areas of bottom with generous amounts of oyster shell were classified as cultch, while areas of scattered oyster shell were classified as either sand with cultch or mud with cultch. The cultch, sand with cultch and mud with cultch classifications were later categorized as either high quality habitat, low quality habitat, or lost habitat, for the purposes of this oyster population estimation effort (Table 1).

Results from the MD DNR survey confirmed anecdotal reports of significant loss of available oyster habitat within Maryland over the past 20 years. Only 2.37% of high quality oyster bottom habitat reported by the MBBS remained. Of the remaining high quality bottom habitat defined by the MBBS, 26.80% had degraded to low quality bottom classification consisting of heavily sedimented shell with sand or mud, and 68.58% was completely lost to sand or mud (Table 1). Overall, there was a 70.83% decline of available oyster habitat within the high quality bottom classifications defined by the MBBS. Given the significant level of habitat degradation on the high quality bottom since the MBBS was conducted, these population estimate calculations assumed a complete loss of low quality habitat identified in the MBBS survey.

MBBS-based adjustments to high quality habitat could not be applied to certain sections of Eastern Bay or the Choptank River (Broad Creek and Harris Creek) due to missing MBBS data. Therefore, oyster bar boundaries from the 1906-1911 Yates survey were used in these two areas (Table 1). The 1999-2000 MD DNR survey found that 85.88% of the charted oyster bars from the Yates survey have been lost to mud or sand. Only 0.95% of the charted Yates oyster bars fit the criteria for high quality and 11.29% meet low quality bottom habitat criteria. Habitat degradation of the charted Yates bars was more significant than the results based upon an assessment of the MBSS. This was expected given the earlier time period of the Yates Survey. These habitat adjustments were applied like the MBSS adjustments.

Significant amounts of fossil dredge shell and, to a lesser extent, shell retrieved from oyster packing houses have been planted in Maryland waters of Chesapeake Bay over the past four decades. The 1999-2000 MD DNR survey included an assessment of length of time after planting that fossil shell and shell from packing houses were suitable oyster habitat. Results indicated that shell plantings became moderately sedimented after an average of 5.5 years and heavily sedimented after an average of 18.6 years. For the purpose of estimating and assessing habitat for the biomass calculations, it was determined that only shell plantings 5 years old or less would be included in habitat estimates (Smith et al. 2005). Any GIS polygons designated as low quality habitat after adjustments to the MBBS and Yates surveys adjustments that overlapped shell plantings 5 years old or less were re-classified as high quality habitat. This did not result in an increase in the total amount of habitat, but simply changed the preliminary bottom classification. Total habitat only increased when the shell plantings did not overlap adjusted MBBS and Yates habitat polygons. These population estimates assumed that 1999-2003 shell plantings were constant throughout the 1994-2006 time period.

Leased oyster bottom within Maryland is another potential source of available habitat. Maryland leases are not legally permitted on charted oyster bottom, and therefore, should not overlap any habitat derived from the MBBS and Yates surveys. Because leases cannot legally occur on natural oyster bottom, lease holders commonly plant shell substrate to enhance spat settlement and/or support seed plantings. Maryland lease harvest data were reviewed to determine the level of lease activity. The average lease harvest was 1,424 bushels between 2000 and 2004 and 3,767 bushels between 1990 and 1999 (MD DNR 2005). Based on this level of activity, it was assumed that there were little or no remaining shell plantings on lease grounds over the past 5 years. Given the functional longevity of shell plantings reported by MD DNR's Cooperative Oxford Laboratory, it was further assumed that any plantings prior to 2000 were no longer providing any suitable oyster habitat

Table 2 presents the sequence of calculated values in the estimation of available oyster habitat for the Choptank River basin. Table 3 presents a summary of estimates of high and low quality habitat for all eight basins delineated in this study.

Assumptions for Step 2

1. The degradation of oyster bottom habitat reported in the MD DNR 1999-2000 survey was representative of all bars within Maryland's portion of the Chesapeake Bay.

2. There was a complete loss of available oyster habitat within the "mud with cultch" and "sand" bottom classifications reported by the MBBS survey.

3. The amount of available high and low quality habitat remained constant throughout the 1994-2006 time series.

4. Shell plantings did not provide suitable oyster habitat after 5 years.

5. Shell plantings between 1999 and 2003 were representative of shell plantings between 1994 and 2006.

6. Maryland leases did not provide any suitable oyster bottom habitat between 1994 and 2006.

2.0 Step 3 – Estimation of Oyster Density in High and Low Quality Habitat

Oyster density estimates for high quality habitat

For high quality habitat, annual estimates of oyster density were calculated using data collected in the Maryland DNR Fall Oyster Dredge Survey (Fall Survey) and estimates of the average tow area and efficiency of the oyster dredge used to collect data in the survey. Maryland's Fall Survey collects oyster size and abundance data at 43 sentinel stations located throughout Maryland's Chesapeake Bay. Bushel count data collected in 2004 and basin averages are presented in Table 4. A detailed description of the survey can be found in the MD DNR report for the 2003 and 2004 Fall Surveys (MD DNR, 2005).

The Fall Survey provides number of oysters per bushel of dredged material. In order to convert number of oysters per bushel of dredge material to number of oysters per m^2, area swept to collect 1 bushel and the average efficiency of the dredge are needed. Historically, data on the Fall Survey dredge tow area was not recorded. Despite this limitation, the Fall Survey data are believed to be the best available data for estimating Maryland's oyster population. As a result, a study was conducted in 2001 and 2002 in order to study tow area of the dredge (unpublished MDNR study, 2002). The average tow area for collecting a one bushel sample of material was estimated to be 45 m^2. The original data used to develop this estimate are unavailable, so variance cannot be assigned.

A study of dredge efficiency initiated by MD DNR in 2001 estimated an average dredge efficiency of 10% (unpublished MDNR study, 2002).

Oyster density on high quality habitat (DH) for each basin was estimated as follows:

$$DH = ((BCbasin/(DE * TA))*M \qquad \text{(Eqn 1)}$$

where:

DH = oyster density (oysters/acre)

BC_{basin} = annual basin average of small and market oysters per bushel of cultch material (oysters/bushel), as determined from the Fall Survey.

DE = dredge efficiency (0.10)

TA = tow area/bu (45 m^2/bu)

M = conversion factor (4046.856 m^2/acre)

An example of estimating oyster density on high quality habitat for the Chester River in 2004 is provided below. Note that the mean bushel count (BC) is the only variable input parameter in these calculations.

Oysters/acre = ((59.5 oysters/bu)/(0.10*45m^2/bu)*4046.856m^2/acre = 53,509 oysters/acre *(Eqn. 2)*

where:

BC = mean bushel count

Chester River Site 1: Buoy Rock = 34 oysters/bushel

Chester River Site 2: Old Field = 85 oysters/bushel

Mean bushel count = 59.5 oysters/bushel

Oyster density estimates for low quality habitat.

Density estimates used for low quality habitat are not well documented. For the period 1994-2001, the mean oyster density was 2.02 oysters/m^2 (personal communication, J. Vanisko).

The 2.02 oysters/m^2 density used is believed to be based upon data from a 1994 patent tong survey of areas categorized as "mud with cultch" and "sand with cultch" by the MBBS. The researchers could not recall the basis for the 2002 oyster density estimate of 0.36 oyster/m^2. We assumed that the reduction was made to account for the increase in disease mortality in recent years.

Examples of estimating oyster density on low quality habitat for the Chester River before/after 2002 are provided below.

Before 2002: Oysters/acre = 2.02 oysters/m^2*4046.856 m^2/acre = 8,175 oysters/acre
(Eqn. 3)

2002 and later: Oysters/acre = 0.36 oysters/m^2*4046.856 m^2/acre = 1,457 oysters/acre
(Eqn. 4)

Assumptions for Step 3

1. Oyster abundance statistics developed from data collected by the Fall Survey were representative of the associated basins.

2. The Fall Survey provided a representative sample of the classified high quality habitat within each basin, including natural oyster bars, managed oyster harvest reserves and oyster sanctuaries.

3. The defined dredge tow area for obtaining one bushel of sample material in the Fall Survey was representative and consistent throughout the 1994-2006 time series.

4. The defined dredge efficiency of the Fall Survey was representative and consistent throughout the 1994-2006 time series.

5. Oyster densities for low quality habitat derived from a 1994 patent tong survey were representative and consistent from 1994-2001.

6. Oyster density defined for low quality habitat in 2002 was representative and consistent from 2002-2006.

Step 4 – Calculation of the Estimated Oyster Population in MD Chesapeake Bay

The estimated density of oysters on high and low quality habitat for each basin was multiplied by the estimated amount of high and low quality habitat for each basin. Table 5 provides an example of the values in this calculation for the Chester River Basin in 2004.

The annual estimate of Maryland's Chesapeake Bay oyster population was calculated as the sum of the annual populations for Maryland's eight basins (Figure 2). Summary statistics from the 2004 calculation are presented in Table 6.

Step 5 – Calculation of Estimated Oyster Biomass in MD Chesapeake Bay

The estimated annual biomass of small and market oysters for each basin was calculated in two steps. In order to distribute the population among size groups, the total estimated number of small and market oysters for each basin was multiplied by the relative abundance within each 5-mm size class ≥ 35 mm. The relative abundance values were taken from the Fall Survey. This distribution was converted to biomass (grams per dry tissue weight) by the formula given below:

log(10) weight = -3.7595 + 2.062584 * log(10) size class (Jordan et al. 2002) (*Eqn 5*)

where:

size class = length in mm of the midpoint of a given size class

Total biomass was calculated as the sum of biomass in all size classes for all basins.

RESULTS

The 1994 baseline population of small and market sized oysters in Maryland Chesapeake Bay was estimated to be 582 million oysters. The biomass estimate was 1.1 million grams dry tissue weight. Maryland's oyster population remained at a relatively stable but historically low level of abundance between 1994 and 2000. In 2001, the population experienced another significant decline in response to increased disease mortality due to a multiple-year drought. The population has remained at this low level of abundance since 2001 (Figure 2, Table 7). Maryland's 2006 oyster population estimate is 59% (based on number of oysters) and 63% (based on oyster biomass) below the 1994 baseline period which was established for measuring progress towards achieving a 10-fold oyster population increase.

DISCUSSION

The methodology presented in this report was developed through an interstate research project jointly funded in 2000 by the National Oceanic and Atmospheric Administration Chesapeake Bay Stock Assessment Committee and U.S. Environmental Protection Agency Chesapeake Bay Program to estimate the 1994 baseline population of oysters and to develop a methodology for producing annual oyster population estimates that could be used to measure progress toward achieving the Chesapeake Bay 2000 Agreement goal of increasing the Chesapeake Bay oyster population 10-fold from its 1994 level of abundance by 2010. This methodology is based upon several critical assumptions that are identified in this report.

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Table 1. Relative abundance of high quality bottom classifications remaining from the values reported by the MBBS and Yates surveys, as reported by the 1999-2000 MD DNR Cooperative Oxford Laboratory acoustic benthic habitat survey.

Habitat Classification	Bottom Classification	MBBS	Yates
		Percent Remaining	
High Quality Habitat	Clean shell	1.16	0.62
	Lightly sedimented shell with sand	1.21	0.33
	Total	**2.37**	**0.95**
Low Quality Habitat	Heavily sedimented shell with mud	21.64	8.33
	Heavily sedimented shell with sand	5.16	2.96
	Total	**26.80**	**11.29**
Total Habitat	**Total**	**29.17**	**12.24**
Habitat Lost	Mud	20.58	32.52
	Sand	48.00	53.36
	Total	**68.58**	**85.88**
Other	Gravel/cobble/boulder	1.37	1.06
	Unidentified	0.88	0.82

Table 2. Values from the 2004 oyster habitat estimate for the Choptank River basin.

Choptank River Basin	Bottom Class	Original Estimate	Adjustment Factor	Current Estimate of High Quality Habitat	Current Estimate of Low Quality Habitat
MBBS	High Quality	14,397.42 acres*	2.37%	340.18 acres	
			26.80%		3,859.55 acres
	Low Quality		0%		
Yates	Not specified	1,028.43 acres*	0.95%	10.20 acres	
			11.29%		115.68 acres
Shell Plantings	High Quality	164.32 acres	0 %	164.32 acres	
Leased Bottom	Not specified		0%		

* Value may vary by a maximum of 1.12 acres due to differences in decimal precision in software employed.

Table 3. Acreages for each habitat type in each basin. Total acreage shown in bold text were used to calculate the annual Maryland oyster population from 1994 – 2006.

Basin	Habitat Type*	High Quality Habitat (ac)	Low Quality Habitat (ac)	Sum
CHESTER	B	126.27	1,432.65	1,558.92
	P	481.23	0.00	481.23
Total		**607.50**	**1,432.65**	2,040.15
CHOPTANK	B	340.18	3,859.55	4,199.73
	P	164.32	0.00	164.32
	Y	10.20	115.68	125.88
Total		**514.70**	**3,975.23**	4,489.93
EASTERN BAY	B	76.28	865.48	941.76
	P	192.11	0.00	192.11
	Y	58.09	659.11	717.20
Total		**326.48**	**1,524.59**	1,851.07
LITTLE CHOPTANK	B	79.36	900.41	979.77
	P	1.00	0.00	1.00
Total		**80.36**	**900.41**	980.77
MD MAINSTEM	B	1,111.05	12,605.65	13,716.70
	P	684.33	0.00	684.33
Total		**1,795.38**	**12,605.65**	14,401.03
MD POTOMAC	B	300.31	3,407.26	3,707.57
	P	12.86	0.00	12.86
Total		**313.17**	**3,407.26**	3,720.43
PATUXENT	B	129.24	1,466.32	1,595.56
	P	56.25	0.00	56.25
Total		**185.49**	**1,466.32**	1,651.81
TANGIER	B	563.15	6,389.26	6,952.41
	P	56.89	0.00	56.89
Total		**620.04**	**6,389.26**	7,009.30
Grand Total				36,144.49

* Habitat codes are as follows:

B = Maryland Bay Bottom Survey

P = shell plantings

Y = Yates survey

Table 4. Small- and market-size oysters per bushel of cultch material in samples collected by the 2004 MD DNR Fall Oyster Survey.

Basin	Water Body	Oyster Bar	Site Code	Oysters/Bu	Basin Average
Chester	Chester River	Buoy Rock	CHBR	34	59.5
	Chester River	Old Field	CHOF	85	
Choptank	Broad Creek	Deep Neck	BCDN	48	24.88
	Choptank River	Cook Point	CRCP	1	
	Choptank River	Lighthouse	CRLI	8	
	Choptank River	Oystershell Point	CROS	20	
	Choptank River	Royston	CRRO	43	
	Choptank River	Sandy Hill	CRSH	20	
	Choptank River	Tilghman Wharf	CRTW	39	
	Tred Avon River	Double Mills	TADM	20	
Eastern Bay	Eastern Bay	Bugby	EBBU	64	80.83
	Eastern Bay	Hollicutts Noose	EBHN	96	
	Eastern Bay	Parsons Island	EBPI	57	
	Miles River	Bruffs Island	MRBI	74	
	Miles River	Long Point	MRLP	42	
	Miles River	Turtle Back	MRTU	152	
Little Choptank	Little Choptank	Cason	LCCA	27	22.50
	Little Choptank	Ragged Point	LCRP	18	
Mainstem	Bay North	Swan Point	BNSP	37	57.57
	Middle Bay	Stone Rock	MESR	54	
	Upper Bay	Hacketts	UBHA	76	
	Western Shore	Butlers	WSBU	123	
	Western Shore	Flagpond	WSFP	34	
	Western Shore	Hog Island	WSHI	74	
	Western Shore	Holland Point	WSHP	5	
Patuxent	Patuxent River	Broome Island	PXBI	17	17.0
Potomac	Potomac River	Cornfield Harbor	PRCH	54	56.57
	Potomac River	Lower Cedar Point	PRLC	18	
	Potomac River	Ragged Point	PRRP	0	
	St. Mary's River	Chickencock	SMCC	67	
	St. Mary's River	Pagan	SMPA	214	
	Wicomico River	Lancaster	WWLA	27	
	Wicomico River	Mills West	WWMW	16	
Tangier	Fishing Bay	Goose Creek	FBGC	7	75.20
	Holland Straits	Holland Straits	HOHO	151	
	Honga River	Normans	HRNO	12	
	Manokin River	Georges	MAGE	176	
	Nanticoke River	Wilson Shoal	NRWS	33	
	Pocomoke Sound	Marumsco	PSMA	106	
	Tangier Sound	Back Cove	TSBC	120	
	Tangier Sound	Old Womans Leg	TSOW	7	
	Tangier Sound	Piney Island	TSPI	85	
	Tangier Sound	Sharkfin Shoal	TSSS	55	

Table 5. Habitat and density data for the 2004 Chester River oyster population estimate.

Habitat Quality	Estimated Oyster Density (oysters/m^2)	Estimated Oyster Density (oysters/acre)	Estimated Available Habitat (acres)	Estimated Oyster Population (# of oysters)
High	59.50	53,508.65	607.50	32,506,371
Low	0.36	1,456.87	1432.65	2,087,182

Table 6. Input data and estimates of the 2004 oyster population by basin and for all basins combined.

		Chester	**Eastern Bay**	**Choptank**	**Little Choptank**	**Tangier Sound**	**Potomac**	**Patuxent**	**Mainstem**	**Total**
Habitat (ac)										
High quality										
	MBBS	126.27	76.28	340.18	79.36	563.15	300.31	129.24	1111.05	2,725.84
	Yates	0	58.09	10.20	0	0	0	0	0	68.29
	Shell plantings	481.23	192.11	164.32	1.00	56.89	12.86	56.25	684.33	1,648.99
	Leased bottom	0	0	0	0	0	0	0	0	0
Total		607.5	326.48	514.70	80.36	620.04	313.17	185.49	1795.38	4443.12
Low quality										
	MBBS	1432.65	865.48	3859.55	900.41	6389.26	3407.26	1466.32	12605.65	30,926.58
	Yates	0	659.11	115.68	0	0	0	0	0	774.79
	Shell plantings	0	0	0	0	0	0	0	0	
	Leased bottom	0	0	0	0	0	0	0	0	
Total		1432.65	1524.59	3975.23	900.41	6389.26	3407.26	1466.32	12605.65	31701.37
Density (oysters/m^2)										
	on high quality habitat	13.22	17.96	5.53	5.00	16.71	12.57	3.78	12.79	
	on low quality habitat	.36	.36	.36	.36	.36	.36	.36	.36	
Population										
	on high quality habitat	32,506,370.82	23,732,981.86	11,513,901.11	1,626,026.74	41,931,730.46	15,932,448.95	2,835,793.87	92,954,116.29	223,033,370.10
	on low quality habitat	2,087,182.17	2,221,126.63	5,791,386.02	1,311,778.66	9,308,309.46	4,963,928.61	2,136,234.92	18,364,770.12	46,184,716.58
Total Basin Population		34,593,552.99	25,954,108.49	17,305,287.12	2,937,805.40	51,240,039.92	20,896,377.55	4,972,028.79	111,318,886.41	269,218,086.68

Table 7. Maryland Oyster Population Estimates by Basin (1994-2006)

	Chester	Eastern Bay	Choptank	Little Choptank	Tangier Sound	Potomac	Patuxent	Mainstem	Total
1994	60,061,223.12	24,892,220.04	97,124,389.50	16,683,089.13	139,327,515.80	64,586,301.14	13,321,142.73	173,281,327.49	589,277,208.95
1995	58,422,246.44	21,662,577.15	89,082,016.36	20,657,821.16	102,023,888.56	72,673,225.99	17,491,427.84	180,316,316.44	562,329,519.95
1996	64,158,664.82	30,911,099.97	93,479,285.13	18,309,115.87	86,578,291.04	55,050,971.85	18,492,296.27	206,611,029.24	573,590,754.19
1997	101,581,965.68	29,002,674.63	77,163,103.66	14,225,982.05	83,176,913.97	63,017,196.32	18,992,730.48	163,939,784.79	551,100,351.58
1998	108,684,197.96	116,790,240.52	118,127,133.73	17,911,642.67	78,548,810.74	83,254,625.16	17,658,239.24	181,238,937.94	722,213,827.97
1999	109,503,686.30	70,596,560.36	106,555,373.82	16,827,624.84	95,165,374.14	51,751,828.38	18,492,296.27	192,771,706.71	661,664,450.83
2000	107,318,384.06	53,371,798.27	88,677,004.77	17,803,240.88	87,191,654.12	45,394,942.19	24,831,129.63	166,015,683.17	590,603,837.08
2001	51,802,808.13	23,018,069.50	38,770,901.75	5,647,849.97	36,184,764.36	15,987,895.81	3,971,160.37	81,794,998.36	257,178,448.23
2002	23,667,041.79	15,433,302.10	14,701,641.14	1,528,582.23	43,210,559.62	9,711,476.53	4,471,594.58	70,031,574.21	182,755,772.20
2003	39,510,483.03	18,809,746.94	13,775,900.35	2,287,394.70	86,759,338.20	38,478,398.24	10,977,239.35	63,573,223.70	274,171,724.51
2004	34,593,552.99	25,954,108.49	17,305,287.12	2,937,805.40	51,240,039.92	20,896,377.55	4,972,028.79	111,318,886.41	269,218,086.68
2005	33,774,064.65	25,905,174.51	30,265,658.22	3,226,876.82	29,437,770.49	14,096,923.33	7,307,388.45	141,996,051.34	286,009,907.81
2006	36,778,855.23	19,690,558.64	30,902,105.01	4,419,296.43	23,415,660.27	15,746,495.07	9,475,936.71	96,556,942.38	236,985,849.74

Table 8. Maryland Oyster Biomass Estimates by Basin (1994-2006)

	Chester	Eastern Bay	Choptank	Little Choptank	TangierSound	Potomac	Patuxent	Mainstem	Total
1994	100,604,202	42,492,811	89,003,017	58,934,152	114,605,118	33,526,888	27,440,701	609,560,420	1,076,167,309
1995	83,018,760	36,564,486	107,353,882	21,951,048	115,619,792	74,609,509	30,259,873	272,420,755	741,798,106
1996	84,401,894	33,925,831	118,572,292	21,735,808	112,748,480	68,748,028	24,039,045	259,758,883	723,930,262
1997	116,205,172	40,108,786	113,908,877	19,006,144	123,478,596	86,500,348	38,790,667	271,806,654	809,805,244
1998	126,640,415	108,261,204	127,855,090	23,603,996	120,699,104	97,199,120	40,131,468	239,120,894	883,511,292
1999	168,252,067	84,869,759	138,946,576	21,301,739	122,908,065	60,204,250	48,857,214	283,108,217	928,447,887
2000	151,286,084	77,214,467	132,172,207	20,039,015	80,800,250	50,947,144	33,327,946	272,765,205	818,552,319
2001	83,792,975	36,420,227	57,078,960	6,776,996	41,429,392	20,935,500	5,434,841	110,525,021	362,393,912
2002	46,141,627	21,617,947	26,480,472	2,000,058	40,872,830	15,292,220	8,809,732	109,005,021	270,220,086
2003	68,103,750	26,515,210	20,581,190	1,493,491	76,380,446	22,077,915	8,655,666	74,869,463	298,677,131
2004	51,407,440	34,581,494	26,750,684	2,964,143	64,446,800	19,018,801	6,208,066	159,467,442	364,844,871
2005	62,418,078	36,978,617	41,481,615	4,224,597	47,944,247	23,701,085	13,173,224	207,064,520	436,985,983
2006	81,982,665	33,809,416	48,614,516	5,899,524	41,059,409	29,945,828	13,712,229	144,731,010	399,754,597

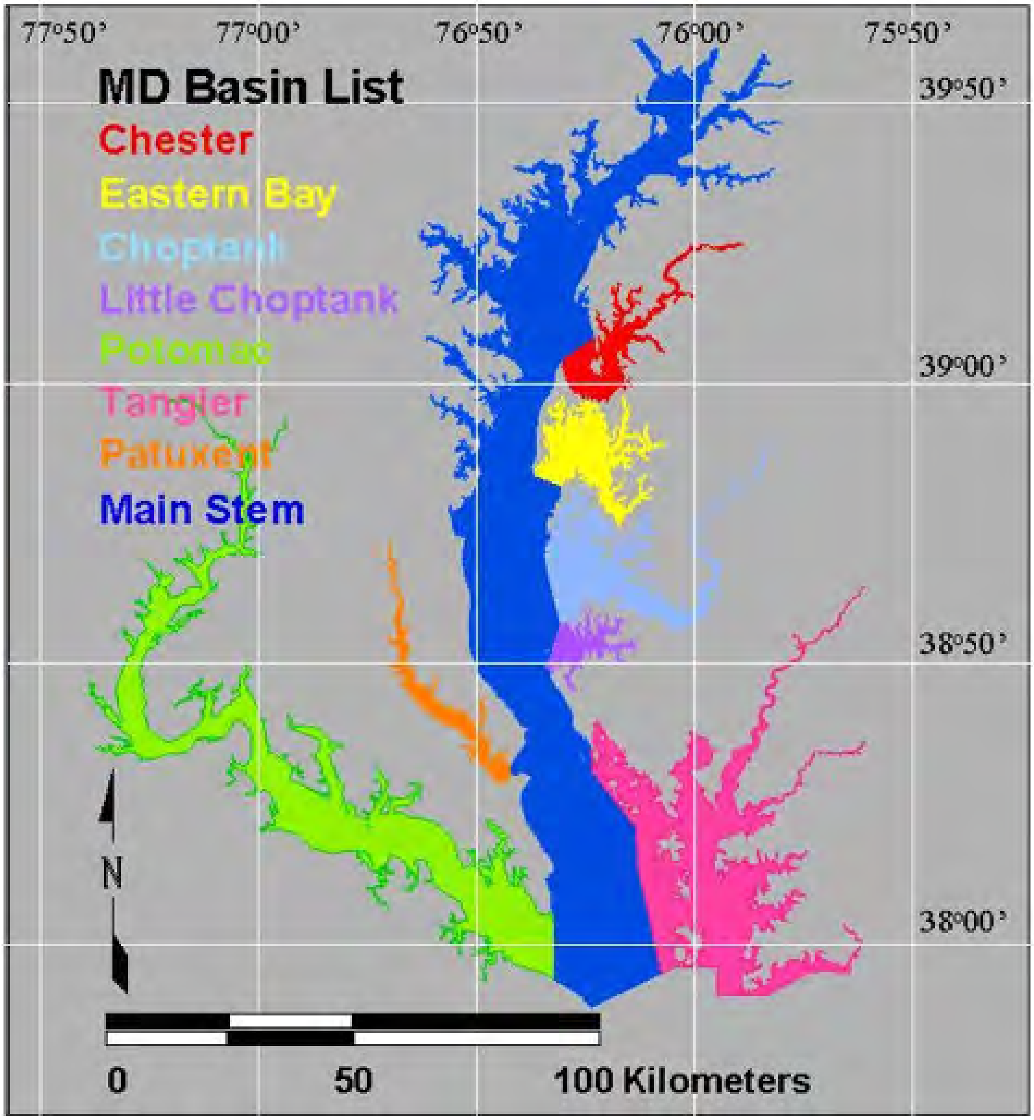

Figure 1. Map showing the 8 Maryland basins used in oyster population estimates.

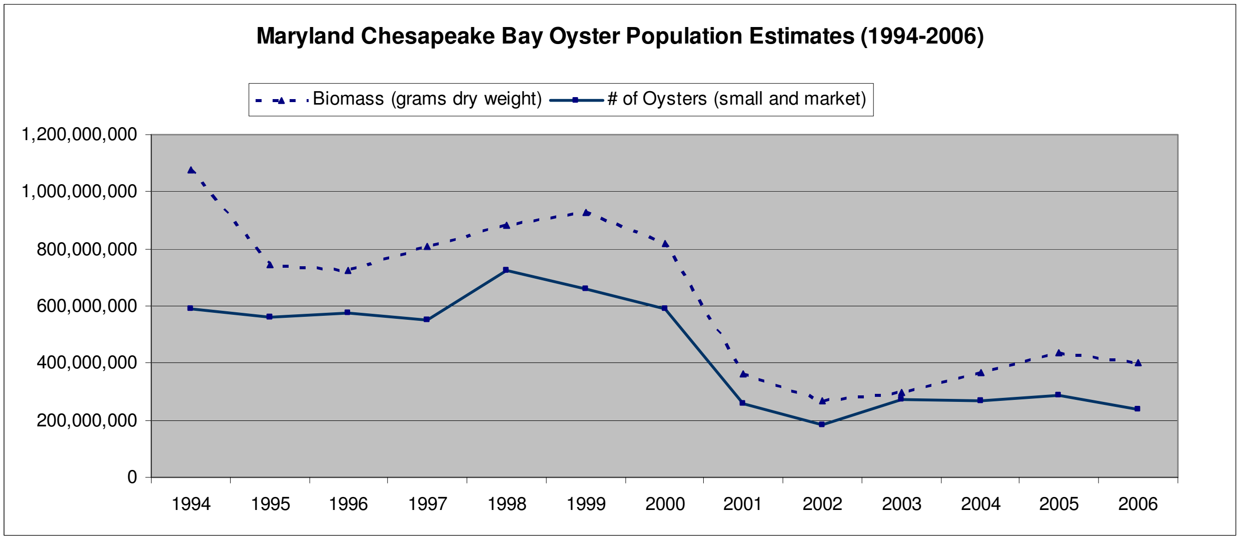

Figure 2. Maryland Chesapeake Bay Oyster Population Estimates (1994-2006)

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Attachment 3

Development of Starting Population

(Barker 2007)

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Spatially Distributed Estimate
of the 2004 Maryland Chesapeake Bay
Population of Crassostrea virginica

Linda S. Barker
Maryland DNR Fisheries Service
March 14, 2007

Introduction

The Maryland Department of Natural Resources (MdDNR), the Army Corps of Engineers (Norfolk district) and the Virginia Marine Resources Commission (VMRC) are the lead agencies in preparing an Environmental Impact Statement (EIS) to evaluate several native and non-native oyster restoration alternatives for Chesapeake Bay. The overall purpose of the EIS is to evaluate alternatives that may restore the ecological and economic benefits of the oyster resource in Chesapeake Bay.

The University of Maryland and Versar, Inc. have been tasked with modeling to support the ecological risk assessment component of the EIS. The model will be used to estimate the probability of achieving the stated goal of re-establishing an oyster population comparable to that observed during the 1920 - 1970 time period. The model is intended to be both spatially and temporally explicit, since several parameters vary over space or time. MdDNR has agreed to supply a spatially distributed estimate of the 2004 population of oysters in Maryland's portion of Chesapeake Bay as the starting point for the model.

This document describes the methods used to determine the spatial distribution and site-specific size composition of the estimated 2004 Maryland Chesapeake Bay oyster population. The starting point for this exercise is the estimate of the 2004 population of "small"- and "market"-size oysters for each of eight basins. The final product was a file of total oyster population (including spat), distributed by 5-mm groups on the bars in the Maryland portion of Chesapeake Bay in 2004 (a matrix of 2115 bars and 28 5-mm height groups).

Methods

The spatially- and size-distributed 2004 Maryland Chesapeake Bay oyster population was calculated in three steps:

Estimation of the 2004 Maryland Chesapeake Bay population of "small-" and "market-"size oysters as reported by MdDNR for the Chesapeake Bay Oyster Population Estimation (Greenhawk and O'Connell 2007).

Expansion of the 2004 Maryland Chesapeake Bay oyster population to include spat, apportioned among NOAA regions.

Distribution of each NOAA region's total oyster population among its bars by 5-mm height groups.

Check of the final answer file consisted of mathematical examination of the values and patterns in the final matrix and subjective consideration of the spatial pattern of population density.

Estimation of the number of "small-" and "market-"size oysters on each oyster bar in Maryland's portion of Chesapeake Bay in 2004 .

The estimated 2004 Maryland Chesapeake Bay "small-" and "market-" size oyster population was supplied by MdDNR Fisheries Service staff. Methods used to develop this estimate are found in Greenhawk and O'Connell (2007).

The basin-specific oyster population and available habitat estimates presented in Greenhawk and O'Connell (2007) were used to calculate oyster density (oysters/acre) as follows. The oyster population in each basin was divided by the amount of available oyster habitat in that basin. The mean oyster density in each basin was then multiplied by each bar area to produce a file of the "small-" and "market-" size oyster population distributed among bars.

Expansion of the 2004 Maryland Chesapeake Bay oyster population to include spat, apportioned among NOAA regions.

Development of representative height frequencies for each NOAA region

The annual MdDNR Fall Oyster Survey samples approximately 400 oyster bars in Maryland's portion of Chesapeake Bay from October through December of each year (Tarnowski, 2005). A subset of these, the "Modified Fall Survey" (MFS) sites, have been deemed representative of the Bay population. Additional measurements are taken at these sites, including oyster counts by 5-mm size group and counts of spat.

One half of the NOAA regions had at least one appropriate MFS site. For those NOAA regions without a MFS site, the closest MFS site in a similar environmental setting was assigned to provide the representative height frequency. For NOAA regions with more than one MFS site, the pooled absolute counts for each height class were used to develop the representative height-frequency distribution.

It should be noted that the NOAA region coding used in this analysis is the "new" system, provided by the NOAA Northeast Fisheries Science Center. This system was used because it encompasses both Maryland and Virginia, enabling the modelers to use a consistent coding system in later work.

Estimation of total population (including spat) for each bar

Since the population values supplied by Greenhawk and O'Connell (2007) included only "small- and market"-size oysters, the next step in the analysis was to "scale up" these values to include spat. A population multiplier was developed for each NOAA region to calculate the total population (including spat). The 5-mm height frequency data for each NOAA region specifically identified spat. The 5-mm height-class data were collapsed into two groups (small <75 mm and market >75 mm) to produce a height frequency of spat, small- and market-size (SSM) oysters. Population multipliers were developed at the NOAA-region scale and were then applied to produce total population for each bar within the NOAA regions as follows:

$$\text{Population Multiplier} = \frac{\text{Spat Count} + \text{Small Count} + \text{Market Count}}{\text{Small Count} + \text{Market Count}} \quad \text{Eqn 1.}$$

$$\text{Total Population} = \text{Population Multiplier} * \text{Small \& Market Population} \quad \text{Eqn 2.}$$

Distribution of each NOAA region's total population among its bars by 5-mm height groups.

The absolute frequency of each bar's total population was a straightforward multiple of the absolute population and the appropriate relative height frequency. For every NOAA region, the associated MFS site provided counts of SSM oysters for each 5-mm height group. Each 5-mm height-group proportion was calculated by dividing the count of each height group by the total count. The final product was a file of total oyster population (including spat), distributed by 5-mm height groups on the oyster bars in Maryland's portion of Chesapeake Bay in 2004 (a matrix of 2115 bars and 28 5-mm height groups).

Checks.

Two checks were performed on the final distributed bar population. A cursory visual check was made to verify that the height-frequency distribution pattern was consistent throughout each NOAA region. Additionally, the "original" SSM population value used to develop the distributed population was compared to the sum of the 5-mm counts for each bar. The percent difference between these values was calculated. All percent differences were less than 2%, which was consistent with rounding error.

RESULTS AND DISCUSSION

Allocation of the basin populations among bars.

One source of error occurred during the distribution of the basin-scale "small"- and "market"-size population among bars. Since the total area of each basin was known, each bar could be assigned a portion of the basin population equal to its proportion of total basin area. However, this method neglected to consider habitat quality. Because the relative proportion of high and low quality habitat was known only at the basin scale, there were no means to allocate the quality ratings among bars within a basin.

Representative height frequencies

Between one and seven MFS sites were used to develop a representative height frequency for each NOAA region. For almost half of the 38 NOAA regions, there was no MFS site within the NOAA region boundaries (Figure 1, Table 1) so the closest MFS site in a similar environmental setting was assigned to provide the representative height frequency. In other NOAA regions where more than one MFS site was within the boundaries (Table 1), the representative height frequency was developed from the sum of counts in all height classes (Table 2). Although these are the best available data, the extent to which these height frequencies are representative of oysters within each bar in a given region is not known.

Graphical representation of the MFS height frequencies used with the most heavily populated NOAA regions are presented in Figures 2-4. These histograms not only demonstrate the variability among the MFS height frequencies, but also the variability of sample sizes.

2004 oyster population.

The 2004 Maryland Chesapeake Bay total population of small and market oysters was 269,218,086 (Greenhawk and O'Connell, 2007). This number increases to 291,751,774 oysters when spat are included. In this report, this population was distributed among 38 NOAA regions with 1 to 273 bars per region, for a final matrix of 28 5-mm height groups x 2115 bars. Table 3 provides the basic statistics on the bar populations and the aggregated NOAA populations.

Although this report provides the spatial distribution and the size composition of the 2004 oyster population in the Maryland portion of Chesapeake Bay, including spat, there are two limitations of note:

1.) The spatial variability portrayed was limited to the scale of each NOAA region.

2.) Total population estimates and height-frequency distributions were developed without variance estimates. Without the ability to assign measures of variance to these values, no associated measures of precision could be developed for our estimates.

ACKNOWLEDGEMENTS

This analysis could not have been performed without the technical expertise and support of Lisa Warner and Kelly Greenhawk of MdDNR. Thanks also to Mitchell Tarnowski and Luke Whitman of MdDNR for review and comments.

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Table 1. Assignment of Modified Fall Survey (MFS) sites within NOAA regions

NOAA	ASSOCIATED MFS SITE(S)	TITLE*
212	NONE - USE MAGE	
217	UBHA, WSHP, MESR, WSFP	4A
218	BNSP	
220	WSHI, WSBU, HOHO	2E
224	BCDN, TADM, CRTW, CRRO, CRCP,CRLI, CRSH	3B
225	CROS	
226	EBHN, EBPI, EBBU, MRBI	3A
228	FBGC	
230	NONE - USE WSHP	
231	HRNO	
232	NONE - USE TSSS	
235	LCRP, LCCA	2A
236	NONE - USE UBHA	
237	MAGE	
239	MRLP, MRTU	2B
243	CHBR, CHOF	1A
245	NRWS	
246	NONE - USE BNSP	
248	PXBI	
249	NONE - USE PXBI	
251	PSMA	
252	PRCH	
253	PRLC	
254	NONE - USE PRLC	
257	NONE - USE WWLA	
258	WWMW, WWLA	2F
268	NONE - USE UBHA	
270	NONE - USE SMCC	
271	NONE - USE UBHA	
273	SMPA, SMCC	2C
276	TSSS, TSPI, TSOW, TSBC	4C
279	NONE - USE NRWS	
308	NONE - USE WSBU	
346	NONE - USE PSMA	
358	NONE - USE TSOW	
380	USE PRCH	
381	USE PRLC	
382	NONE - USE PRLC	

* Where more than one MFS was assigned to a NOAA region, a title was assigned to the group.

Table 2. NOAA regions, associated MFS sites, spat, small- and market-size counts from the 2004 MdDNR Fall Oyster Survey, and population multiplier used to estimate total population (including spat).

NOAA code	MFS code	Spat Count	Small Count	Market Count	Population Multiplier
212	MAGE	4	149	27	1.02
217	4A	0	106	63	1.00
218	BNSP	0	3	34	1.00
220	2E	1	117	231	1.00
224	3B	206	92	87	2.15
225	CROS	0	1	19	1.00
226	3A	0	149	142	1.00
228	FBGC	0	1	6	1.00
230	WSHP	0	2	3	1.00
231	HRNO	0	6	6	1.00
232	TSSS	2	36	19	1.04
235	2A	7	41	4	1.16
236	UBHA	0	38	38	1.00
237	MAGE	4	149	27	1.02
239	2B	1	126	68	1.01
243	1A	1	64	55	1.01
245	NRWS	0	17	16	1.00
246	BNSP	0	3	34	1.00
248	PXBI	0	12	5	1.00
249	PXBI	0	12	5	1.00
251	PSMA	14	55	51	1.13
252	PRCH	0	32	22	1.00
253	PRLC	0	6	12	1.00
254	PRLC	0	6	12	1.00
257	WWLA	0	6	21	1.00
258	2F	0	14	29	1.00
268	UBHA	0	38	38	1.00
270	SMCC	2	61	6	1.03
271	UBHA	0	38	38	1.00
273	2C	8	274	7	1.03
276	4C	109	188	79	1.41
279	NRWS	0	17	16	1.00
308	WSBU	0	58	65	1.00
346	PSMA	14	55	51	1.13
358	TSOW	29	3	4	5.14
380	PRCH	0	32	22	1.00
381	PRCH	0	32	22	1.00
382	PRLC	0	6	12	1.00

Table 3. Basic statistics on 2004 Maryland Chesapeake Bay oyster population, by NOAA region and by bar.

	NOAA	bar
mean	7,677,678	137,944
median	2,839,501	25,759
min	18,678	461
max	41,026,637	8,838,600
SE	1,792,304	8,688

Figure 1. NOAA regions and locations of assigned MFS height frequency sites.

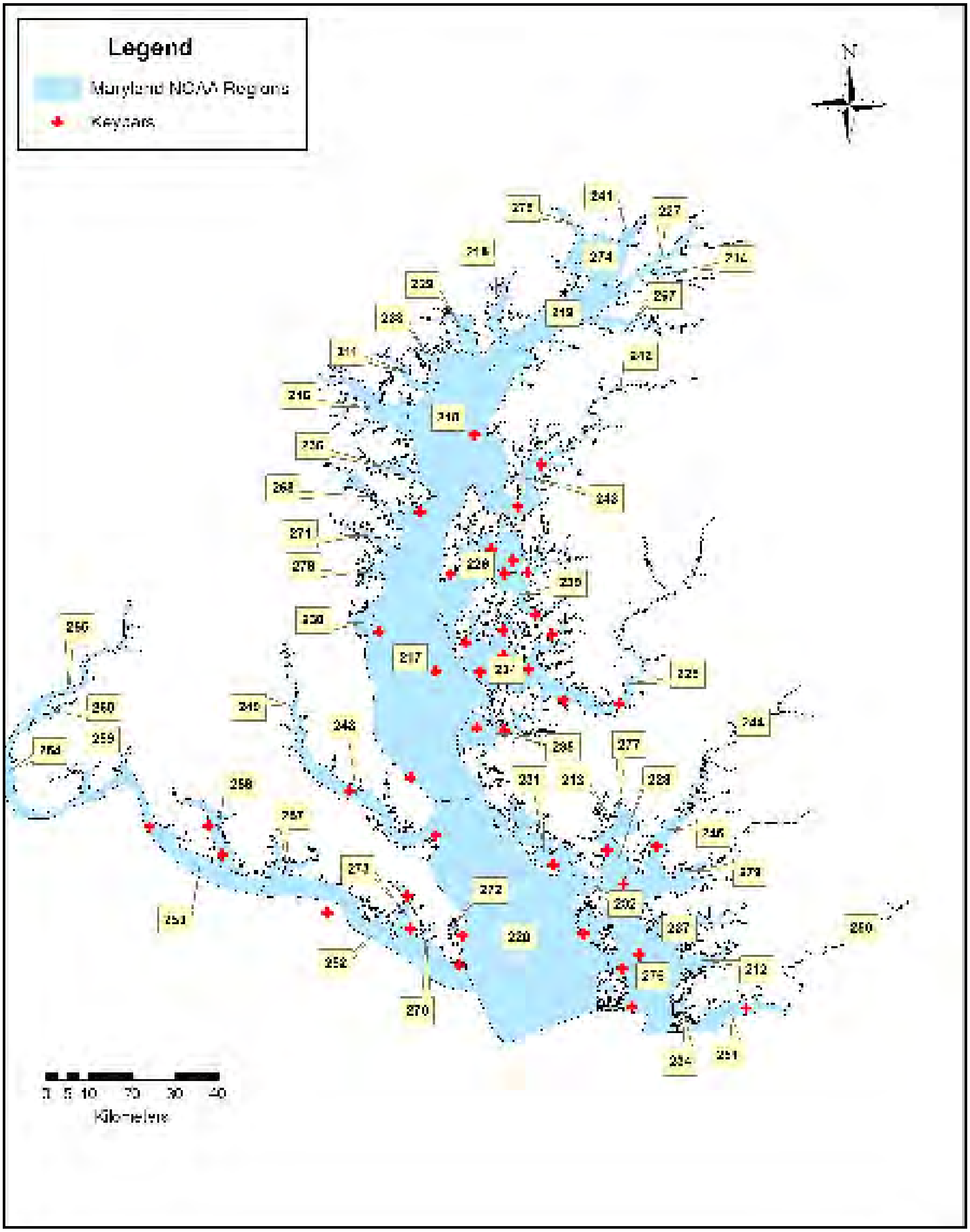


Figure 2. Height frequency for NOAA 217, population 4.10 x 107, representing 14% of the total Maryland Chesapeake Bay 2004 oyster population. Developed from length group totals of MFS sites UBHA, WSHP, MESR, WSFP (total n = 169).

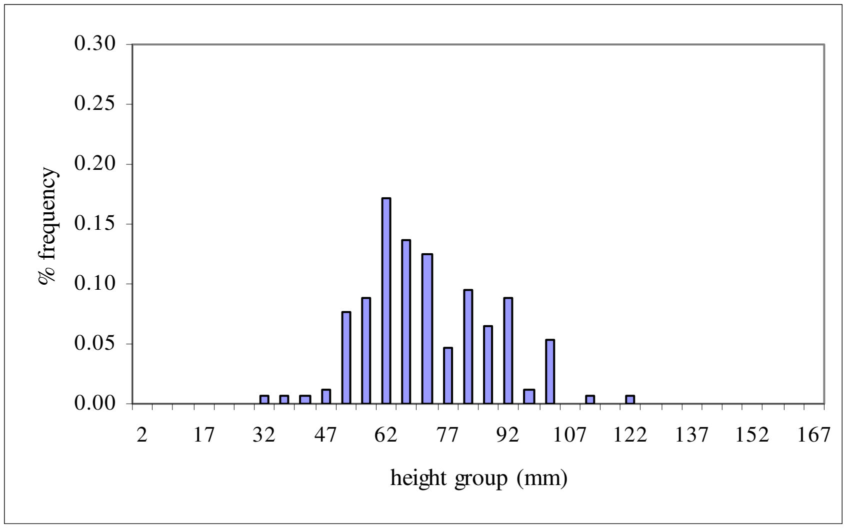


Figure 3. Height frequency for NOAA 218 and 246, total population 3.65 x 107, representing 13% of the total Maryland Chesapeake Bay 2004 oyster population. Developed from MFS site BNSP (n = 37).

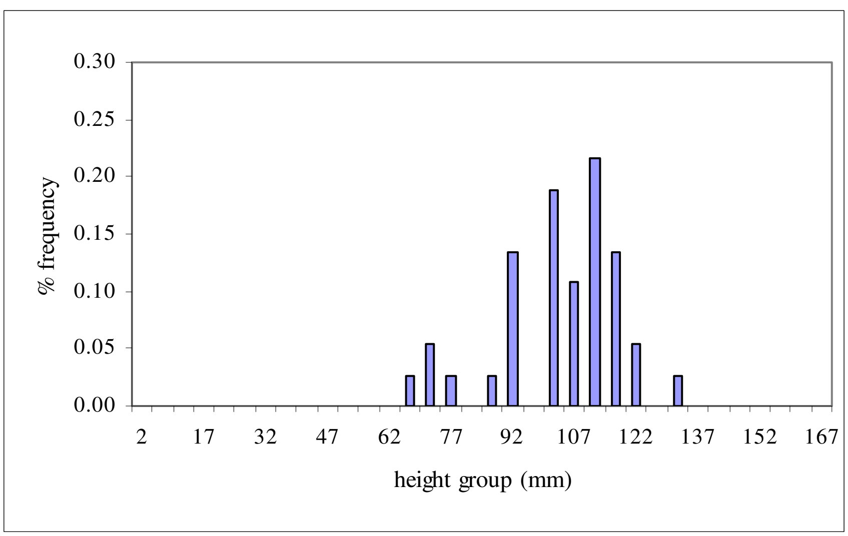


Figure 4. Height frequency for NOAA 235, total population 3.55 x 107, representing 12% of the total Maryland Chesapeake Bay 2004 oyster population. Developed from length group totals of MFS sites LCRP and LCCA (n = 52).

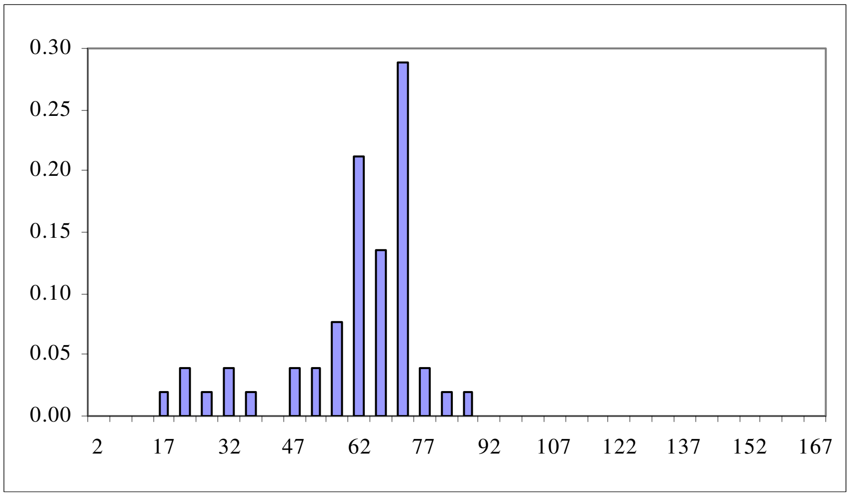
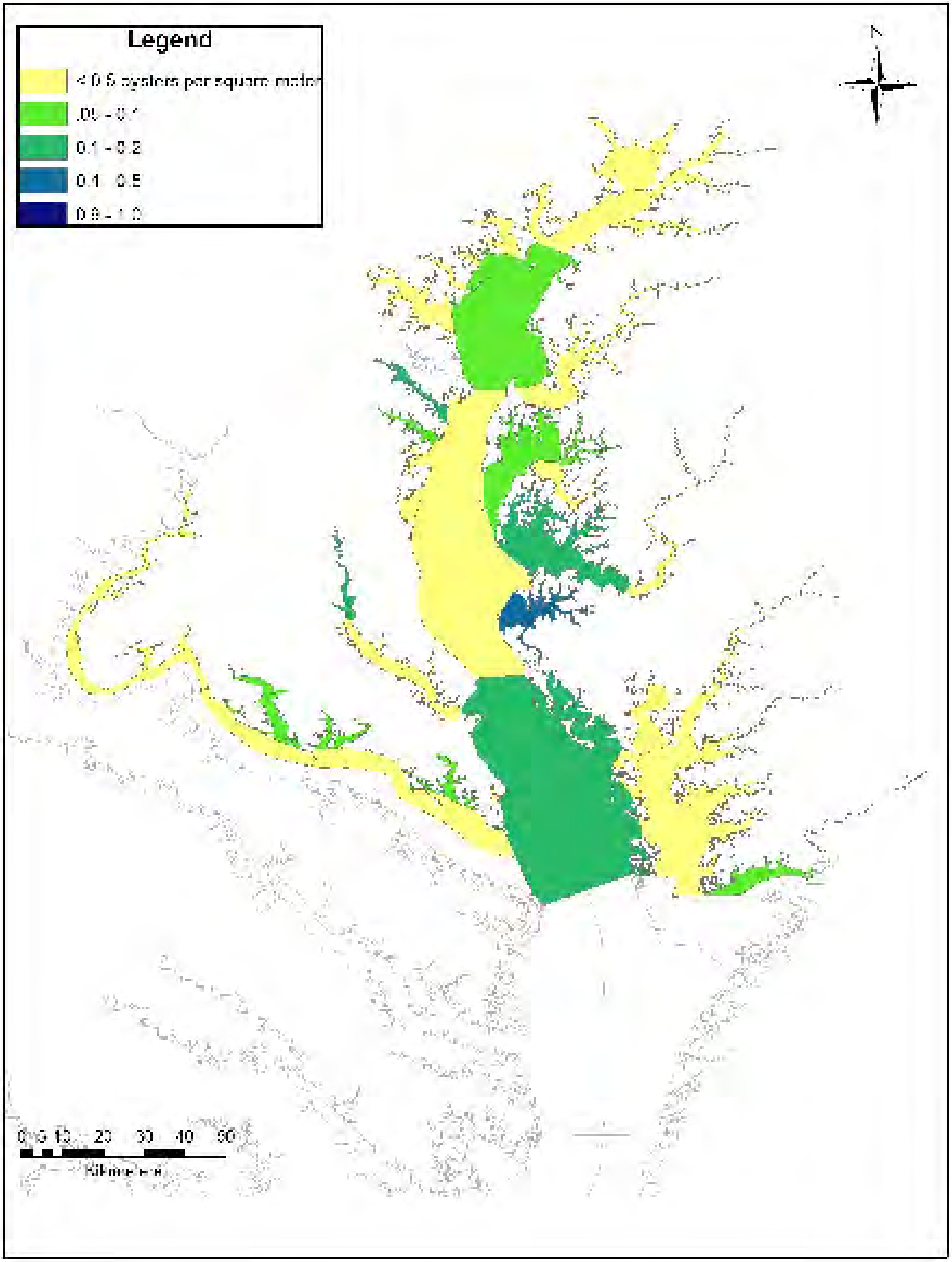


Figure 5. Maryland Chesapeake Bay 2004 Estimated Oyster Population Density by NOAA Region.



Addendum

Determining the Starting Population Size and Size Class Distribution for Virginia Oyster Reefs

J. Dew-Baxter, Versar, Inc.

The Barker report describes the methods used in establishing the starting population of oysters in Maryland. In order to derive a Bay-wide starting population, a similar estimate had to be derived for oysters in Viginia. Relevant information is available from the Chesapeake Bay Oyster Population Estimate web page[1] but not in terms of numbers of oysters per bar or by size class. A method was developed for deriving those figures. The 2004 Virginia Basin estimate of total number of oysters in Virginia (2.31E+09 oysters) was used to determine the total number of oysters on each oyster bar for each of the following river basins: Potomac and its tributaries, Great/Little Wicomico, Rappahannock, Piankatank, York and Mobjack, Poquoson and Back, James, Lynnhaven, and Tangier/Eastern Shore. The total number of oyster per basin was calculated by:

$Y_i = PZ_i$ * 2.31E+09

where: Y_i = the total number of oysters per basin, i, and

PZ_i = the proportion of oysters in the area sampled per basin calculated by:

$PZ_i = Z_i / \sum Z_i$

where: Z_i = the total number of oysters per basin in the area sampled, calculated by:

$Z_i = AO_i * A_i$

where: AO_i = the average density (number of oysters per square meters) in the area sampled per basin,

A_i = the total area sampled in each basin (square meters), and

The total number of oysters on each oyster bar was calculated by:

$N_{ij} = PA_{ij} * Y_i$

where: N_{ij} = the total number of oysters per oyster bar, j, and basin, i, and

PA_{ij} = the proportion of area of each oyster bar to the total area of all oysters bars in the basin calculated by:

$PA_{ij} = OBA_{ij} / BA_i$

where: OBA_{ij} = the area of each oyster bar in each basin, and

BA_i = the total oyster bar area of each basin

Various datasets provide by Roger Mann were used to determine the oyster size class distribution per bar. For the James River Basin, the proportion of oysters in each size class was determined by the average size class distribution of the 2004 James River dataset. For the Great/Little Wicomico, Rappahannock, and Piankatank Basins, the average size class distribution for 2004 data in these three basins was used. Because data was lacking in the Potomac and Eastern Shore/Tangier Basin, the size class distribution of the average Maryland Potomac oyster bars and Eastern Shore oysters bars was used. For the remaining basins, a size distribution of 30 mm for spat, 50 mm for smalls, and 76 mm for markets were used as suggested by Roger Mann and Juli Harding due to a lack of data.

Using this approach, the number of market size oysters in Virginia in 2004 was estimated to be 173,832,742. The revised estimate of number of market size oysters in Maryland in 2004 presented in Table 8 of Attachment 7 of this appendix 635,288,773. Estimated total number of market size oysters in the Chesapeake Bay in 2004 is thus 809.1 million.

[1] http://www.vims.edu/mollusc/cbope/VAPDFfiles/VABasin2004.pdf

Attachment 4

Estimation of Annual Mortality Rates for Eastern Oysters (*Crassostrea virginica*) in Chesapeake Bay Based on Box Counts and Application of Those Rates to Project Population Growth of *C. virginica* and *C. ariakensis*

(Vølstad, J. H., J. Dew, and M. Tarnowski, 2008, Journal of Shellfish Management, 27(3): 525-533)

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Estimation of annual mortality rates for eastern oysters (*Crassostrea virginica*)

in Chesapeake Bay based on box counts and application of those rates to project population growth of *C. virginica* and *C. ariakensis*

by

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Keywords: natural mortality, Crassostrea virginica, Crassostrea ariakensis, Chesapeake Bay, population model, ecological risk assessment

Abstract

In an effort to restore the ecological role of oysters in Chesapeake Bay and the economic benefits of a commercial fishery, the states of Maryland and Virginia are considering introducing the non-native Asian oyster (*Crassostrea ariakensis*) into the Bay. As part of an ecological risk assessment (ERA) to evaluate the proposed action and alternatives, demographic modeling is being employed to project the change in populations of both the Asian and the native eastern oyster (*C. virginica*) in the Bay across space and time. Annual mortality rates are vital input to the demographic model. We present two approaches for parameterizing mortality rates for *C. virginica* by salinity ranges and disease-intensity categories and discuss how these rates could be applied to project population growth for the Asian oyster. We estimated mortality rates from empirical data collected during annual dredge surveys of oyster beds in Maryland. We compared counts of recent boxes (dead oysters without fouling or sedimentation on the inner valve surfaces, including "gapers" of one or two weeks old with tissue remaining in the shell), old boxes (dead oysters without tissue remnants but with fouling, sedimentation or both on the inner valve surfaces), and live oysters in market-size and small classes. Our mortality estimates based on counts of recent boxes consistently differentiated between years with high disease intensity and those with low disease intensity, between wet and dry years, and between salinity zones. In contrast, traditional estimates of yearly mortality based on total box counts often were out of phase with measured levels of disease intensity and weather (dry or wet). To model populations of *C. ariakensis*, we propose to adjust the mortality rates for *C. virginica* based on research results that provide estimates of differences between the two species' resistance to MSX and dermo and to other mortality factors, such as predation.

Introduction

The eastern oyster (*Crassostrea virginica*) historically supported a valued fishery and formed an important component of the Chesapeake Bay's ecosystem. In recent years, the abundance of eastern oyster in the Chesapeake Bay has declined to less than 1% of estimated virgin stock due to intense fishing pressure during the 19^{th} and 20^{th} centuries, habitat destruction, degraded water quality, and disease (NRC 2004; Gottlieb and Schweighofer 1996).

The states of Maryland and Virginia recognized the need to reverse the decline in oyster stocks to restore the ecological role of oysters in the Bay and the economic benefits of a commercial fishery. To achieve those objectives, managers in Maryland and Virginia have proposed options for increasing the biomass of oyster stocks (NRC 2004), including the deliberate release of diploid Asian oysters (*C. ariakensis*) into Chesapeake Bay on a large scale to establish a self-recruiting population.

A comprehensive study of the potential effects of introducing the non-native Asian oyster into Chesapeake Bay is being conducted to support a programmatic Environmental Impact Statement (EIS) that will evaluate alternative restoration strategies. The EIS will address the proposed action to introduce diploid *C. ariakensis* and seven restoration alternatives, which include stocking and aquaculture of the Asian oyster and of the native eastern oyster. The comprehensive study, known as an ecological risk assessment (ERA), is being conducted as one element of the overall EIS. The ERA will identify the ecological risks and benefits posed by each of the eight restoration alternatives.

Evaluating the ecological effects of the proposed restoration alternatives requires constructing a demographic model that can project the change in populations of Asian and eastern oyster in the Bay that might result from implementing each alternative. The model must account for the primary population dynamics: growth, stock recruitment, and mortality. The reliability of model projections depends on the validity of the various input parameters, including mortality. Accurate and precise estimates of annual natural mortality rates (M) for Asian and eastern oyster are critical to the performance of the demographic model and the reliability of conclusions to be drawn from the ERA and the EIS.

The accuracy and precision of estimates of mortality are determined by the quantity and quality of the data and the validity of methods used to calculate the estimates. The Maryland Department of Natural Resources (DNR) collects empirical data through annual surveys of oyster beds in Maryland. Samples of oysters are collected by dredging at representatively selected oyster bars during fall. Oysters from each sample are sorted by size and classified into one of two mortality categories: live oyster or "box." The box category refers to dead, articulated shells. DNR classifies boxes further as "recent" (open shells with tissue remaining inside them, known as "gapers," and empty shells without fouling or sedimentation on the inner valve surfaces) or "old" (empty shells with fouling, sedimentation or both on the inner valve surfaces). DNR estimates annual mortality as the proportion of boxes to live oysters (Tarnowski 2003). Natural mortality of oysters in Delaware Bay and Virginia is also estimated from annual collections of live oysters and boxes (Southworth et al. 2005; Ford et al. 2006). Ford et al. (2006) found that mortality rates obtained from counts of recent boxes and rates based on total box counts both provided reliable indices of total mortality for the year prior to the survey.

Here we describe a method for estimating annual mortality based solely on counts of recent boxes of small (shell height from 40 to 76 mm) and market-size (shell height $\geq$ 76 mm) oysters. We compare estimated mortality rates for Chesapeake Bay based on counts of recent boxes with estimates based on total box counts (Jordan et al. 2002; Jordan and Coakley 2004). We estimate oyster mortality rates for specific ranges of salinity and disease intensity to enhance their applicability for spatially explicit modeling of oyster population dynamics, and we discuss how the rates for *C. virginica* could be adapted to model population growth for *C. ariakensis.*

Material and methods

We analyzed data from Maryland DNR's annual fall survey of oysters for the period from 1980 to 2005. The survey is conducted mostly during October (early November in some years) using a standard oyster dredge to collect samples of live oysters and boxes from 200 to 400 representative oyster bars (Tarnowski 2003). A fixed set of 43 "disease bars" has been sampled every year since 1980; length frequency data and tissue samples from each size class (for disease studies) have been collected annually from these bars since 1990. A composite sample of one Maryland bushel (~0.046 m^3) is collected at each of the disease bars by pooling two, ½-bushel subsamples from replicate tows, and at each bar in seed-production areas by pooling five, $1/5$ - bushel subsamples from replicate tows. At all other bars, DNR collects a ½-bushel sample from a single tow. DNR has reported counts of recent and old boxes-per-bushel separately for small and market-size oysters since 1991 and for spat (age 0) since 1992. The counts of live oysters and boxes of age 1+ in each sample is classified into two size categories (shell height; market: ≥76 mm; small: < 75 mm). Spat is identified morphologically by their asymmetric valves. Spat have one valve that is thinner and narrower than the other (the lower valve if they are oriented parallel to the substrate; M. Tarnowski, MD DNR personal communication). All counts are standardized to a volume of one bushel. We estimated mortality rates using only the counts of small and market-size boxes. Box counts for spat are considered to be unreliable because boxes can break apart easily during collection.

We made the following assumptions to estimate mortality from counts of recent boxes: (1) time since death (TSD) is between one and two weeks; (2) the instantaneous (1-week) mortality rate is constant from June to October; and (3) the cumulative natural mortality from October through May is negligible. Data from an intense mortality study conducted by Maryland DNR in the Choptank River during 2002 provide some support for assumptions 1 and 2. The Choptank study was conducted when freshwater run-off into the Bay was low to estimate the extent to which mortality might increase because of increased Haplosporidium nelsoni (MSX disease) infection. MSX is likely to cause additional mortality during years in which salinity is high due to drought. Maryland DNR counted live oysters and boxes from one-bushel samples at each of six oyster bars located in waters that normally are moderately salty every month from June through August, and during the annual fall oyster survey in October 2002. DNR's empirical data from the study in the Choptank River during 2002 (results summarized later in this paper) support assumptions (1) and (2). Assumption (3) is supported by numerous studies showing that natural mortality from *Perkinsus marinus* (dermo disease) and *H. nelsoni* (MSX) occurs primarily from early summer to October (Andrews 1996; Burreson and Ragone Calvo 1996; Ford and Tripp 1996; Ford and Haskin 1982) and that predation on oysters is greatest during summer months (Carriker 1955; Manzi 1970; Gunter 1979; Garton and Stickle 1980; Pearse and Wharton 1938; Landers and Rhodes 1970). When using total box counts to estimate mortality rates, we followed Jordan et al. (2002) and assumed that the TSD of a box is up to one year. According to that assumption, all boxes observed in the fall survey died within one year prior to the survey, and shells from oysters that died during the year remained articulated until the fall.

To refine the parameters for use in our demographic model, we estimated mortality rates for specific levels of salinity and disease intensity. Dermo infections in Chesapeake Bay are heaviest and cause most mortality at medium and high salinities (NRC 2004). We calculated average annual mortality rates by post-stratifying the counts of live oysters and boxes from all oyster bars across years by salinity class and disease tier. The mean salinity from May through September for each bar by year was estimated from the nearest Maryland Chesapeake Bay Monitoring Program station, or interpolated by kriging. We classified the yearly observations of live oysters and boxes from each bar into three salinity (S) classes (low: $S < 11$ ppt; medium: $11 \le S < 15$ ppt; and high: $S \ge 15$ ppt). The salinity thresholds were defined in consultation with Chesapeake Bay oyster biologists. Maryland DNR uses an index of disease intensity ranging from one to seven based on pathogen concentration in hemolymph or solid tissue (see Gieseker 2001) to classify dermo disease-intensity into three tiers (Tarnowski 2003). Tier 1 (dermo intensity > 2.85) and Tier 2 (2 < dermo intensity $\le$ 2.85) represent years with high and medium disease intensity, respectively; Tier 3 (dermo intensity $\le$ 2) represents years with relatively low disease intensity (Figure 1). Disease tiers 1 and 2 are generally associated with dry (lower 25 percentile of yearly USGS flow estimates from 1937-2003) (USGS 2004) and average (normal range of flow, 25-75 percentiles) years; Tier 3, indicating low disease-intensity, generally is associated with wet years (> 75 percentile of yearly flow estimates) (Table 1).

We calculated mean annual mortality rates for each size class by salinity zone j and disease tier k based on counts of live oysters and recent boxes from each bar over time ($i = 1, \ldots, n_{jk}$), using the following equations:

$$s_{jk} = \frac{\sum_i live_{ijk}}{\sum_i (live_{ijk} + newbox_{ijk})} \tag{0.1}$$

$$m_{jk} = -\log(s_{jk}) \tag{0.2}$$

$$totm_{jk} = 1 - \exp^{(-m_{jk} \times T)} \tag{0.3}$$

where: s_{jk} = 1- or 2 -week survival rate,

$live_{jk}$ = number of live oysters,

$newbox_{jk}$ = number of recent boxes,

m_{jk} = instantaneous (1- or 2 -week) mortality,

T = expansion factor to total number of weeks (20) when natural mortality occurs (T = 20 for 1-week mortality, and T = 10 for 2-week mortality)

$totm_{jk}$ = mean annual mortality rate

across all bars by salinity zone j and disease tier k during the time series. The numerical representation of instantaneous and annual proportional mortality rates above follows Ricker (1975).

For comparison, we also calculated the annual mortality rates by size class (except spat) from counts of recent and old boxes using the estimator

$$totm_{jk} = \frac{\sum_i allboxes_{ijk}}{\sum_i (live_{ijk} + allboxes_{ijk})}, \quad (0.4)$$

where $allboxes_{ijk}$ is the total number of recent and old boxes. The ratio estimators (equations 1.1 and 1.4) provide a weighted mean mortality across individual bars, with weights proportional to the number of live and dead oysters at each bar. Mortality estimates for individual bars are highly skewed. We applied the same assumption as Jordan et al. (2002), Jordan and Coakley (2004), and Ford et al. (2006) that shells from dead oysters (boxes) remain articulated for no more than one year, on average. Our estimates are based on the total box counts from Maryland DNR's dredge surveys of 200 to 400 bars per year from 1991 to 2005. Jordan and Coakley (2004) based their yearly estimates on data for the 43 disease bars sampled from 1985 to 2000. The mean annual mortality rate, or actual mortality rate (Ricker 1975), based on either method is an estimate of the annual expectation of death for an individual oyster.

We calculated the mortality rates from equations (0.3) and(0.4) and the associated variances by bootstrapping (Efron and Tibshirani 1993). We ran 2000 bootstrap re-samples, each consisting of n_{jk} randomly selected observations (with replacement) where n_{jk} is the number of samples collected across all bars over the time series of fall surveys (or yearly) in the respective salinity zone and disease tier. The standard error and the 95% confidence interval (CI) for the annual mean mortality rates were estimated directly from the distribution of the bootstrap estimates. The mean annual mortality rates based on recent box counts were calculated under the assumption that the TSD was 1-week, and 2-weeks. We then pooled the two bootstrap distributions to obtain estimates of mean mortality rates and variances that represent uncertainty in the TDS (i.e., allowing TSD to vary between 1 and 2 weeks). Our estimates of mortality are expressed as means with associated 95% confidence limits in brackets, unless otherwise noted.

Results

From 1980 to 1985, a period when disease intensity of dermo and MSX were limited, the estimated average annual mortality rate of market-size oysters across salinity zones based on total box counts was 0.153 (0.147-0.158). The natural mortality increased significantly after 1985, with an average annual rate of 0.293 (0.289-0.298) from 1986 to 2006. Mortality estimates were generally higher for dry years (e.g., 2002) with elevated disease levels than for wet years (e.g., 1994) with below-average disease levels (Figures 2 and 3). The discrepancy between our yearly mortality estimates from total box counts and those reported by Jordan and Coakley (2004; Figure 2) is due primarily to a bias in their estimates due to an offset of one year (see Discussion).

The annual mortality rate estimated across all years and salinity regimes based on recent boxes (TSD 1-2 weeks) averaged 0.37 (0.17 - 0.56) and did not differ significantly from our estimated average mortality rate based on total boxes, 0.30 (0.29 - 0.31). The average mortalities by salinity zones based on recent (TSD of 1-2 weeks) and total boxes did not differ significantly (Figure 4), and the 95% confidence intervals for our estimates overlapped with mortality rates provided by Jordan and Coakley (2004). Table 2 shows estimates of the average annual mortality rates by salinity-class and disease-intensity based on recent boxes according to different assumptions for TSD.

Our mortality estimates for market-size oysters by year based on recent boxes (TSD of 1-2 weeks) differed significantly from estimates based on total boxes for 12 of 15 years (Figure 3). Estimates based on the number of recent boxes generally improved the separation of mortality rates for dry and wet years (Figure 3). Mortality estimates based on recent boxes were significantly lower than those derived using total boxes for 5 of 6 wet years and significantly higher for 4 of 5 dry years. In 2003, a wet year, the mortality rate for market-size oysters based on total boxes, 0.40 (0.38 - 0.42), was significantly higher than the mortality rate based on recent boxes, 0.17 (0.06 - 0.28).

Mortality rates based on recent boxes (TSD of 1-2 weeks) for market-size and small oysters by salinity zone increased consistently with increasing salinity and differed greatly from mean mortality rates across salinity zones in dry years such as 1991 and 2002 (Figure 5). In 2002, for example, which was the second dry year in a row, mortality rates for market-size oysters were 0.88 (0.73 – 1.00), 0.69 (0.44 - 0.97), and 0.43 (0.19 - 0.66) for high, medium, and low salinity classes, respectively, as compared to 0.75 (0.52 - 0.98) for a mean 2002 annual mortality rate across salinity zones. Using a mean mortality rate regardless of salinity would generally underestimate mortality for oysters in high salinity areas and overestimate mortality for oysters in low salinity areas.

To ensure that results from the predictive demographic model being used in the ERA correctly account for the effects of salinity, the mean annual mortality rate based on recent box counts was estimated individually for each salinity class and disease tier and was compared to mortality rates based on total box counts. In contrast to the mean mortality rates based on total box counts, the mean mortality rates based on recent box counts consistently differentiated between salinity classes and disease tiers (Figure 6). In high salinity, mean mortality rates based on recent box counts (TSD of 1-2 weeks) for market-size oysters were 0.79 (0.57 – 1.00), 0.51 (0.27 - 0.75), and 0.23 (0.09 - 0.37) for disease tiers 1, 2, and 3 respectively, whereas respective mean mortality rates based on total box counts for market-size oysters were 0.45 (0.44 - 0.45), 0.53 (0.50 - 0.53), and 0.26 (0.24 - 0.28).

Figure 7 shows monthly mortality rates for market-size and small oysters in June, July, August, and October from the study conducted by Maryland DNR in a medium salinity section of the Choptank River during 2002. For comparison, we included the cumulative mortality rate from June to October and an annual mortality rate using our method based on recent box counts (TSD of 1-2 weeks) in the Maryland DNR fall oyster survey. Monthly mortality rates for market-sized oysters were 0.31 (0.11 - 0.51), 0.36 (0.15 - 0.58), 0.33 (0.14 - 0.52), and 0.22 (0.08 - 0.36) for June to August and October, respectively. The cumulative mortality rate from June to October was 0.78 (0.44 - 0.91); September’s mortality rate was imputed using the mean of the August and October estimates. The estimated average annual mortality rate based on the recent box counts from the fall oyster survey for medium salinity and Tier 1 disease intensity was 0.59 (0.34 - 0.83).

Discussion

Estimates of natural mortality rates for oysters (age 1+) based on counts of recent boxes appear to be more accurate (i.e., closer to the true average mortality) than estimates based on total box counts for Chesapeake Bay. Mortality estimates based on recent boxes increase consistently with increasing disease intensity and salinity, and they are higher during years of drought than during wet years, when reduced salinity commonly decreases disease mortality from MSX and dermo (Matthiessen et al. 1990; Gottlieb and Schweighofer 1996). The mortality rates estimated from total box counts, in contrast, did not always reflect variation in mortality due to changes in disease levels linked with freshwater runoff into Chesapeake Bay. These mortality estimates were similar for 2003 (wet) and 2001 (dry), for example. The difference between the mortality rates for 2003 based on recent boxes and those based on total boxes might be attributable to a longer time-to-disarticulation than the one year assumed in this study. Estimates based on total boxes may incorporate mortality over more than one year because boxes may take longer than one year to disarticulate (Christmas et al. 1997). Given the high annual mortality rates from 1999 to 2002 (Figure 4), which probably resulted from three successive dry years and one year near the 25^{th} percentile of runoff, a significant proportion of the old boxes counted in 2003 could represent oysters that died in 2002 and 2001, thus biasing the estimated mortality rate for 2003. The lower than average estimate of mortality for 2003 based on recent boxes is more credible for a wet year with below-average disease intensity.

One reason for the difference between our estimates of annual mortality based on total box counts and those reported by Jordan and Coakley (2004) is sampling variability. Our estimates are based on counts of live oysters and boxes collected from 200 to 400 bars per year, while Jordan and Coakley (2004) restricted their analysis to data from 43 disease bars. This difference, however, probably is small. Of more concern is a systematic error (bias) in the estimates provided by Jordan and Coakley (2004). They used fall box counts to estimate natural mortality for the following year (i.e., October 1985 counts were used to estimate mortality for 1986); however, most natural deaths in a give year probably occur between May and October, just before the fall survey. For example, by following a cohort of market-size oysters through one year from October 1985 to October 1986, we see that individuals are subject to mortality due to fishing from October 1985 to April 1986 and to natural mortality from October 1985 to October 1986. Hence, natural mortality during 1985 (i.e., November 1984 through October 1985) would have occurred primarily between May 1985 and October 1985, and therefore should be estimated from October1985 box counts, not from October 1984 counts. The bias caused by the one year offset in Jordan and Coakley's (2004) estimates of M is readily apparent in Figure 3. Estimating natural mortality for the current year based on box counts from the previous year's fall survey could cause a bias in stock assessments of an unknown magnitude and direction. The natural mortality due to disease is strongly linked to climatic conditions; consequently, the offset could result in very large biases for adjacent wet and dry years, with unknown implications for long-term projections.

Estimates of natural mortality are based on important assumptions, such as a qualitative assumption about the time an oyster shell sits before being subject to sedimentation or fouling (recent-box method) and an assumption about the typical time between death and disarticulation of the shell (total-box method). Our estimates of annual mortality using counts of recent boxes are based on the assumption that most natural deaths within a year occur during a 20-week period from May to October. We also assumed that instantaneous (1-week) mortality rates were uniform over the 20-week time period. This assumption was necessary because live oysters and recent boxes only were counted during the fall each year. The mortality study in the Choptank showed variability in monthly mortality rates based on counts of recent boxes (1-2 weeks TSD). Ford and Tripp (1996; Figure 7) also demonstrated that mortality was not uniform over this period and that samples of recent boxes collected in November for some years may significantly underestimate disease mortality in prior months. An additional source of bias in our estimates of annual mortality from counts of recent boxes is that mortality can occur outside this 20-week period, for example due to late winter epizootic outbreaks of MSX, and due to winter and spring freshets. Ford and Tripp (1996) showed that increased mortality caused by MSX can occur during the late winter/early spring; 15% of the small and market-size oysters that survived to the fall survey were killed when MSX outbreaks occurred two or more years in a row. Sources of bias in mortality estimates based on total box counts include violations of the assumption of a one-year disarticulation rate and the assumption that all individuals stay in the same size class for one year. Individuals in a size class (e.g., small oysters) may stay in the same size class between two fall surveys, or grow larger (i.e., achieve market size) within one year. The possibility that oysters will grow to the next larger size class within a year introduces a bias of unknown magnitude in estimates of annual mortality rates. If recent boxes really are only one or two weeks old, then live oysters within the size class of the recent boxes will not have sufficient growth time to reach the next size class before the boxes of their size cohorts are collected and counted. We recognize that our mortality estimates by salinity zones are subject to bias if predation varies geographically, and if the TSD for recent and old boxes varies by salinity and temperature. TSD for recent and old boxes may decrease progressively with increasing salinity (see Christmas et al. 1997; Ford et al. 2006).

We recommend conducting experiments in Chesapeake Bay to estimate the average TSD of recent and total boxes by salinity zone. Results from experimental studies similar to those conducted by Ford et al. (2006) in Delaware Bay could help to refine the TSD and, hence, the annual mortality estimates for Chesapeake Bay oysters. Mortality rates can then be calibrated through forecasting, starting with the first year in a time series of survey data, for areas where accurate abundance and demographic data are available. Such calibration was conducted using abundance-at-age data from 1994 to 2004 for 23 oyster bars in the James River, Virginia, (data provided by R. Mann, Virginia Institute of Marine Science) to help determine the average TSD of recent boxes. Results indicated that mortality parameters based on the assumption that recent boxes have a TSD of one to two weeks produced population projections that matched the survey observations reasonably.

We used mean estimates of annual mortality by salinity and disease tier and allowed TSD to vary from one to two weeks (Table 2) in the oyster demographic model. After the model randomly selects years between 2004 and 2014 and the climatic condition of each year (dry, average, or wet rainfall year) using block bootstrapping from historic USGS data, the disease tier for each year is assigned randomly; probabilities are based on the historic data (Table 1). Next, the model applies randomly selected mortality rates for the appropriate salinity class and disease tier by drawing randomly from a normal distribution with estimated means and associated variances. The empirical mortality estimates for *C. virginica* presented here can also be useful for specifying approximate mortality rates for *C. ariakensis* in the Chesapeake Bay for oysters that are one-year old or older. A mortality rate for a disease and salinity category may be selected based on an evaluation of this species' susceptibility to mortality caused by dermo and MSX and to predation. Estimated mortality rates for *C. virginica* for low disease levels (Tier 3; Table 2) could be justified for *C. ariakensis* since *C. ariakensis* appears to experience low disease-related mortality. The Virginia Seafood Council grew triploid *C. ariakensis* from 2003 to spring 2005, and results from their trials in October 2004 showed no MSX prevalence in the oysters, and low levels of dermo (http://www.vims.edu/vsc/). Mortality rates from these trials supported our assumption that most mortality occurs during the summer months, and mortality rates for *C. ariakensis* were lower than rates for *C. virginica* (S. Allen, pers. com.). Laboratory studies (Newell et al. in review) comparing the relative susceptibility of juvenile diploids (shell height <25 mm) of both oyster species to invertebrate predators of eastern oyster juveniles suggest that *C. ariakensis* generally will have weaker shells than *C. virginica*. Both species developed stronger shells in response to cues from predators, but *C. virgincia* showed inducible changes in shell composition that make it comparatively stronger. If this comparative difference in shell strength persists over time following introduction to Chesapeake Bay, juvenile *C. ariakensis* probably would experience greater mortality due to predation than *C. virginica*, resulting in reduced recruitment to the spawning stock. This differential predation mortality may not hold for oysters larger than 40 mm. We note that the study conducted by Newell et al. (in review) covered a fairly short time period. If *C. ariakensis* is introduced to Chesapeake Bay, it may adapt genetically to develop shell strength similar to the native oyster's. Freeman and Byers (2006) showed that New England mussels can adapt genetically to grow thicker shells in response to invasive predators in fewer than 15 years.

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Figure Captions

Figure1. Annual mean dermo disease intensity across 43 MD oyster bars and mean discharge (liters/sec) into the Chesapeake Bay from 1991 to 2005 (USGS 2004). High, medium, and low dermo intensity correspond to disease Tiers 1-3; high, medium and low flow correspond to dry (lower 25th percentile), average (25-75th percentiles), and wet years (upper 75th percentile) based on USGS flow estimates from 1937-2005.

Figure 2. Yearly natural mortality rates for market-size oysters based on total boxes across all Maryland bars surveyed, versus estimates of mortality reported in Jordan and Coakley (2004). Error bars for our estimates represent 95% confidence intervals.

Figure 3. Yearly mortality estimates for market-size oysters (> 76 mm) based on recent and total boxes, under the assumptions of average time-since-death (TSD) of 1-2 -weeks and 1-year, respectively. The climatic condition (dry, average, wet) for each year is based on USGS flow estimates. Error bars represent 95% confidence intervals.

Figure 4. Mean annual natural mortality rates by salinity class for market-size oysters over all years (1991-2005). Error bars represent 95% confidence intervals. We assumed an average TSD of 1-year for total boxes, and 1-2-weeks for recent boxes. Mortality estimates per salinity class reported in Jordan and Coakley (2004) are also shown.

Figure 5. Annual natural mortality rates for small and market-size oysters based on counts of recent boxes (TSD=1-2 -weeks) across all bars in each salinity class. Error bars represent 95% confidence intervals. Market-size oysters are defined as being greater than or equal to 76 mm in shell length. Small oysters are defined as being between 40 mm and 75 mm in shell length.

Figure 6. Mean annual natural mortality rates by disease level (tier 1 = high dermo intensity; tier 2 = medium dermo intensity; and tier 3 = low dermo intensity) and salinity class for small and market-size oysters over all years (1991-2005). Error bars represent 95% confidence intervals. We assumed an average TSD of 1-year for total boxes, and 1-2 -weeks for recent boxes.

Figure 7. Monthly and cumulative natural mortality at 6 oyster bars in Choptank River (medium salinity) compared to (1) the estimated 2002 mortality rate for medium salinity and (2) the mortality rate across all medium salinity bars in years with high disease intensity. Error bars represent 95% confidence intervals. All estimates are based on counts of recent boxes (TSD = 1-2 -weeks).

Table 1. Proportion of years (1991-2005) in each disease tier for three climatic condition classes (dry, average, or wet years) as defined by run-off measured by USGS. Tiers 1-3 represent high. medium, and low disease intensity, respectively.

	Disease Tier		
Condition	1	2	3
Dry	0.80	0.20	0.00
Average	0.00	0.75	0.25
Wet	0.00	0.17	0.83

Table 2. Estimates of proportional annual natural mortality by size class, salinity zone, and disease intensity (Tier), based on counts of live oysters and recent boxes from 1991- 2005 dredge surveys. The relative standard error, RSE=S.E./Mean; LCL, and UCL are lower and upper 95% confidence limits.

TSD Recent Boxes (Weeks)	Salinity	Tier	Market-Size Oysters				Small Oysters			
			Mean	RSE	LCL	UCL	Mean	RSE	LCL	UCL
1	High	1	0.90	0.01	0.88	0.91	0.81	0.02	0.78	0.84
1	High	2	0.63	0.05	0.57	0.68	0.59	0.03	0.56	0.62
1	High	3	0.30	0.09	0.26	0.34	0.44	0.05	0.40	0.47
1	Med	1	0.71	0.02	0.68	0.74	0.68	0.03	0.65	0.71
1	Med	2	0.54	0.04	0.51	0.57	0.49	0.05	0.45	0.53
1	Med	3	0.17	0.07	0.15	0.19	0.21	0.05	0.20	0.23
1	Low	1	0.44	0.10	0.37	0.52	0.37	0.10	0.31	0.43
1	Low	2	0.28	0.10	0.23	0.32	0.20	0.10	0.17	0.23
1	Low	3	0.13	0.26	0.07	0.19	0.11	0.08	0.09	0.12
2	High	1	0.68	0.02	0.65	0.70	0.56	0.03	0.53	0.59
2	High	2	0.39	0.07	0.35	0.44	0.36	0.04	0.34	0.39
2	High	3	0.16	0.10	0.14	0.19	0.25	0.06	0.22	0.27
2	Med	1	0.46	0.03	0.44	0.49	0.43	0.04	0.41	0.46
2	Med	2	0.32	0.04	0.30	0.34	0.28	0.06	0.26	0.31
2	Med	3	0.09	0.08	0.08	0.10	0.11	0.05	0.10	0.12
2	Low	1	0.25	0.12	0.20	0.30	0.21	0.11	0.17	0.24
2	Low	2	0.15	0.10	0.13	0.18	0.10	0.11	0.09	0.12
2	Low	3	0.06	0.10	0.05	0.08	0.06	0.08	0.05	0.06
1-2	High	1	0.79	0.14	0.57	1.00	0.69	0.18	0.45	0.93
1-2	High	2	0.51	0.24	0.27	0.75	0.47	0.25	0.25	0.70
1-2	High	3	0.23	0.31	0.09	0.37	0.34	0.28	0.16	0.53
1-2	Med	1	0.59	0.21	0.34	0.83	0.56	0.22	0.31	0.80
1-2	Med	2	0.43	0.26	0.21	0.64	0.39	0.27	0.18	0.59
1-2	Med	3	0.13	0.32	0.05	0.21	0.16	0.31	0.06	0.26
1-2	Low	1	0.34	0.29	0.15	0.54	0.29	0.30	0.12	0.46
1-2	Low	2	0.22	0.31	0.08	0.35	0.15	0.33	0.05	0.25
1-2	Low	3	0.10	0.33	0.03	0.16	0.08	0.33	0.03	0.13

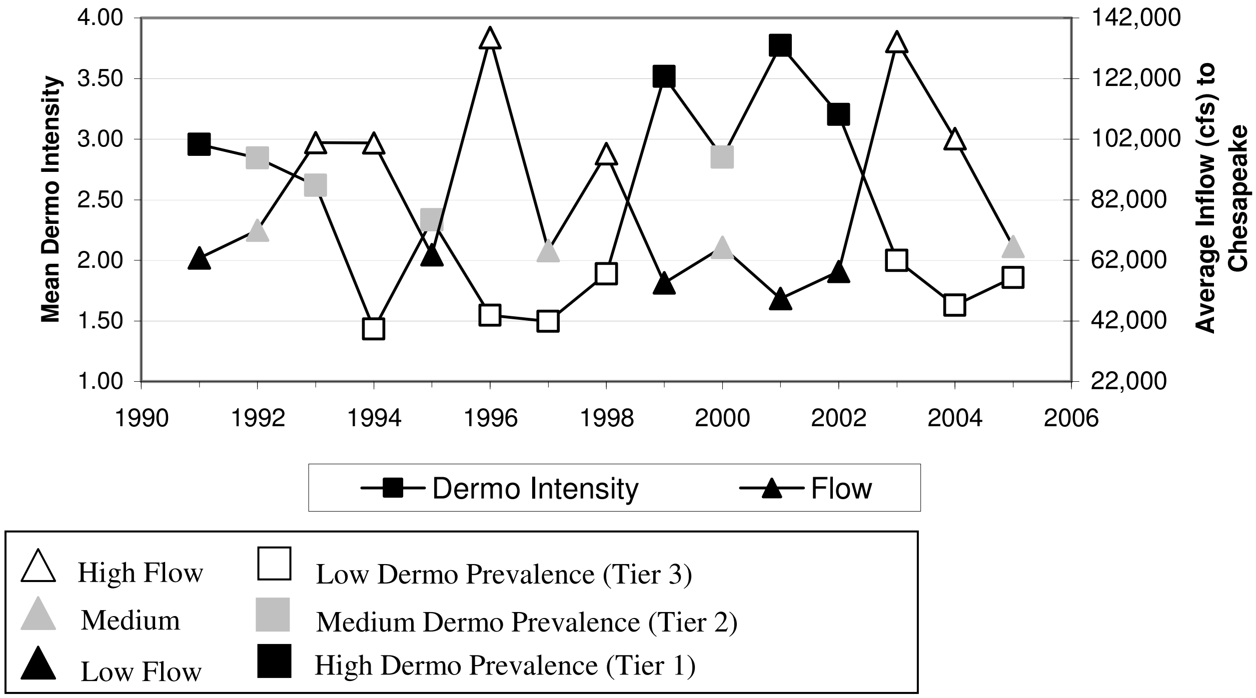

4.00
3.50
3.00
2.50
2.00
1.50
1.00
Mean Dermo Intensity
142,000
122,000
102,000
82,000
62,000
42,000
22,000
Average Inflow (cfs) to Chesapeake
1990
1992
1994
1996
1998
2000
2002
2004
2006
Dermo Intensity
Flow
High Flow
Medium
Low Flow
Low Dermo Prevalence (Tier 3)
Medium Dermo Prevalence (Tier 2)
High Dermo Prevalence (Tier 1)

Figure1

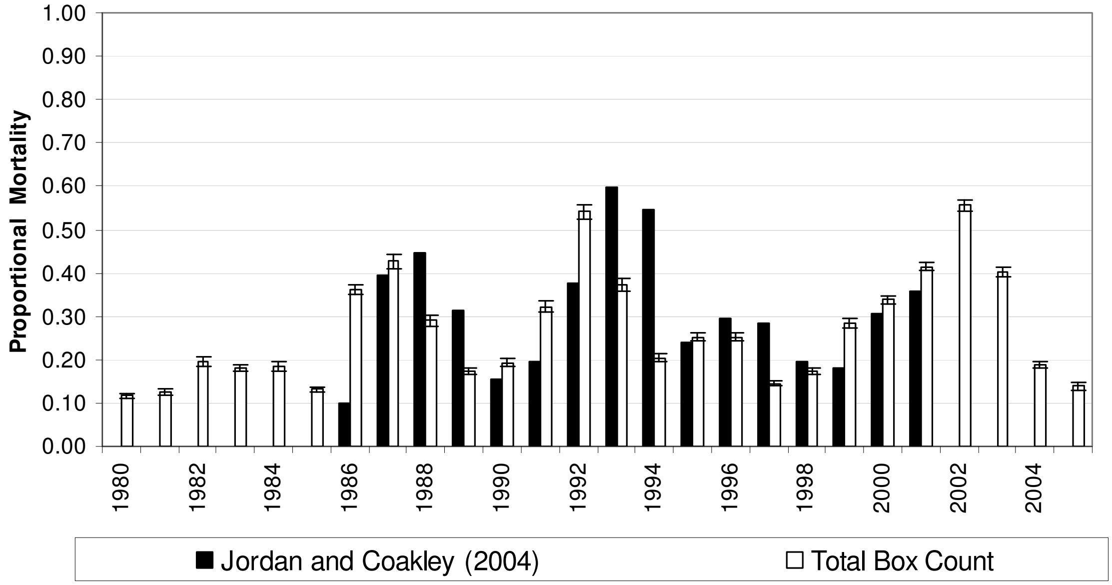

Proportional Mortality
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Jordan and Coakley (2004)
Total Box Count

Figure 2

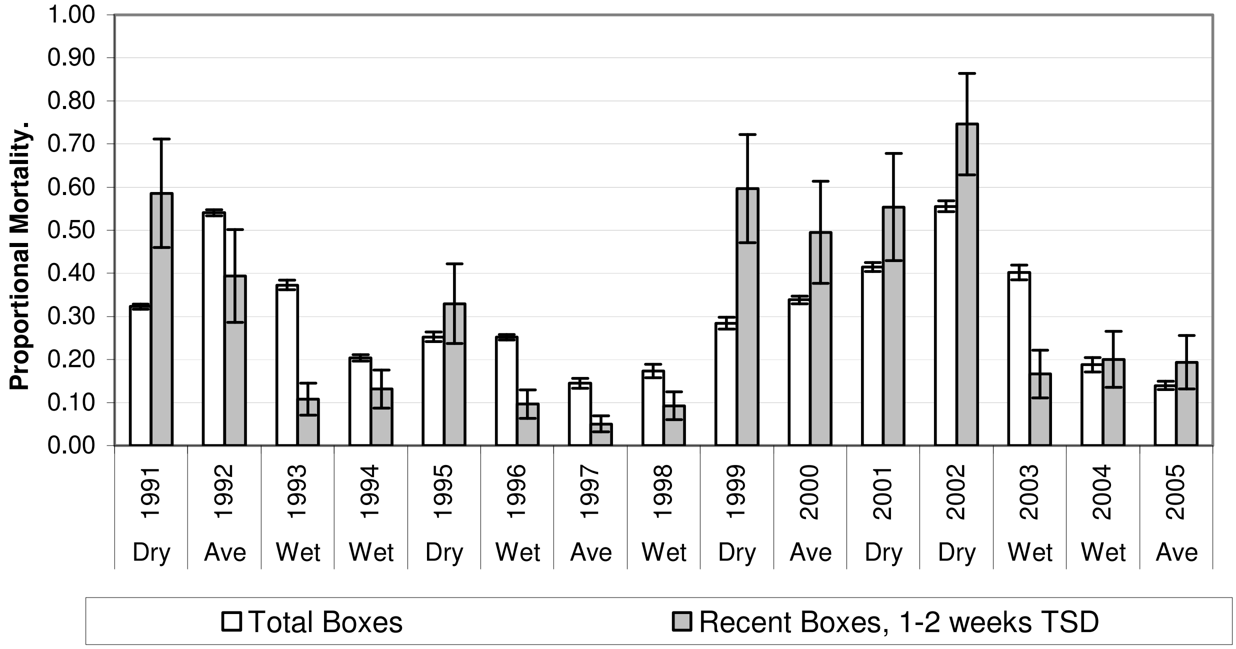


Figure 3

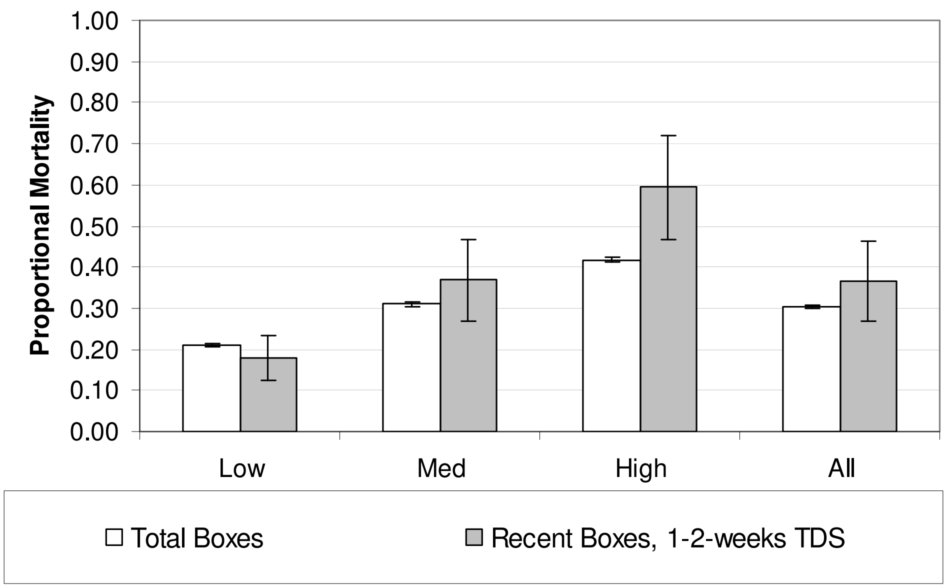
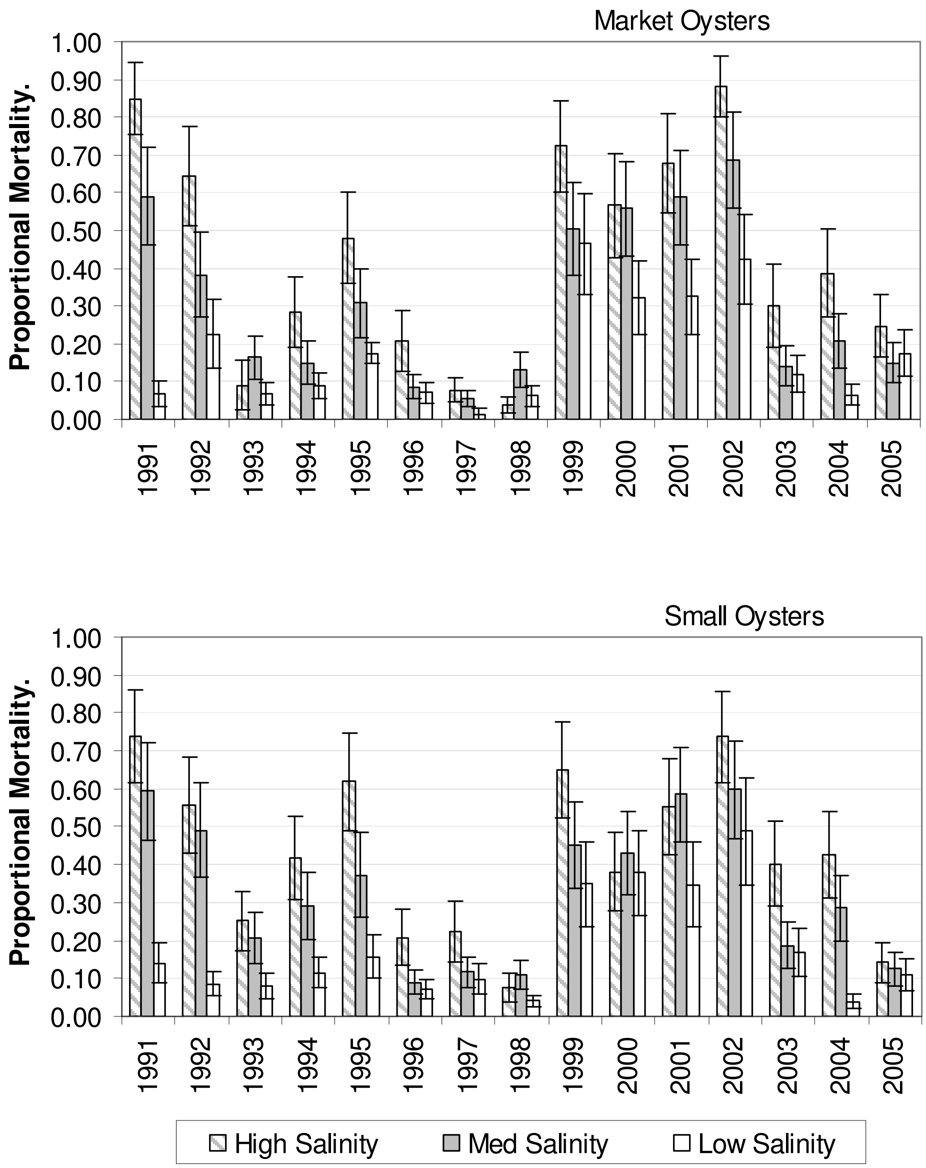


Figure 4



Market Oysters
Proportional Mortality.
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Small Oysters
Proportional Mortality.
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
High Salinity
Med Salinity
Low Salinity

Figure 5

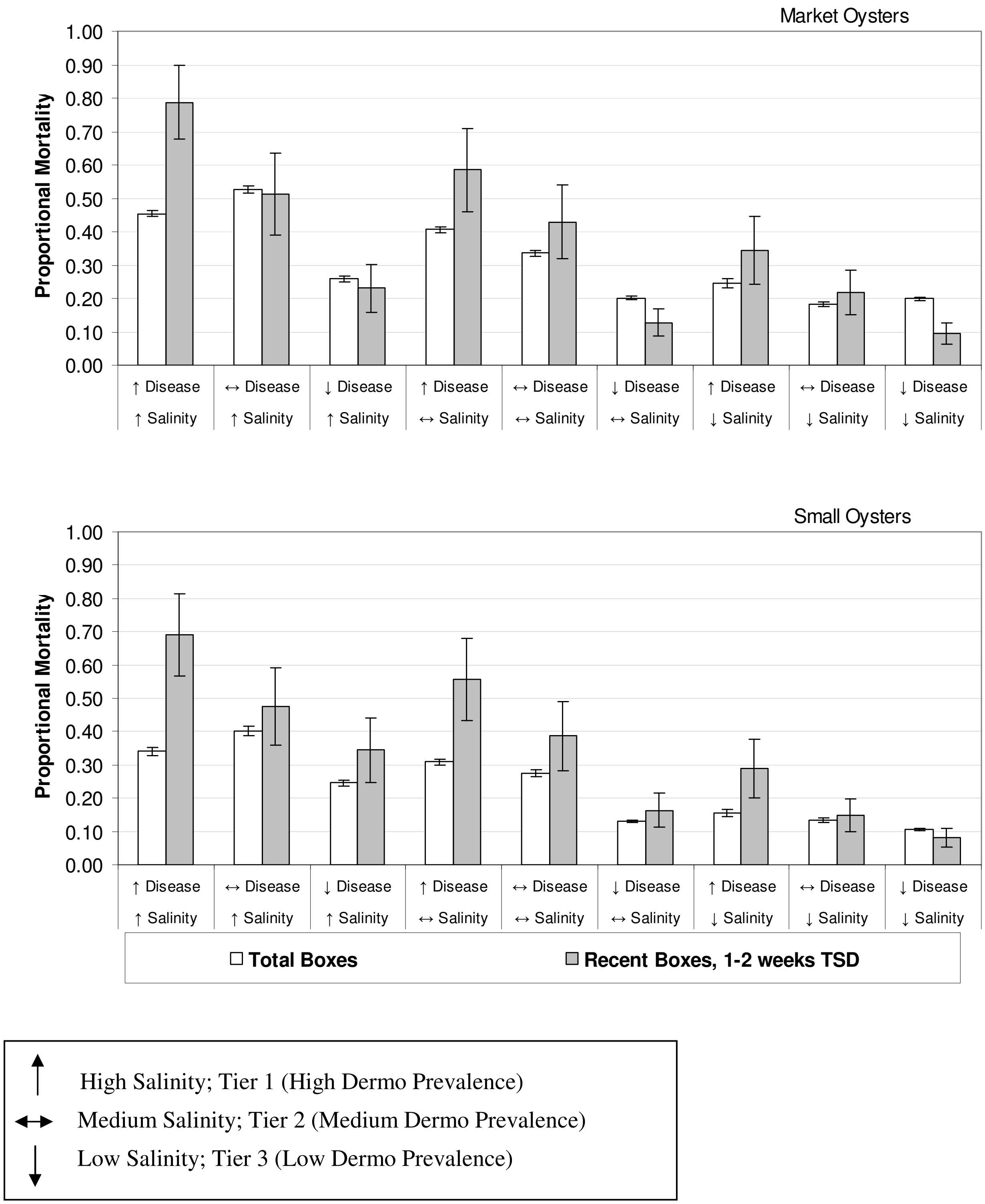
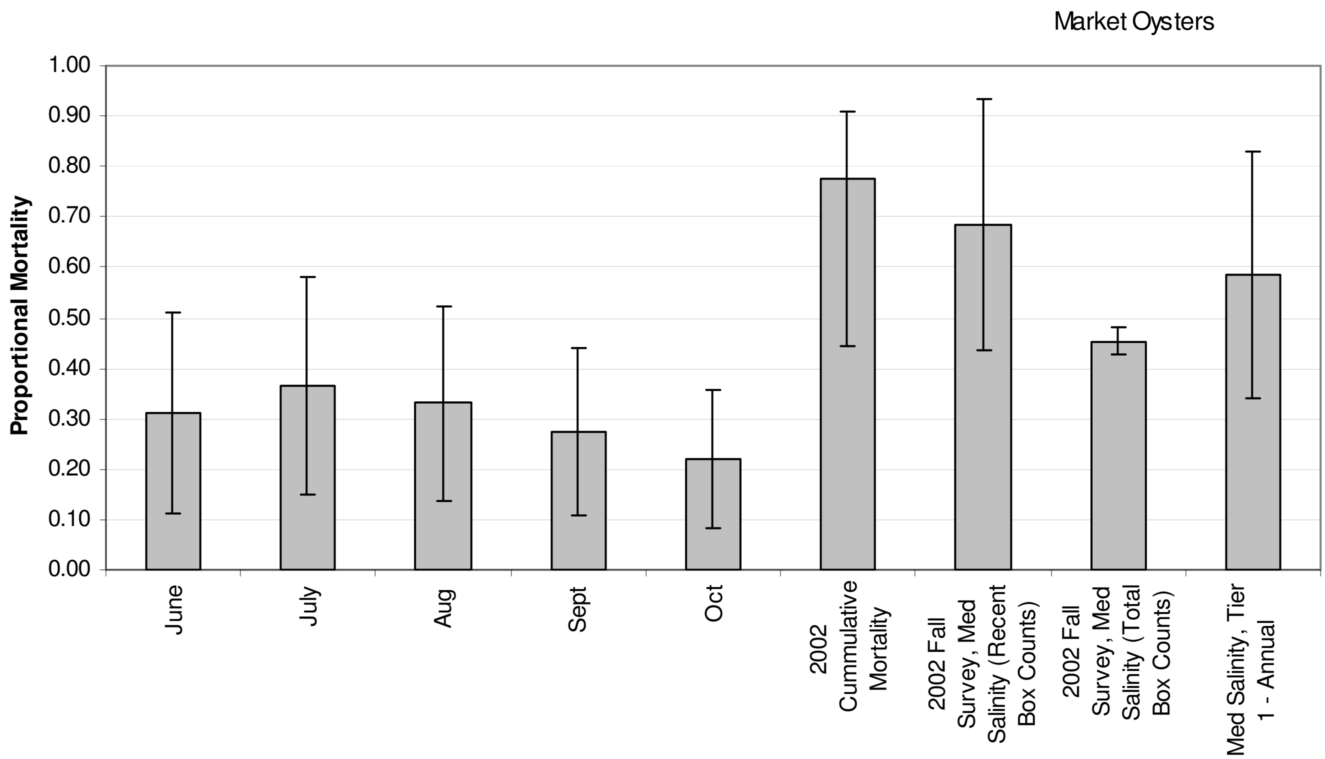

Market Oysters
Proportional Mortality
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
↑ Disease ↑ Salinity
↔ Disease ↑ Salinity
↓ Disease ↑ Salinity
↑ Disease ↔ Salinity
↔ Disease ↔ Salinity
↓ Disease ↔ Salinity
↑ Disease ↓ Salinity
↔ Disease ↓ Salinity
↓ Disease ↓ Salinity
Small Oysters
Total Boxes
Recent Boxes, 1-2 weeks TSD
High Salinity; Tier 1 (High Dermo Prevalence)
Medium Salinity; Tier 2 (Medium Dermo Prevalence)
Low Salinity; Tier 3 (Low Dermo Prevalence)

Figure 6


Market Oysters
Proportional Mortality
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
June
July
Aug
Sept
Oct
2002 Cummulative Mortality
2002 Fall Survey, Med Salinity (Recent Box Counts)
2002 Fall Survey, Med Salinity (Total Box Counts)
Med Salinity, Tier 1 - Annual

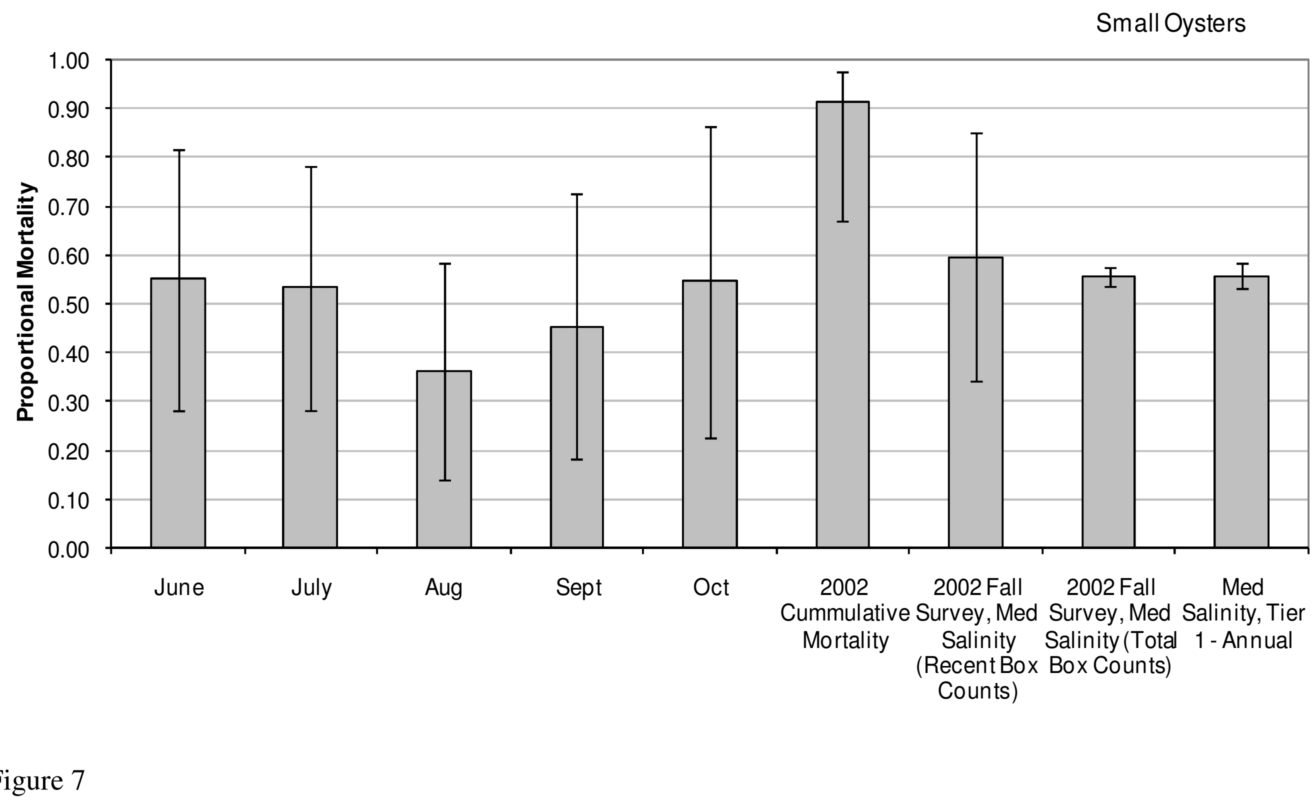

Small Oysters
Proportional Mortality
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
June
July
Aug
Sept
Oct
2002 Cummulative Mortality
2002 Fall Survey, Med Salinity (Recent Box Counts)
2002 Fall Survey, Med Salinity (Total Box Counts)
Med Salinity, Tier 1 - Annual

Figure 7

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Attachment 5

Description of Alternative Restoration Strategies

(P. Jones)

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Alternative 1--No Action

Oyster management activities are restricted to the native oyster. Oyster population restoration and habitat rehabilitation efforts continue at current levels.

Population restoration

Oyster population restoration activities carried out under Alternative 1 are summarized in Table 1. Maryland hatcheries will produce 225 million seed each year, of which 25 million will be allocated to the Potomac River. Virginia will produce 50 million hatchery seed annually.

Hatchery seed will be planted on oyster sanctuaries, harvest reserves and open harvest areas in the three management regions (Figure 1). The number of hatchery seed planted will range from one million to five million per acre. Differences in the number planted per acre are due to salinity dependent differences in the natural mortality of stocked hatchery seed and different management objectives for sanctuaries, harvest reserves and open harvest areas. The number of seed that will be stocked per acre each year in each region is as follows: Maryland sanctuaries – 2 million per acre, Maryland harvest reserves - 1 million per acre, Potomac River open harvest areas - 1 million per acre and Virginia sanctuaries - 5 million per acre.

In Maryland, 40 million hatchery seed will be planted on 20 acres of oyster bars located in sanctuaries and 160 million hatchery seed will be planted on 160 acres of oyster habitat in harvest reserves each year. In the Potomac River, 25 million hatchery seed will be planted on 25 acres of oyster bars that are open to harvest. Virginia will plant 50 million hatchery seed on 10 acres of oyster bars located in sanctuaries each year. Several hatchery seed plantings will occur on these bars over the 10 year period. As a result, for some bars, the total number of acres planted with hatchery seed will exceed the total size of the bar.

Table 1. Total number of hatchery seed planted, allocation of seed within each management area and number of acres to be planted annually under Alternative 1 – No Action.

Region	Number of hatchery seed planted annually (in millions)	Allocation of hatchery seed (in millions)			Number of acres planted with hatchery seed annually		
		sanctuaries	reserves	harvest areas	sanctuaries	reserves	harvest areas
Maryland	200	40	160		20	160	
Potomac	25			25			25
Virginia	50	50			10		
Bay wide	275	90	160	25	30	160	25

Under Alternative 1, ten sanctuaries in Maryland and three in Virginia will receive hatchery seed annually (Table 2). In Maryland, approximately 30 million hatchery seed will be planted on sanctuaries in low salinity waters (5 – 12 ppt) and 10 million on sanctuaries in intermediate to high salinity waters (above 12 pt). A total of 200 acres will be planted in Maryland and 100 acres will be planted in Virginia over the 10 year period.

Table 2. Summary of hatchery seed planting information for Maryland and Virginia sanctuaries under Alternative 1 - No Action.

Sanctuary				**Total acres planted with hatchery seed at each location over the 10 year period**
Region	**Location**	**Name**	**size (acres)**	
Maryland	Upper Bay	Gales Lump	248	20
	Severn River	Severn River	148	20
	Upper Bay	Thomas Pt. South	46	20
	Chester River	Strong Bay	76	20
	Eastern Bay	Mill Hill	76	20
	Choptank River	Cambridge	142	20
	Patuxent River	Trent Hall	41	20
	Potomac River	Dukeheart Channel	138	20
	Upper Bay	Outer Magothy	167	20
	Chester River	Hells Delight	175	20
		Total	1257	200
Virginia				
	Great Wicomico R.	Shell Bar	14	33
	Great Wicomico R.	Haynie Bar	6	17
	Piankatank River	Palaces	53	50
		Total	73	100

Summary information on hatchery seed plantings on Maryland's harvest reserves is presented in Table 3. In Maryland, ten harvest reserves will receive 160 million hatchery seed annually. A total of 1600 acres will be planted over 10 years. Each year, approximately 128 million seed will be planted on harvest reserves in low salinity waters (5-12 ppt) and 32 million in intermediate to high salinity sites (above 12ppt).

Table 3. Summary of hatchery seed planting information for Maryland harvest reserves under Alternative 1 - No Action.

Reserve			Total acres planted with hatchery seed at each location over the 10 year period
Location	Name	size (acres)	
Chester River	Blunt	63	100
Choptank River	Bolingbroke Sand	22	40
Chester River	Emory Hollow	120	200
Patuxent River	Broadneck	271	300
Choptank River	Howell Point	71	140
Choptank River	Black Buoy	88	150
Upper Bay	Swan Point	184	220
Upper Bay	Belvedere	234	300
Chester River	Devil's Playground	38	50
Chester River	Boat House	58	100
	Total	1149	1600

Information on hatchery seed plantings on Potomac River open harvest areas is presented in Table 4. Hatchery seed will be planted on seven oyster bars each year. A total of 250 acres will be planted over the 10 year period.

Table 4. Summary of hatchery seed planting information for Potomac River open harvest areas under Alternative 1 – No Action.

Open harvest area		Total acres planted with hatchery seed at each location over the 10 year period
Name	size (acres)	
Ragged Point	165	40
Colonial Beach	99	40
Sheepshead	107	40
Cobb Bar	68	30
Swan Point	113	40
Gum Bar	44	30
Lower Cedar Point	42	30
Total	638	250

Habitat rehabilitation

Oyster bar habitat rehabilitation activities to be carried out under Alternative 1 are summarized in Table 5. The locations in which these activities will be undertaken are presented in Figure 1. Maryland will rehabilitate 200 acres of oyster bar habitat each year of the 10 year period. Of this total, approximately 40 acres will be in sanctuaries and 160 acres in open harvest areas. In the Potomac River, habitat rehabilitation activities will be undertaken on 55 acres of oyster bottom in open harvest areas annually. Virginia will add shell to 223-1,484 acres of oyster bottom each year.

Table 5. Total acres of oyster bars rehabilitated within each management area and acres restored in sanctuaries, reserves and open harvest areas under Alternative 1 – No Action.

Region	**Total number of acres of oyster habitat rehabilitated annually**	**Number of acres rehabilitated annually**		
		sanctuaries	reserves	harvest areas
Maryland	200	40		160
Potomac	55			55
Virginia	223-1484	223-1484		

Habitat rehabilitation will occur on three sanctuaries (Table 6) and 14 open harvest areas in Maryland (Table 7) and 12 open harvest areas in the Potomac River. Virginia will plant shell on 19-55 sanctuary sites each year.

Over the 10 year study period, 400 acres of sanctuaries and 1600 acres of open harvest areas in Maryland and 550 acres of open harvest areas in the Potomac River will be rehabilitated. In Virginia, a total of 9,501 acres of oyster bars in sanctuaries will receive shell over the 10 year study period.

Table 6. Summary of habitat rehabilitation information for Maryland sanctuaries under Alternative 1 – No Action.

Sanctuaries			**Total acres rehabilitated at each location over the 10 year period**
Location	**Name**	**size (acres)**	
Choptank River	Black Walnut	211	210
St. Mary's Shore	Point Look-In	111	110
Lower Bay	NW Middleground	103	80
Total		425	400

Table 7. Summary of habitat rehabilitation information for Maryland and Potomac River open harvest areas under Alternative 1 – No Action.

Open harvest areas				Total acres rehabilitated at each location over the 10 year period
Region	**Location**	**Name**	**size (acres)**	
Maryland				
	Tangier Sound	Piney Island West(a)	154	150
	Tangier Sound	Piney Island West(b)	204	200
	Manokin River	Drum Point(a)	22	20
	Manokin River	Drum Point(b)	19	10
	Tangier Sound	Harris Addition	113	100
	Little Annamessex	Great Rock	323	320
	Pocomoke Sound	Gumby	117	100
	Pocomoke Sound	Marumsco	128	120
	Eastern Bay	Rich Neck	82	80
	Eastern Bay	Lowes Point	76	70
	St. Mary's River	Cherry	36	30
	Lower Bay	Butler	65	50
	Choptank	Wild Cherry Tree	283	250
	Main Bay	Lulu	152	100
	Total		1774	1600
Potomac				
		Jones Shore	4	4
		Poseys Bluff	110	110
		Great Neck	98	94
		Kitts Point	3	2
		Hog Island	22	20
		Heron Island	38	30
		St. Georges	17	10
		Ragged Point	165	160
		Thickett Point	11	10
		Bonums	12	10
		Tall Timbers	42	40
		King Copsico	62	60
	Total		584	550

Alternative 2--Expand Native Oyster Restoration Program

Under Alternative 2, a non-native oyster is not introduced in the Bay. Instead, native oyster recovery efforts undergo significant expansion from current levels. Changes from the status quo include large-scale increases in oyster population restoration and habitat rehabilitation activities. Changes from the status quo also include an assessment of cultch limitations and development of potential long-term solutions, and evaluation of the feasibility of the development, production, and deployment of large quantities of disease resistant strain(s) of the native oyster for brood stock enhancement.

Population restoration

Under Alternative 2, hatchery seed plantings increase from 200 million to 2 billion annually in Maryland, 25 million to 125 million a year in the Potomac River and 50 to 200 million in Virginia (Table 8). The number of acres of sanctuaries planted with hatchery seed annually increases from 75 to 750 in Maryland and from 10 to 40 in Virginia. Harvest reserve plantings increase from 50 to 500 acres per year and open harvest area hatchery seed plantings increase from 25 to 125 acres annually over the 10 year period. The number of seed stocked per acre each year is the same as in Alternative 1: Maryland sanctuaries – 2 million per acre, Maryland harvest reserves and Potomac River open harvest areas - 1 million per acre, and Virginia sanctuaries - 5 million per acre.

Table 8. Total number of hatchery seed planted, allocation of seed within each management area and number of acres to be planted annually under Alternative2 – Expand Native Oyster Restoration Program

Year	**Number of hatchery seed**			**Allocation of hatchery seed**				**Number of acres planted with**			
	Md	**Pot**	**Va**	**sanctuaries**		**reserves**	**harvest**	**sanctuaries**		**reserves**	**harvest**
				Md	Va	Md	Pot	Md	Va	Md	Pot
1	0.200	0.025	0.050	0.150	0.050	0.050	0.025	75	10	50	25
2	0.350	0.045	0.100	0.263	0.100	0.087	0.045	131	20	87	45
3	0.500	0.070	0.200	0.375	0.200	0.125	0.070	188	40	125	70
4	0.750	0.090	0.200	0.563	0.200	0.187	0.090	281	40	187	90
5	1.000	0.120	0.200	0.750	0.200	0.250	0.120	375	40	250	120
6	1.500	0.125	0.200	1.125	0.200	0.375	0.125	563	40	375	125
7	2.000	0.125	0.200	1.500	0.200	0.500	0.125	750	40	500	125
8	2.000	0.125	0.200	1.500	0.200	0.500	0.125	750	40	500	125
9	2.000	0.125	0.200	1.500	0.200	0.500	0.125	750	40	500	125
10	2.000	0.125	0.200	1.500	0.200	0.500	0.125	750	40	500	125
Total	12.300	0.975	1.750	9.226	1.750	3.074	0.975	4613	350	3074	975

As was the case in Alternative 1, hatchery seed in Alternative 2 will be planted on oyster bars located in sanctuaries, harvest reserves and open harvest areas in the three management regions (Figures 2 and 3). Several hatchery seed plantings will occur on these bars over the 10 year period. As a result, for some bars, the total number of acres planted with hatchery seed will exceed the total size of the bar.

Note that in Alternative 2, the evaluation of Maryland sanctuaries is subset into Alternative 2a and Alternative 2b (Table 9). The two subsets differ in the number of sanctuaries that receive seed and the location of the sanctuaries. In Alternative 2a a total of 32 sanctuaries, which are all located in low salinity waters (5 -12 ppt), will be planted with hatchery seed (Figure 2). In Alternative 2b, a total of 39 sanctuary areas receive seed. Of these, 26 are in low salinity, and 13 are in moderate to high salinity waters (Figure 3).

Table 9. Summary of hatchery seed planting information for Maryland sanctuaries under Alternative 2 -Expand Native Oyster Restoration Program.

Sanctuary			**Total acres planted with hatchery seed at each location over the 10 year period**	
Location	**Name**	**size (acres)**	**Alternative 2a**	**Alternative 2b**
Upper Bay	Gales Lump	248	295	270
Upper Bay	Severn River	208	253	190
Upper Bay	Thomas Point South	46	70	50
Middle Bay	Hering Bay	30	53	50
Chester River	Strong Bay	76	115	110
Chester River	Ringgold	16	30	30
Chester River	ORA Zone A	116	165	105
Eastern Bay	Mill Hill	76	135	130
Eastern Bay	Cabin Creek	22	40	40
Miles River	Miles River	49	70	70
Choptank River	Howell Point	5	10	10
Choptank River	Oxford Lab	4	10	10
Choptank River	Cambridge	95	134	234
Choptank River	States Bank	20	40	40
Patuxent River	Elbow/Teague	32	60	60
Patuxent River	Kitts Marsh	13	20	20
Patuxent River	Trent Hall	63	122	80
Wicomico River	Russell	38	71	71
Potomac River	Dukeheart Channel	138	222	212
Upper Bay	Bodkin Point South	634	705	680
Upper Bay	Outer Magothy	377	490	355
Upper Bay	Tea Table	274	306	251
Chester River	Hells Delight	175	235	175
Choptank River	Royston	175	231	168
Choptank River	Castle Haven	19	40	40
Potomac River	Bluff Point Lumps	5	10	10
Upper Bay	Broad Creek	108	107	
Upper Bay	Love Point	94	91	
Upper Bay	Swan Point	75	75	
Chester River	Long Point	59	58	
Upper Bay	Graveyard	43	40	
Upper Bay	Craighill	310	310	
	Subtotal	**3643**		**3461**
Middle Bay	Plum Point	91		109
Patuxent River	Mears	20		32

Sanctuary			Total acres planted with hatchery seed at each location over the 10 year period	
Location	**Name**	**size (acres)**	**Alternative 2a**	**Alternative 2b**
Patuxent River	Neal Addition	77		120
Choptank river	Cook Point	72		120
Lower Bay	Dorchester PD	14		20
Tangier Sound	Somerset PD	369		270
Lower Bay	St Mary's PD	114		107
Lower Bay	SW Middleground	149		140
Pocomoke Sound	Kitts Creek	33		50
St Mary's River	Piny Point	13		20
Potomac River	Jones Shore	6		10
Tangier Sound	Sharkfin Shoal	90		109
Potomac River	Cooper Creek	27		50
	Subtotal	**1075**		**1157**
	Total	**4718**	**4613**	**4618**

Under Alternative 2, three sanctuaries in Virginia will receive hatchery seed annually (Table 10). A total of 350 acres of hatchery seed will be planted over the 10 year period.

Table 10. Summary of hatchery seed planting information for Virginia sanctuaries under Alternative 2 -Expand Native Oyster Restoration Program.

Sanctuary			Total acres planted with hatchery seed at each location over the 10 year period
Location	**Name**	**size (acres)**	
Great Wicomico R.	Shell Bar	14	122
Great Wicomico R.	Haynie Bar	6	53
Piankatank River	Palaces	53	175
	Total	73	350

Summary information on hatchery seed planting on Maryland’s harvest reserves is presented in Table 11. In Maryland, 18 harvest reserves, which are all in low salinity waters, will receive 50 to 500 million hatchery seed annually. Over the ten year study period a total of 3,074 acres will be planted with hatchery seed.

Table 11. Summary of hatchery seed planting information for Maryland harvest reserves under Alternative 2 - Expand Native Oyster Restoration Program.

Reserve			Total acres planted with hatchery seed at each location over the 10 year period
Location	**Name**	**size (acres)**	
Chester River	Blunt	63	110
Choptank River	Bolingbroke Sand	22	40
Chester River	Emory Hollow	120	200
Patuxent River	Broadneck	271	220
Choptank River	Howell Point	71	120
Choptank River	Black Buoy	88	174
Upper Bay	Swan Point	184	280
Belvedere	Belvedere	234	220
Chester River	Devil's Playground	38	50
Chester River	Boat House	58	100
Upper Bay	Six foot knoll	854	500
Upper Bay	Hackett Point	213	196
West Wicomico	Lancaster	250	250
Choptank River	Dickinson	261	250
Patuxent River	Holland Point	67	56
Miles River	Persimmon Tree	233	196
Wye River	Middleground	12	12
Choptank River	Lighthouse	145	100
	Total	3184	3074

Information on hatchery seed plantings on Potomac River open harvest areas is presented in Table 12. Hatchery seed will be planted on seven bars each year. A total of 975 acres will be planted over the 10 year period

Table 12. Summary of hatchery seed planting information for Potomac River open harvest areas under Alternative 2- Expand Native Oyster Restoration Program.

Open harvest area		**Total acres planted with hatchery seed at each location over the 10 year period**
Name	**size (acres)**	**Alternative 2b**
Ragged Point	165	207
Colonial Beach	99	152
Sheepshead	107	161
Cobb Bar	68	117
Swan Point	113	168
Gum Bar	44	86
Lower Cedar Point	42	84
Total	638	975

Habitat rehabilitation

Oyster bar habitat rehabilitation activities under Alternative 2 are summarized in Table 13. Maryland will rehabilitate 400 acres of oyster bar habitat each year of the 10 year period. Of this total, approximately 80 acres in open harvest areas and 320 acres in sanctuaries will be rehabilitated. In the Potomac River, habitat rehabilitation activities will be undertaken on 110 acres of oyster bottom in open harvest areas each year. In Virginia 522- 2,850 acres of oyster habitat in sanctuaries will receive shell each year.

Table 13. Total acres of oyster bars rehabilitated within each management area and acres restored in sanctuaries, reserves and open harvest areas under Alternative 2 – – Expand Native Oyster Restoration Program.

Region	**Total number of acres of oyster habitat rehabilitated annually**	**Number of acres rehabilitated annually**		
		sanctuaries	**reserves**	**harvest areas**
Maryland	400	320		80
Potomac	110			110
Virginia	522-2850	522-2850		

Habitat rehabilitation will be undertaken on 11 sanctuaries in Maryland (Table 14). A total of eight open harvest areas in Maryland and 12 open harvest areas in the Potomac River will also be rehabilitated (Tables 15). Over the 10 year study period, 3,200 acres of sanctuaries and 800 acres of open harvest areas in Maryland and 1,100 acres in the Potomac River will be rehabilitated. In Virginia a total of 16,899 acres will receive shell over the 10 year period.

Table 14. Summary of habitat rehabilitation information for Maryland sanctuaries under Alternative 2 – Expand Native Oyster Restoration Program.

Sanctuaries			**Total acres planted with oyster shell at each location over the 10 year period**
Location	**Name**	**size (acres)**	
Choptank River	Black Walnut	211	210
Lower Bay	Point Look-In	111	110
Choptank River	Stone Rock	1113	1100
Herring Bay	Holland Point	394	390
Lower Bay	NW Middleground	103	100
Lower Bay	Church Creek	135	130
Little Choptank	Ragged Point	188	180
Little Choptank	Nine Acres	204	200
St. Mary's Shore	Rock Beach	351	350
Eastern Bay	Bald Eagle	120	120
West Wicomico	White Point	311	310
Total		3241	3200

Table 15. Summary of habitat rehabilitation information for Maryland and the Potomac River open harvest areas under Alternative 2 - Expand Native Oyster Restoration Program.

Open harvest areas				Total acres planted with oyster shell at each location over the 10 year period
Region	**Location**	**Name**	**size (acres)**	
Maryland				
	Tangier Sound	Piney Island West(b)	204	200
	Manokin River	Drum Point(a)	22	20
	Tangier Sound	Harris Addition	113	100
	Little Annamessex	Great Rock	323	200
	Pocomoke Sound	Marumsco	128	120
	Eastern Bay	Rich Neck	82	80
	St. Mary's River	Cherry	36	30
	Lower Bay	Butler	65	50
	Total		973	800
Potomac				
		Jones Shore	4	8
		Poseys Bluff	110	220
		Great Neck	98	194
		Kitts Point	3	4
		Hog Island	22	44
		Heron Island	38	74
		St. Georges	17	32
		Ragged Point	165	280
		Thickett Point	11	20
		Bonums	12	20
		Tall Timbers	42	80
		King Copsico	62	124
		Total	584	1100

Comparison of Alternative 1--No Action and Alternative 2 - Expand Native Oyster Restoration Program.

There are significant increases in the numbers of acres of hatchery seed planted under Alternative 2 compared to Alternative 1 (Table 16). Over the 10 year study period, 200 acres in sanctuaries are planted with hatchery seed under Alternative 1 compared to 4,613 acres under Alternative 2. For harvest reserves in Maryland, 1,600 acres are planted with hatchery seed under Alternative 1 versus 3,074 acres under Alternative 2. In Virginia, the number of acres planted with hatchery seed in sanctuaries increases from 100 for Alternative 1 to 350 for Alternative 2. In the Potomac, the number of open harvest areas seeded increases from 250 in Alternative 1 to 975 in Alternative 2.

In Maryland, the amount of habitat rehabilitated in sanctuaries over the 10 year period increases from 400 acres under Alternative 1 to 3,200 acres under Alternative 2. One result of the increase in the rehabilitation of oyster habitat in sanctuaries is a decline in rehabilitated habitat in open harvest areas in Maryland from 1,600 acres in Alternative 1 to 800 acres rehabilitated in Alternative 2 over the 10 year period. In the Potomac River, 550 acres are restored in Alternative 1 compared to 1100 acres in Alternative 2. In Virginia 9,501 acres of oyster habitat are restored in Alternative 1 and 16,899 acres in Alternative 2.

Table 16. Comparison of number of acres planted under Alternative 1 – No Action and Alternative 2 - Expand Native Oyster Restoration Program.

Year	Maryland				Virginia		Potomac	
	Sanctuaries		Reserves		Sanctuaries		Harvest areas	
	Alt 1	Alt 2	Alt 1	Alt 2	Alt 1	Alt 2	Alt 1	Alt 2
1	20	75	160	50	10	10	25	25
2	20	131	160	87	10	20	25	45
3	20	188	160	125	10	40	25	70
4	20	281	160	187	10	40	25	90
5	20	375	160	250	10	40	25	120
6	20	563	160	375	10	40	25	125
7	20	750	160	500	10	40	25	125
8	20	750	160	500	10	40	25	125
9	20	750	160	500	10	40	25	125
10	20	750	160	500	10	40	25	125
Total	200	4613	1600	3074	100	350	250	975

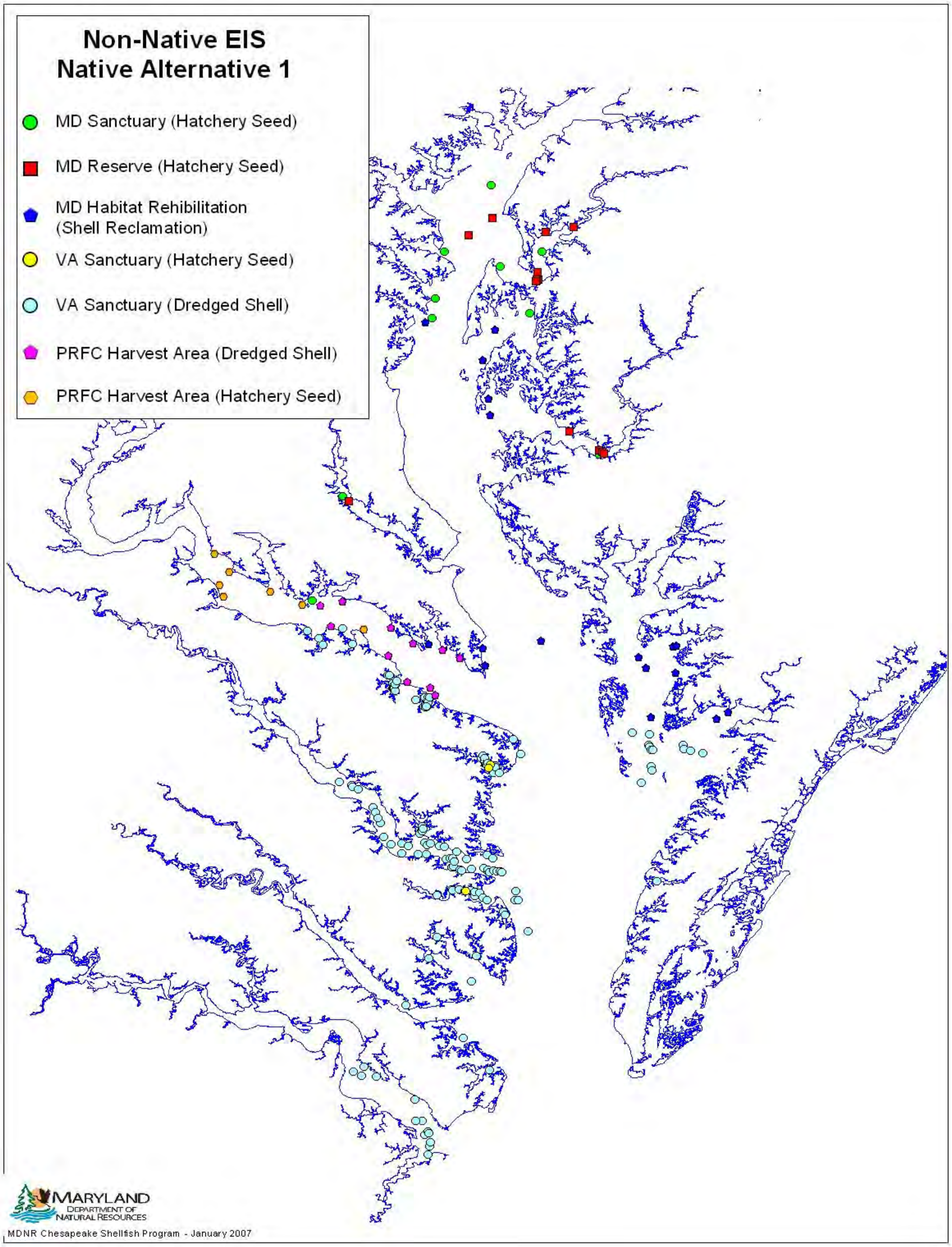

Figure 1. Location of hatchery seed plantings on sanctuaries, harvest reserves and open harvest areas and location of oyster bar rehabilitation activities for Alternative 1 – No Action.

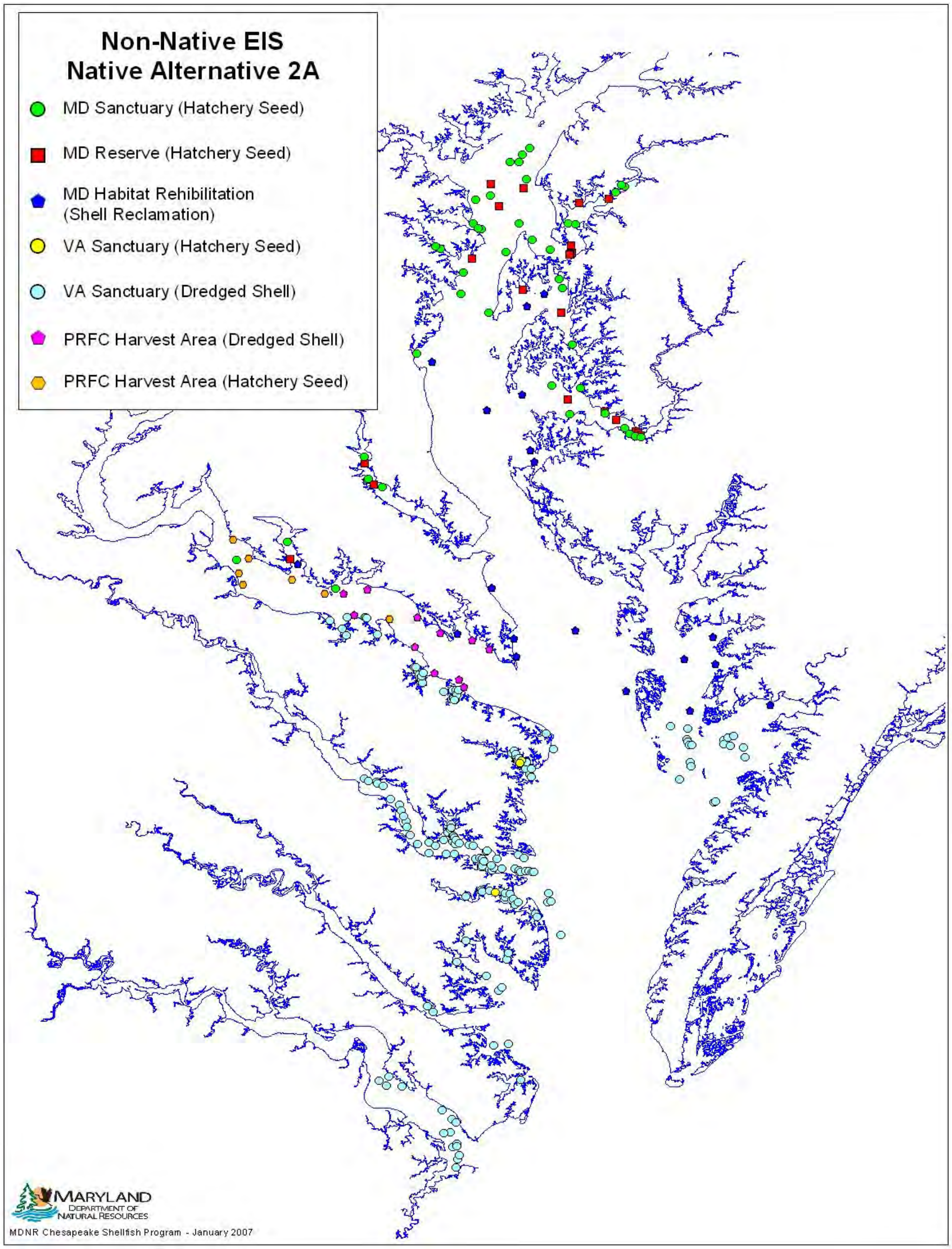

Figure 2. Location of hatchery seed plantings on sanctuaries, harvest reserves and open harvest areas and location of oyster bar rehabilitation activities for Alternative 2a – Expand Native Oyster Restoration.

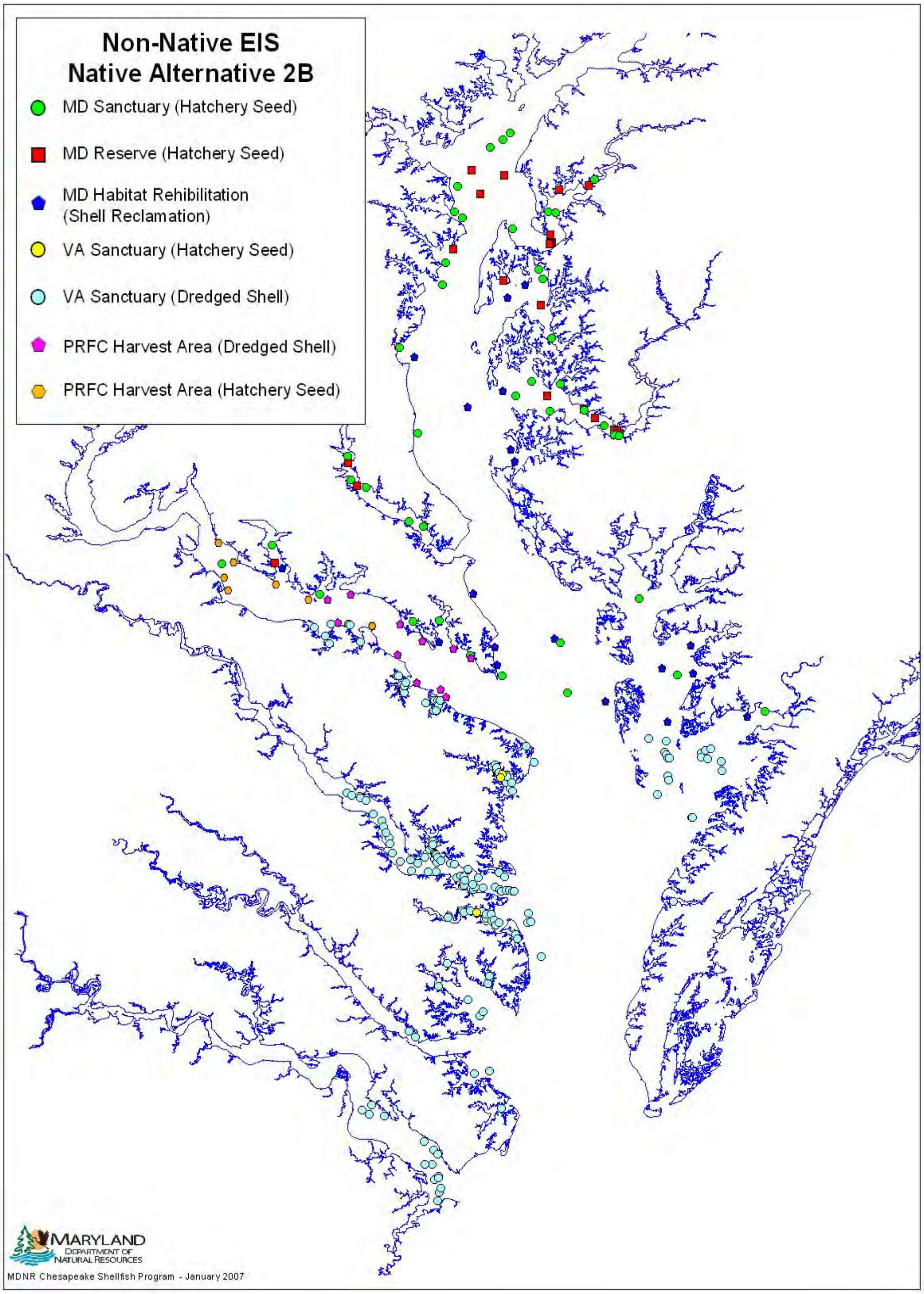

Figure 3. Location of hatchery seed plantings on sanctuaries, harvest reserves and open harvest areas and location of oyster bar rehabilitation activities for Alternative 2b – Expand Native Oyster Restoration.

Attachment 6

Explanation for Effects of Harvest

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Harvest had less effect on modeled abundances than might intuitively be expected for several reasons. The most important cause is that harvest does not simply simulate a large removal of a healthy population, as does an increase in natural mortality due to disease; harvest occurs as an additional removal of remaining larger oysters from a population that has already experienced relatively high natural mortality rates due to disease. Under these conditions, the year class that has just reached market size, but has not yet experienced natural mortality or harvest rates for market sized oysters, composes a large proportion of the total number of market sized oysters.

We use a simplified example to illustrate. Here we assume that a bar has constant salinity, disease level, natural mortality rates, and recruitment of 1,000 spat per year. If the bar is located in medium salinity and experiences tier 2 disease prevalence, then mean natural mortality rates are 0.39 for small oysters and 0.43 for market sized oysters (Table 3). If no harvest occurs, a cohort of 1,000 spat recruited would decline to 610 oysters at age 1 (i.e., 1,000 * 0.61), 372 oysters at age 2, etc., as listed below. The total number of market sized oysters on the bar would be 527 (i.e., 227 + 129 + … + 0).

Age	Natural mortality rate	Size	N
1	0.39	Small	610
2	0.39	Small	372
3	0.39	Market	227
4	0.43	Market	129
5	0.43	Market	74
6	0.43	Market	42
7	0.43	Market	24
8	0.43	Market	14
9	0.43	Market	8
10	0.43	Market	4
11	0.43	Market	3
12	0.43	Market	1
13	0.43	Market	1
14	0.43	Market	0
	Total Market		527

If harvest begins on the bar at a constant rate, the numbers will reach a new equilibrium after several years. For example, if the bar experiences a 20% harvest rate, small oysters experience 39% natural mortality, and then an additional 2.2% incidental harvest (10% of the catch of market-size oysters, Section 2.11; i.e., $0.2 / 0.9 = X / 0.1$, $X \approx 0.022$). Market-size oysters experience 43% natural mortality, and then 20% of the remaining oysters are harvested. Note that a model year begins in the fall, after recruitment and natural mortality are calculated because most natural mortality due to disease and predation is believed to occur during summer

(Andrews 1996; Burreson and Ragone Calvo 1996; Ford and Tripp 1996; Ford and Haskin 1982; Carriker 1955; Manzi 1970; Gunter 1979; Garton and Stickle 1980; Pearse and Wharton 1938; Landers and Rhodes 1970; citations in Vølstad et al. 2008, Attachment 4). Harvest occurs during winter (Figure 9). Thus harvest corresponds to the exploitation rate (F; Ricker 1975) for the winter, and occurs independently of natural mortality. The population will stabilize after six years to a total of 400 market-size oysters (i.e., 217 + 99 + … + 0). Six-hundred-ten oysters will reach small size each year from the 1,000 spat recruited the previous year, which experience 39% mortality. Other yearly abundances (N_f) are calculated by multiplying the number of oysters alive from the previous year by the appropriate survival rate.

				Year 1			Year 2			Year 3			Year 4			Year 5			Year 6		
Age	Natural mortality rate	Size	Year 0, No harvest	N_h[1]	N_r[2]	N_f[3]	N_h	N_r	N_f	N_h	N_r	N_f	N_h	N_r	N_f	N_h	N_r	N_f	N_h	N_r	N_f
1	0.39	Small	610	13	597	610	13	597	610	13	597	610	13	597	610	13	597	610	13	597	610
2	0.39	Small	372	8	364	364	8	356	364	8	356	364	8	356	364	8	356	364	8	356	364
3	0.39	Market	227	45	182	222	44	178	217	43	174	217	43	174	217	43	174	217	43	174	217
4	0.43	Market	129	26	104	104	21	83	101	20	81	99	20	79	99	20	79	99	20	79	99
5	0.43	Market	74	15	59	59	12	47	47	9	38	46	9	37	45	9	36	45	9	36	45
6	0.43	Market	42	8	34	34	7	27	27	5	22	22	4	17	21	4	17	21	4	16	21
7	0.43	Market	24	5	19	19	4	15	15	3	12	12	2	10	10	2	8	10	2	8	9
8	0.43	Market	14	3	11	11	2	9	9	2	7	7	1	6	6	1	4	4	1	4	4
9	0.43	Market	8	2	6	6	1	5	5	1	4	4	1	3	3	1	3	3	1	2	2
10	0.43	Market	4	1	4	4	1	3	3	1	2	2	0	2	2	0	1	1	0	1	1
11	0.43	Market	3	1	2	2	0	2	2	0	1	1	0	1	1	0	1	1	0	1	1
12	0.43	Market	1	0	1	1	0	1	1	0	1	1	0	1	1	0	0	0	0	0	0
13	0.43	Market	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
14	0.43	Market	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total market-size oysters			527			462			428			412			405			402			400

[1]N_h Number harvested
[2]N_r Number remaining after harvest
[3]N_f Final number after recruitment and mortality

We conducted similar calculations for harvest rates of 40%, 60%, and 80% to determine the population structure of the bar at equilibrium. Under these conditions, a 20% harvest rate results in 76% of the number of market-size oysters that would have been present if no harvest occurred (i.e., 100 x 400 / 527), but an 80% harvest rate still results in 40% of the number of markets that would have been present if there were no harvest. This is because most of the population of market-size oysters consists of age-3 animals under any harvest rate.

Number of oysters under constant conditions, tier 2 mortality, medium salinity:

Age	Size Class	Natural mortality rate	No harvest	Harvest rate 20%	40%	60%	80%
0	Spat		1,000	1,000	1,000	1,000	1,000
1	Small	0.39	610	610	610	610	610
2	Small	0.39	372	364	356	350	339
3	Market	0.39	227	217	207	199	188
4	Market	0.43	129	99	71	45	21
5	Market	0.43	74	45	24	10	2
6	Market	0.43	42	21	8	2	0
7	Market	0.43	24	9	3	1	0
8	Market	0.43	14	4	1	0	0
9	Market	0.43	8	2	0	0	0
10	Market	0.43	4	1	0	0	0
11	Market	0.43	3	1	0	0	0
12	Market	0.43	1	0	0	0	0
13	Market	0.43	1	0	0	0	0
14	Market	0.43	0	0	0	0	0
Total market-size oysters			527	400	315	258	213
Percent of mkt pop with no harvest				76	60	49	40

The effect is more pronounced when natural mortality rates are higher. For example, if the same calculations are performed using tier 1 mortality rates in high salinity (Table 3), the population of market-size oysters consists almost entirely of age-3 animals. In this case, an 80% harvest rate still yields 69% of the number of market-sized oysters that would have survived if no harvest had occurred.

Number of oysters under constant conditions, tier 1 mortality, high salinity:

Age	Size Class	Natural mortality rate	No harvest	Harvest rate 20%	40%	60%	80%
0	Spat		1,000	1,000	1,000	1,000	1,000
1	Small	0.69	310	310	310	310	310
2	Small	0.69	96	94	92	90	88
3	Market	0.79	20	19	19	18	17
4	Market	0.79	4	3	2	1	1
5	Market	0.79	1	1	0	0	0
6	Market	0.79	0	0	0	0	0
Total market-size oysters			25	23	21	19	17
Percent of mkt pop with no harvest				91	83	75	69

Jim Wesson of the Virginia Marine Resources Commission recently presented empirical data that support this result. A comparison of oyster population structures on harvested bars and nearby unharvested bars revealed that density of market-size oysters on bars that were unharvested for several years were only slightly greater than densities on harvested bars.

These examples neglect the stock-recruitment relationship, which would increase differences in abundance among scenarios slightly. However, the effect is small given the population on most bars in the model. It is important to note that small oysters provide some reproduction before reaching sizes when they are exposed to the greatest natural mortality and fishing mortality. These oysters provide some protection from driving small populations to extinction in the model, as they do in the Bay.

A second reason that harvest was less important than expected is that a large portion of the habitat layer was designated as sanctuaries, reserves, or closed areas that were not fished. Approximately 22% of the market-size oysters in the starting population were located on bars that were not fished. This means that nominal harvest rates of 20, 40, 60, and 80 percent were actually 16, 31, 47, and 62 percent harvest rates, respectively, for the first year of the simulation. All other conditions being equal, the population on unfished bars grows faster than on similar fished bars in the model, thereby increasing the proportion of the population not exposed to fishing with each yearly iteration. Sensitivity analysis revealed that a 10% poaching rate reduced the total population of the Bay by 13%, and a 25% poaching rate reduced the population by 16%.

Overall, the model produced credible results. Although absolute differences in predicted abundance were not large in relation to the restoration goal, percent changes in abundance varied with harvest rates within the expected range (Figures 11-12, and below).

		Harvest rate			
	No harvest	20%	40%	60%	80%
Alternative 1 abundance	469,327,386	374,725,116	330,207,716	313,302,325	304,097,062
Percent of market-size population in no-harvest scenario		0.80	0.70	0.67	0.65
Alternative 2A abundance	1,761,651,246	1,605,625,007	1,396,503,468	1,278,520,298	1,170,811,992
Percent of market-size population in no-harvest scenario		0.91	0.79	0.73	0.66

As noted in the text, we do not suggest that fishing is unimportant in controlling oyster populations in the Bay. Fishing becomes an increasingly important factor in limiting population growth as natural mortality decreases or the population size increases. This means that managing harvest will likely be necessary to achieve the restoration goal. Further, fishing may reduce the development of disease resistance through natural selection, or have other effects that are not modeled, as described in the text.

Attachment 7

Oyster Population Estimates for the Maryland Portion of Chesapeake Bay Population Size, Biomass, and Exploitation Rate Time Series Estimates for 1994 – 2007

(Barker, L., K. Greenhawk, and T. O'Connell)

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Oyster Population Estimates for the
Maryland Portion of Chesapeake Bay

Population Size, Biomass, and Exploitation Rate
Time Series Estimates for 1994 – 2007

Prepared by: Maryland Department of Natural Resources, Fisheries Service
Linda Barker, Kelly Greenhawk, and Tom O'Connell

September 8, 2008

(corrected variance estimates)

INTRODUCTION

This report provides documentation for a revised method to estimate the oyster population in Maryland's portion of Chesapeake Bay, and presents time series of population values for 1994-2007. These estimates are then used to provide estimates of associated biomass and exploitation rate. An earlier version of this report, Greenhawk et al. (2007), presented an explanation of the initial method used to develop estimates of oyster abundance in the Maryland portion of Chesapeake Bay, and presented 1994-2007 estimates of population and biomass. That report was included as Attachment A to Appendix A of the Draft Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay (PEIS). Unrealistic estimates of fishing mortality suggested that those population levels may have been under-estimated. An additional method of estimation has been developed since the preparation of that first report and is included here. This method follows the formerly approved estimation procedure but employs different oyster density values. In addition, estimates of variance were developed for the population estimates, in order to determine whether this method could be used to discern statistically significant differences among years.

Population estimates developed in this report were used to estimate oyster exploitation rates in Maryland for the period 1994 to 2004. Those exploitation rates were required for and have been used in various analyses presented in the PEIS, and have contributed to estimation of the PEIS restoration goal. Also, Maryland's population estimate of market sized oysters for the year 2004 was combined with the similar estimate from Virginia to provide a starting population (year 2004) for PEIS assessments of alternatives.

METHODS

Oyster abundance was based on estimates of suitable oyster habitat and estimates of oyster density in each of eight basins in the Maryland portion of Chesapeake Bay. The steps used to calculate the population estimates are presented as follows.

Step 1 - Delineation of Maryland Basins

The Maryland portion of the Chesapeake Bay was divided into eight basins. This was done in an attempt to account for the significant observed variation in oyster abundance among Choptank River; 4) Little Choptank River; 5) Tangier Sound; 6) Potomac River; 7) Patuxent River; and 8) Chesapeake Bay mainstem (Figure 1).

Step 2 - Calculation of Available Oyster Habitat in Maryland Basins

Maryland's oyster population estimates are based on multiplying the annual measured oyster density by the amount of available oyster habitat within each basin. The most recent comprehensive survey of available oyster habitat is the Maryland Bay Bottom Survey (MBBS), conducted between 1976 and 1983. (Note: A digital dataset of the MBBS is available from MD DNR.) It is widely accepted in the scientific community that the amount and quality of existing oyster habitat in Maryland has declined significantly since the MBBS survey was conducted. Because the oyster population estimates are based on the amount and quality of available habitat, changes in habitat availability and quality since the MBSS was completed needed to be taken into account in our study.

A survey was conducted by the MD DNR Cooperative Oxford Laboratory between 1999 and 2000 at 15 oyster bars located throughout the Maryland portion of the Chesapeake Bay (Smith et al. 2005). The objective of the 1999-2000 MD DNR survey was to assess the relative abundance of oyster habitat within the cultch bottom classifications of both the 1978-1983 MBBS and a survey conducted by C.C. Yates between 1906-1911. The 15 bars surveyed were believed to be a fair representation of bars typically found in the Chesapeake Bay based upon a similarity of bottom types found at each bar. The MBBS classified oyster habitat into the following seven bottom classes: cultch, mud with cultch, sand with cultch, mud, sand, hard bottom and leased bottom (Smith et al. 2001). Areas of bottom with generous amounts of oyster shell were classified as cultch, while areas of scattered oyster shell were classified as either sand with cultch or mud with cultch. The cultch, sand with cultch and mud with cultch classifications were later categorized as either high quality habitat, low quality habitat, or lost habitat, for the purposes of this oyster population estimation effort (Table 1).

Results from the MD DNR survey confirmed anecdotal reports of significant loss of available oyster habitat within Maryland over the past 20 years. Only 2.37% of high quality oyster bottom habitat reported by the MBBS remained. Of the remaining high quality bottom habitat defined by the MBBS, 26.80% had degraded to low quality bottom classification consisting of heavily sedimented shell with sand or mud, and 68.58% was completely lost to sand or mud (Table 1). Overall, there was a 70.83% decline of available oyster habitat within the high quality bottom classifications defined by the MBBS. Given the significant level of habitat degradation on the high quality bottom since the MBBS was conducted, these population estimate calculations assumed a complete loss of low quality habitat identified in the MBBS survey.

MBBS-based adjustments to high quality habitat could not be applied to certain sections of Eastern Bay and the Choptank River (Broad Creek and Harris Creek) due to missing MBBS data. Therefore, oyster bar boundaries from the 1906-1911 Yates survey were used in these two areas (Table 1). The 1999-2000 MD DNR survey found that 85.88% of the charted oyster bars from the Yates survey have been lost to mud or sand. Only 0.95% of the charted Yates oyster bars fit the criteria for high quality and 11.29% meet low quality bottom habitat criteria. Habitat degradation of the charted Yates bars was more significant than the results based upon an assessment of the MBSS. This was expected given the earlier time period of the Yates Survey. These habitat adjustments were applied like the MBSS adjustments.

Significant amounts of fossil dredge shell and, to a lesser extent, shell retrieved from oyster packing houses have been planted in Maryland waters of Chesapeake Bay over the past four decades. The 1999-2000 MD DNR survey included an assessment of length of time after planting that fossil shell and shell from packing houses were suitable oyster habitat. Results indicated that shell plantings became moderately sedimented after an average of 5.5 years and heavily sedimented after an average of 18.6 years. For the purpose of estimating and assessing habitat for the biomass calculations, it was determined that only shell plantings 5 years old or less would be included in habitat estimates (Smith et al. 2005). Any GIS polygons designated as low quality habitat after adjustments to the MBBS and Yates surveys adjustments that overlapped shell plantings 5 years old or less were re-classified as high quality habitat. This did not result in an increase in the total amount of habitat, but simply changed the preliminary bottom classification. Total habitat only increased when the shell plantings did not overlap adjusted MBBS and Yates habitat polygons. These population estimates assumed that 1999-2003 shell plantings were constant throughout the 1994-2007 time period.

Leased oyster bottom within Maryland is another potential source of available habitat. Maryland leases are not legally permitted on charted oyster bottom, and therefore, should not overlap any habitat derived from the MBBS and Yates surveys. Because leases cannot legally occur on natural oyster bottom, lease holders commonly plant shell substrate to enhance spat settlement and/or support seed plantings. Maryland lease harvest data were reviewed to determine the level of lease activity. The average reported lease harvest was 1,424 bushels between 2000 and 2004 and 3,767 bushels between 1990 and 1999 (MD DNR 2005). Based on this level of reported activity, it was assumed that there were little or no remaining shell plantings on lease grounds over the past 5 years. Given the functional longevity of shell plantings reported by MD DNR Cooperative Oxford Laboratory, it was further assumed that any plantings prior to 2000 were no longer providing any suitable oyster habitat

Table 2 presents the sequence of calculated values in the estimation of available oyster habitat for the Choptank River basin. Table 3 presents a summary of estimates of high and low quality habitat for all eight basins delineated in this study.

Assumptions for Step 2

1. The degradation of oyster bottom habitat reported in the MD DNR 1999-2000 survey was representative of all bars within Maryland's portion of the Chesapeake Bay.
2. There was a complete loss of available oyster habitat within the "mud with cultch" and "sand" bottom classifications reported by the MBBS survey.
3. The amount of available high and low quality habitat remained constant throughout the 1994-2007 time series.
4. Shell plantings did not provide suitable oyster habitat after 5 years.
5. Shell plantings between 1999 and 2003 were representative of shell plantings between 1994 and 2007.
6. Maryland leases did not provide any suitable oyster bottom habitat between 1994 and 2007.

Step 3 – Estimation of Oyster Density

Annual estimates of oyster density were calculated using data collected in the Maryland DNR Fall Oyster Dredge Survey (Fall Survey) and estimates of the average tow area and efficiency of the oyster dredge used to collect data in the survey. Maryland's Fall Survey collects oyster size and abundance data at 43 sentinel stations located throughout Maryland's Chesapeake Bay. Bushel count data collected in 2004 and basin averages are presented in Table 4. A detailed description of the survey can be found in the MD DNR report for the 2003 and 2004 Fall Surveys (MD DNR, 2005).

Whereas the Fall Survey provides number of oysters per bushel of dredged material, the number of oysters per m^2 was needed for the population calculations. Therefore, the area swept to collect 1 bushel was needed. Studies were conducted in 2001, 2002, 2005 and 2006 to determine tow area of the dredge. Starting and ending positions (latitude and longitude), distance traveled and the amount of material collected (bu) for each tow were noted for all years except 2002. For 2002, a GIS program was used to translate these positions into distance traveled. The width of the original dredge used for this study was measured (33 inches) in order to calculate the area covered during the tow. This area was divided by the amount of material collected to calculate the mean area to collect a one bushel sample of material. [Earlier versions of this document used an estimate of 45 m^2/bu, which was the recorded value developed by the original researchers. However, no supporting documentation has been found for the calculation of this value.] Re-calculation from the original data sheets provided estimates for mean and variance for each study year. The values for 2001, 2005 and 2006 were all less than 10% different from their mean. However, the value for 2002 was 46% different. Because the 2002 value was based on distances that were calculated using a different methodology than the other studies, these data were eliminated from the data set. The resultant unweighted mean value for the 2001, 2005 and 2006 sample data was 55 m^2/bu. The 6% relative error for this mean indicated high precision for this estimate (i.e., the tow area was highly consistent over time).

The average efficiency of the dredge was also needed to translate the Fall Survey values for oyster density to population numbers. A study of dredge efficiency initiated by MD DNR in 2001 estimated an average dredge efficiency of 10% (unpublished MDNR study, 2002). To date, no documentation has been found for this value. Chai et al. (1992) found dredge efficiencies from 2 to 26% in their study that used a dredge tow distance of 131 meters. They referenced the asymptotic decrease in dredge effectiveness with tow length found by Allen and Cranfield (1976), and stated that tow distances longer than a few meters will underestimate oyster density. The mean Maryland DNR dredge tow distance was 68 meters, so a dredge efficiency value of 10% seemed reasonable, as it was in the lower area of the range found by Chai et al. (1992).

Therefore oyster density was estimated as follows:

$$DH = ((BC_{basin}/(DE * TA))*M \qquad \textit{(Eqn 1)}$$

where:

DH = oyster density (oysters/acre)
BC_{basin} = annual basin average of small and market oysters per bushel of cultch material (oysters/bushel), as determined from the Fall Survey.
DE = dredge efficiency (0.10)
TA = tow area (55 m^2/bu)
M = conversion factor (4046.856 m^2/acre)

An example of estimating oyster density for the Chester River in 2004 is provided below. Note that the mean bushel count (BC) is the only variable input parameter in these calculations.

$$\text{Oysters/acre} = ((59.5 \text{ oysters/bu})/(0.1*55 \text{ m}^2\text{/bu})*4046.856 \text{ m}^2\text{/ac} = 43{,}405 \text{ oysters/ac} \qquad \textit{(Eqn. 2)}$$

where:

59.5 oysters/bushel = arithmetic mean of
Chester River Site 1: Buoy Rock = 34 oysters/bushel
Chester River Site 2: Old Field = 85 oysters/bushel

Assumptions for Step 3

1. Oyster abundance statistics developed from data collected by the Fall Survey were representative of the associated basins.
2. The Fall Survey provided a representative sample of the classified high quality habitat within each basin, including natural oyster bars, managed oyster harvest reserves and oyster sanctuaries. Even though seed densities for plantings on sanctuaries and harvest reserve areas are significantly greater, no subsequent population estimates were available, and so were not incorporated into these calculations.
3. The mean dredge tow area for obtaining one bushel of sample material and the defined dredge efficiency for the Fall Survey were representative and consistent throughout the 1994-2007 time series.
4. Oyster densities for low quality habitat derived from a 1994 patent tong survey were representative and consistent from 1994-2001 and oyster density defined for low quality habitat in 2002 was representative and consistent from 2002-2007.

Step 4 – Calculation of the Estimated Oyster Population in MD Chesapeake Bay

The estimated population of oysters in each basin was the multiple of the density estimate and the area estimate for that basin. The estimate of Maryland's Chesapeake Bay total annual population was calculated as the sum of the populations for Maryland's eight basins. An example of the 2004 calculation of total population is presented in Table 5.

Step 5 – Calculation of the Confidence Limits for the Population Estimate

Because variance is additive, the estimated variance for the population was calculated as the sum of the basin variances. Each basin variance was based solely on the variance associated with the MDNR Fall Survey mean basin bushel count using the multiplicative property of variance:

If $Y = K X$, (*Eqn 3*)

then

$\sigma^2_Y = K^2 \sigma^2_X$ (*Eqn 4*)

where:

X (variable) = mean MDNR Fall Survey bushel count (oysters/bu)

K (constant) = area scaling factor (total basin area in acres x 729.5 bu/ac).

Step 6 – Calculation of Estimated Oyster Biomass in MD Chesapeake Bay

The estimated annual biomass of small and market oysters for each basin was calculated in two steps. In order to distribute the population among size groups, the total estimated number of small and market oysters for each basin was multiplied by the relative abundance within each 5-mm size class ≥ 35 mm. The relative abundance values were taken from the Fall Survey. This distribution was converted to biomass (grams per dry tissue weight) by the formula given below:

$\log_{10}\text{weight} = -3.7595 + 2.062584*\log_{10}$ size class (Jordan et al. 2002) (*Eqn 5*)

where:

size class = length in mm of the midpoint of a given size class

Total biomass was calculated as the sum of biomass in all size classes for all basins. Estimates of variance were not developed for the biomass estimates. If estimates were to be developed, error associated with aging and measurement would have to be added in addition to the errors already discussed.

Step 7 – Calculation of Exploitation Rate in MD Chesapeake Bay

Annual exploitation rate was calculated by dividing the number of market-sized oysters harvested by the total number of market-sized oysters in the population. The number of market-sized oysters harvested was estimated as the multiple of bushels harvested and 350 market-sized oysters/ MD bushel (C. Judy, personal communication). The number of bushels harvested was derived from MDNR Fisheries Statistics data, using only harvest from Maryland Chesapeake Bay. The total number of market-sized oysters in the population was calculated as the sum of oysters ≥ 77mm in each basin.

RESULTS

Population estimates using MDNR Fall Survey density applied to total habitat are presented in Table 6 and Figures 2 and 3. Using MDNR Fall Survey oyster densities as representative of all habitat in Maryland, the point estimate of the 1994 baseline population of small and market sized oysters in Maryland Chesapeake Bay was estimated to be 2.45 billion oysters. The 2007 population was estimated to be 1.25 billion oysters.

The variance associated with the population estimates was too great to enable detection of statistical trend in the time series or statistical differences among years (Table 6, Figure 2). Even though the variance associated with observed values (MDNR FS bushel count) was very low (0.3 to 1.5% relative error), the variance associated with total population estimates ranged from 31% to 42% relative error. (Total variance was primarily a reflection of the scaling factor used to transform mean bushel count to number of oysters in the basin.) Even so, these values are underestimates, because tow area and dredge efficiency were assumed constant over time and space, and habitat area was assumed constant over time.

The time series of biomass estimates is presented in Table 7. Although confidence intervals were not calculated for biomass, the time series showed a trend similar to that of the population point estimates (Figure 3). The biomass time series is slightly different from the population time series because biomass reflects the changing proportions of small and market sized oysters in each basin each year.

The time series of annual exploitation rate based on population estimates derived from use of MDNR Fall Survey oyster densities applied to all habitat in Maryland is presented in Table 8. The 1994-2007 time series high rate was approximately 19% in 2001, and has been 5% or less for the past 4 years. These calculated exploitation rates indicate that the population estimates are reasonable.

DISCUSSION

These revised estimates differ both in magnitude and variability from the abundance estimates based on the method approved by the Chesapeake Bay Program in 2002. The original method classified 90% of the habitat as “low quality” with an associated very low oyster density, held constant within two time periods 1994-2001 and 2002-2007. Because these estimates did not use this classification, a higher density was applied to all habitat, with resulting abundance estimates roughly 5–8 times higher than previously published results. Because an annual density estimate was used, the estimates show more annual variability than previously published results.

The current method employs data from a survey designed to produce a relative index of abundance (MDNR FS density estimates) in order to produce an absolute estimate of abundance. However “reasonable” the resulting point estimates of abundance are, the associated (large) variance demonstrates a fundamental issue in the estimation procedure and suggests that development of an absolute estimate of abundance that has sufficient precision to show real trends in the bay-wide oyster population will require different stock assessment methods, at significantly more cost.

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Table 1. Relative abundance of high quality bottom classifications remaining from the values reported by the MBBS and Yates surveys, as reported by the 1999-2000 MD DNR Cooperative Oxford Laboratory acoustic benthic habitat survey.

Habitat Classification	Bottom Classification	MBBS	Yates
		Percent Remaining	
High Quality Habitat	Clean shell	1.16	0.62
	Lightly sedimented shell with sand	1.21	0.33
	Total	**2.37**	**0.95**
Low Quality Habitat	Heavily sedimented shell with mud	21.64	8.33
	Heavily sedimented shell with sand	5.16	2.96
	Total	**26.80**	**11.29**
Total Habitat	**Total**	**29.17**	**12.24**
Habitat Lost	Mud	20.58	32.52
	Sand	48.00	53.36
	Total	**68.58**	**85.88**
Other	Gravel/cobble/boulder	1.37	1.06
	Unidentified	0.88	0.82

Table 2. Values from the 2004 oyster habitat estimate for the Choptank River basin. The Choptank provides an example of the use of Yates values.

Area Source	Bottom Class	Original Estimate	Adjustment Factor	Current Estimate of High Quality Habitat	Current Estimate of Low Quality Habitat
MBBS	High Quality	14,397.42 acres	2.37%	340.18 acres*	
			26.80%		3,859.55 acres
	Low Quality		0%		
Yates	Not specified	1,028.43 acres	0.95%	10.20 acres*	
			11.29%		115.68 acres
Shell Plantings	High Quality	164.32 acres	0 %	164.32 acres	
Leased Bottom	Not specified		0%		

* Values may vary by a maximum of 1.12 acres due to differences in decimal precision in software employed.

Table 3. Acreages for each habitat type in each basin. Total acreage shown in bold text were used to calculate the annual Maryland oyster population from 1994 – 2007.

Basin	Habitat Type*	High Quality Habitat (ac)	Low Quality Habitat (ac)	Sum
Chester	B	126.27	1,432.65	1,558.92
	P	481.23	0.00	481.23
Total		607.50	1,432.65	**2,040.15**
Choptank	B	340.18	3,859.55	4,199.73
	P	164.32	0.00	164.32
	Y	10.20	115.68	125.88
Total		514.70	3,975.23	**4,489.93**
Eastern Bay	B	76.28	865.48	941.76
	P	192.11	0.00	192.11
	Y	58.09	659.11	717.20
Total		326.48	1,524.59	**1,851.07**
Little Choptank	B	79.36	900.41	979.77
	P	1.00	0.00	1.00
Total		80.36	900.41	**980.77**
Md. Mainstem	B	1,111.05	12,605.65	13,716.70
	P	684.33	0.00	684.33
Total		1,795.38	12,605.65	**14,401.03**
Md. Potomac	B	300.31	3,407.26	3,707.57
	P	12.86	0.00	12.86
Total		313.17	3,407.26	**3,720.43**
Patuxent	B	129.24	1,466.32	1,595.56
	P	56.25	0.00	56.25
Total		185.49	1,466.32	**1,651.81**
Tangier	B	563.15	6,389.26	6,952.41
	P	56.89	0.00	56.89
Total		620.04	6,389.26	**7,009.30**
Grand Total				**36,144.49**

* Habitat codes are as follows:
B = Maryland Bay Bottom Survey
P = shell plantings
Y = Yates survey

Table 4. Small- and market-size oysters per bushel of cultch material in samples collected by the 2004 MDNR Fall Oyster Survey.

Basin	Water Body	Oyster Bar	Site Code	Oysters /Bu	Basin Average
Chester	Chester River	Buoy Rock	CHBR	34	59.50
Chester	Chester River	Old Field	CHOF	85	
Choptank	Broad Creek	Deep Neck	BCDN	48	24.88
Choptank	Choptank River	Cook Point	CRCP	1	
Choptank	Choptank River	Lighthouse	CRLI	8	
Choptank	Choptank River	Oystershell Point	CROS	20	
Choptank	Choptank River	Royston	CRRO	43	
Choptank	Choptank River	Sandy Hill	CRSH	20	
Choptank	Choptank River	Tilghman Wharf	CRTW	39	
Choptank	Tred Avon River	Double Mills	TADM	20	
Eastern Bay	Eastern Bay	Bugby	EBBU	64	80.83
Eastern Bay	Eastern Bay	Hollicutts Noose	EBHN	96	
Eastern Bay	Eastern Bay	Parsons Island	EBPI	57	
Eastern Bay	Miles River	Bruffs Island	MRBI	74	
Eastern Bay	Miles River	Long Point	MRLP	42	
Eastern Bay	Miles River	Turtle Back	MRTU	152	
Little Choptank	Little Choptank	Cason	LCCA	27	22.50
Little Choptank	Little Choptank	Ragged Point	LCRP	18	
Md Mainstem	Bay North	Swan Point	BNSP	37	57.57
Md Mainstem	Middle Bay	Stone Rock	MESR	54	
Md Mainstem	Upper Bay	Hacketts	UBHA	76	
Md Mainstem	Western Shore	Butlers	WSBU	123	
Md Mainstem	Western Shore	Flagpond	WSFP	34	
Md Mainstem	Western Shore	Hog Island	WSHI	74	
Md Mainstem	Western Shore	Holland Point	WSHP	5	
Md Potomac	Potomac River	Cornfield Harbor	PRCH	54	56.57
Md Potomac	Potomac River	Lower Cedar Point	PRLC	18	
Md Potomac	Potomac River	Ragged Point	PRRP	0	
Md Potomac	St. Mary's River	Chickencock	SMCC	67	
Md Potomac	St. Mary's River	Pagan	SMPA	214	
Md Potomac	Wicomico River	Lancaster	WWLA	27	
Md Potomac	Wicomico River	Mills West	WWMW	16	
Patuxent	Patuxent River	Broome Island	PXBI	17	17.0
Tangier	Fishing Bay	Goose Creek	FBGC	7	75.20
Tangier	Holland Straits	Holland Straits	HOHO	151	
Tangier	Honga River	Normans	HRNO	12	
Tangier	Manokin River	Georges	MAGE	176	
Tangier	Nanticoke River	Wilson Shoal	NRWS	33	
Tangier	Pocomoke Sound	Marumsco	PSMA	106	
Tangier	Tangier Sound	Back Cove	TSBC	120	
Tangier	Tangier Sound	Old Womans Leg	TSOW	7	
Tangier	Tangier Sound	Piney Island	TSPI	85	
Tangier	Tangier Sound	Sharkfin Shoal	TSSS	55	

Table 5. Calculation of 2004 oyster population estimates for small and market oysters in the Maryland portion of Chesapeake Bay (estimated by applying MDNR Fall Survey density estimates to total habitat).

Basin	Density (oyst/bu)	Density (oyst/ac)	Area (acres)	Total (oysters)
Chester	59.50	43,405	2,040.15	88,552,423
Choptank	24.88	18,146	4,489.93	81,474,939
Eastern Bay	80.83	58,967	1,851.07	109,152,759
Little Choptank	22.50	16,414	980.77	16,097,969
MD Mainstem	57.57	41,998	14,401.03	604,814,155
MD Potomac	56.57	41,268	3,720.43	153,536,512
Patuxent	17.00	12,401	1,651.81	20,484,737
Tangier	75.20	54,858	7,009.30	384,515,520
2004 Population				1,458,629,014

Table 6. Revised oyster population estimates for small and market oysters in the Maryland portion of Chesapeake Bay over the period 1994–2007 (estimated by applying MDNR Fall Survey density estimates to total habitat).

	Chester	Choptank	Eastern Bay	Little Choptank	Md Mainstem	Md Potomac	Patuxent	Tangier	Total	LCL_{95}	UCL_{96}	RE
1994	1.3E+08	4.6E+08	5.7E+07	9.2E+07	5.5E+08	3.5E+08	9.6E+06	8.0E+08	2,448,595,330	6.6E+08	4.2E+09	0.31
1995	1.3E+08	4.0E+08	4.2E+07	1.3E+08	5.0E+08	4.3E+08	4.0E+07	4.6E+08	2,132,674,680	3.4E+08	3.9E+09	0.38
1996	1.4E+08	4.3E+08	8.5E+07	1.1E+08	6.7E+08	2.6E+08	4.7E+07	3.1E+08	2,065,562,218	2.8E+08	3.9E+09	0.38
1997	2.4E+08	3.2E+08	7.6E+07	6.8E+07	4.0E+08	3.4E+08	5.1E+07	2.8E+08	1,774,399,398	0	3.6E+09	0.31
1998	2.6E+08	6.1E+08	4.8E+08	1.0E+08	5.1E+08	5.3E+08	4.1E+07	2.4E+08	2,779,360,129	9.9E+08	4.6E+09	0.41
1999	2.7E+08	5.2E+08	2.7E+08	9.4E+07	5.8E+08	2.3E+08	4.7E+07	3.9E+08	2,406,377,018	6.2E+08	4.2E+09	0.39
2000	2.6E+08	4.0E+08	1.9E+08	1.0E+08	4.1E+08	1.7E+08	9.3E+07	3.2E+08	1,941,671,372	1.5E+08	3.7E+09	0.34
2001	1.4E+08	2.3E+08	9.6E+07	4.3E+07	4.1E+08	1.1E+08	1.3E+07	2.5E+08	1,286,042,936	0	3.1E+09	0.35
2002	5.9E+07	6.3E+07	6.1E+07	2.1E+06	3.4E+08	4.6E+07	1.7E+07	3.1E+08	894,429,778	0	2.7E+09	0.38
2003	1.0E+08	5.7E+07	7.6E+07	9.7E+06	7.4E+08	3.2E+08	6.4E+07	7.1E+08	2,078,345,516	2.9E+08	3.9E+09	0.42
2004	8.9E+07	8.1E+07	1.1E+08	1.6E+07	6.0E+08	1.5E+08	2.0E+07	3.8E+08	1,458,629,014	0	3.2E+09	0.38
2005	8.6E+07	1.7E+08	1.1E+08	1.9E+07	8.0E+08	8.8E+07	3.7E+07	1.8E+08	1,501,765,312	0	3.3E+09	0.35
2006	9.5E+07	1.8E+08	8.0E+07	3.1E+07	5.1E+08	1.0E+08	5.3E+07	1.3E+08	1,178,362,091	0	3.0E+09	0.32
2007	4.0E+07	1.4E+08	3.1E+07	5.7E+07	2.4E+08	1.8E+08	4.8E+06	5.6E+08	1,251,144,884	0	3.0E+09	0.42

Table 7. Biomass estimates of small and market oysters in the Maryland portion of Chesapeake Bay over the period 1994–2007 (estimated by applying MDNR Fall Survey density estimates to total habitat).

	Chester	Choptank	Eastern Bay	Little Choptank	Main Stem	Md Potomac	Patuxent	Tangier	Total Biomass (g dry weight)	Total Biomass (kg dry weight)
1994	2.2E+08	4.5E+08	9.8E+07	5.9E+07	7.8E+08	3.7E+08	2.0E+07	6.6E+08	2,649,830,647	2.6E+06
1995	1.8E+08	4.8E+08	7.1E+07	1.4E+08	7.6E+08	4.4E+08	6.9E+07	5.2E+08	2,663,910,262	2.7E+06
1996	1.9E+08	5.5E+08	9.3E+07	1.3E+08	8.5E+08	3.3E+08	6.1E+07	4.1E+08	2,602,889,363	2.6E+06
1997	2.8E+08	4.7E+08	1.1E+08	9.1E+07	6.6E+08	4.7E+08	1.0E+08	4.2E+08	2,589,344,841	2.6E+06
1998	3.1E+08	6.6E+08	4.4E+08	1.4E+08	6.7E+08	6.2E+08	9.3E+07	3.7E+08	3,304,599,224	3.3E+06
1999	4.1E+08	6.8E+08	3.2E+08	1.2E+08	8.6E+08	2.7E+08	1.2E+08	5.1E+08	3,290,709,824	3.3E+06
2000	3.7E+08	5.9E+08	2.7E+08	1.2E+08	6.7E+08	1.9E+08	1.2E+08	3.0E+08	2,632,765,899	2.6E+06
2001	2.2E+08	3.4E+08	1.5E+08	5.2E+07	5.6E+08	1.4E+08	1.8E+07	2.8E+08	1,762,591,900	1.8E+06
2002	1.1E+08	1.1E+08	8.5E+07	2.8E+06	5.2E+08	7.2E+07	3.3E+07	2.9E+08	1,238,701,563	1.2E+06
2003	1.8E+08	8.4E+07	1.1E+08	6.3E+06	8.7E+08	1.9E+08	5.0E+07	6.3E+08	2,102,732,965	2.1E+06
2004	1.3E+08	1.3E+08	1.5E+08	1.6E+07	8.7E+08	1.4E+08	2.6E+07	4.8E+08	1,934,558,351	1.9E+06
2005	1.6E+08	2.4E+08	1.6E+08	2.5E+07	1.2E+09	1.5E+08	6.7E+07	3.0E+08	2,266,176,953	2.3E+06
2006	2.1E+08	2.8E+08	1.4E+08	4.1E+07	7.6E+08	2.0E+08	7.7E+07	2.3E+08	1,932,981,880	1.9E+06
2007	2.3E+08	2.9E+08	1.9E+08	4.7E+07	9.5E+08	1.1E+08	4.1E+07	1.1E+08	1,958,570,459	2.0E+06

Table 8. Estimates of exploitation rate based on population estimated by applying MDNR Fall Survey density estimates to total habitat (population estimates presented in Table 10).

	# Oysters (Small and Market)	# Markets	# Bushels Harvested	# Markets Harvested	Exploitation Rate
1994	2,448,595,330	738,955,888	79,579	27,852,822	3.8%
1995	2,132,674,680	905,517,993	166,308	58,207,685	6.4%
1996	2,065,562,218	948,113,414	200,771	70,269,878	7.4%
1997	1,774,399,398	958,400,019	176,871	61,904,941	6.5%
1998	2,779,360,129	1,065,044,590	284,573	99,600,715	9.4%
1999	2,406,377,018	1,121,918,052	425,101	148,785,497	13.3%
2000	1,941,671,372	956,077,374	339,200	118,720,063	12.4%
2001	1,286,042,936	638,582,553	343,015	120,055,366	18.8%
2002	894,429,778	385,728,075	146,962	51,436,756	13.3%
2003	2,078,345,516	511,200,897	51,915	18,170,222	3.6%
2004	1,458,629,014	635,288,773	21,619	7,566,650	1.2%
2005	1,501,765,312	925,871,594	65,646	22,976,244	2.5%
2006	1,178,362,091	774,783,789	130,496	45,673,572	5.9%
2007	1,251,144,884	684,019,736	164,412	57,544,200	8.4%

Figure 1. Map showing the 8 Maryland basins used in oyster population estimates.

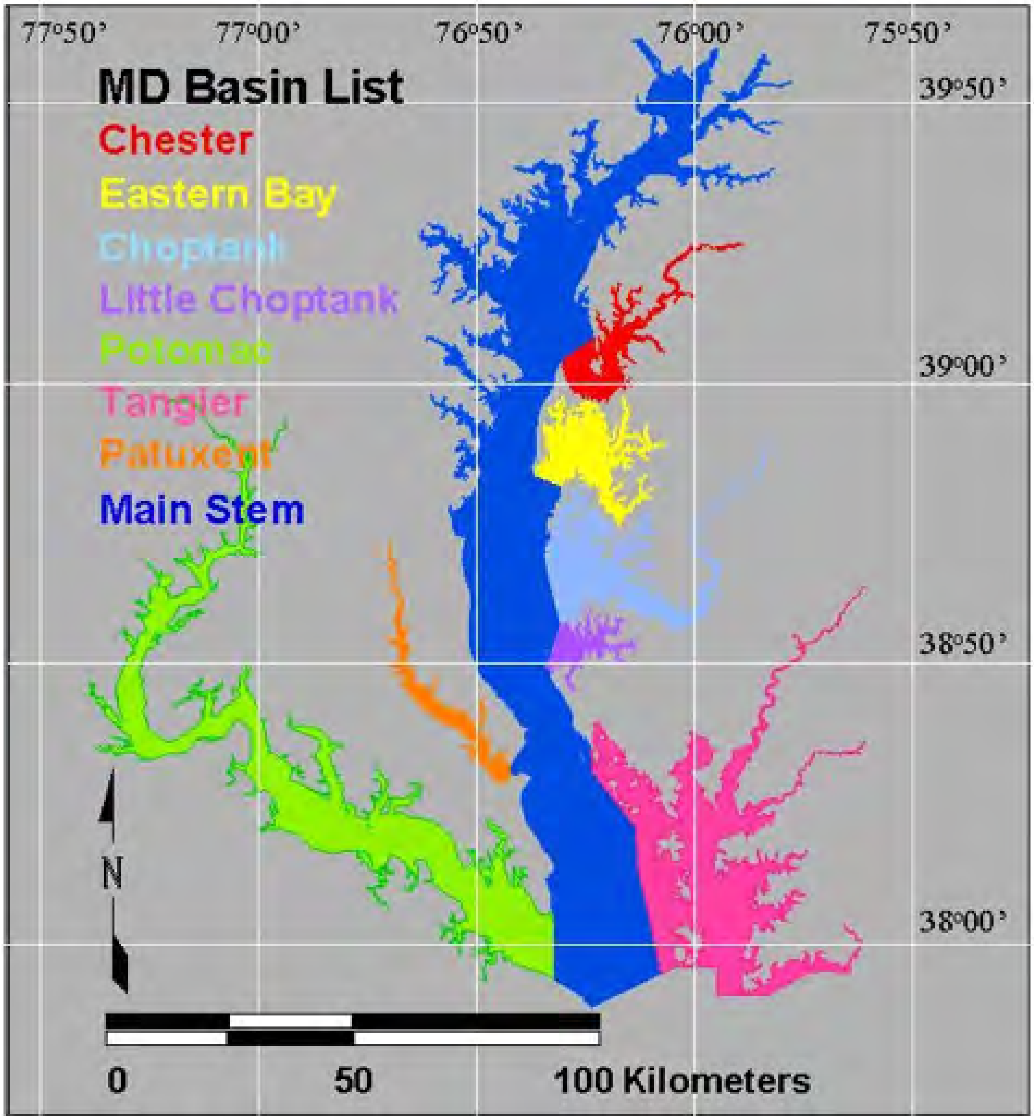

Figure 2. Revised oyster population estimates with 95% confidence intervals for small and market oysters in the Maryland portion of Chesapeake Bay over the period 1994–2007 (estimated by applying MDNR Fall Survey density estimates to total habitat).

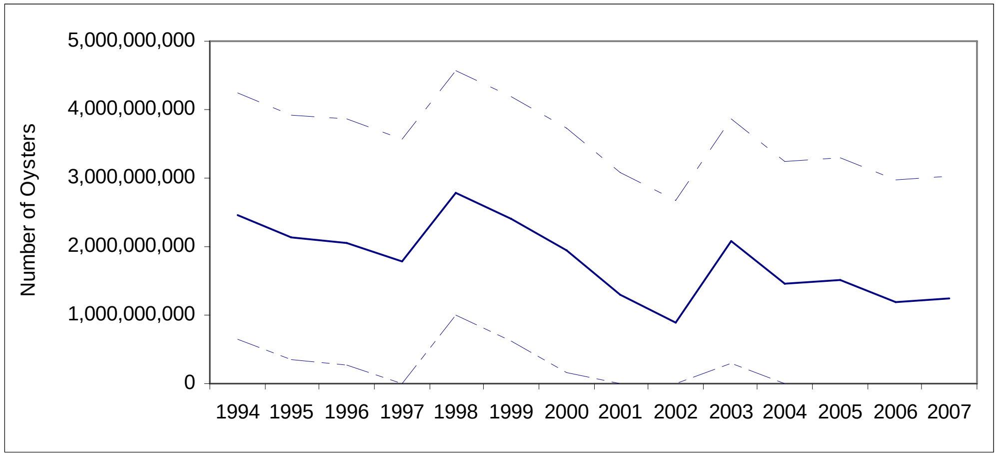

Figure 3. Maryland Chesapeake Bay Oyster Population and Biomass Point Estimates for 1994-2007 (estimated by applying MDNR Fall Survey density estimates to total habitat).