***Sustainable Fisheries Goal Implementation Team Executive Committee***

# ADOPTION STATEMENT

Restoration Goals, Quantitative Metrics and Assessment Protocols
for Evaluating Success on Restored Oyster Reef Sanctuaries

A product of the Oyster Metrics Workgroup
as convened by the
Sustainable Fisheries Goal Implementation Team
of the Chesapeake Bay Program

We, the undersigned, adopt the results and metrics provided by the Oyster Metrics Workgroup for the restoration of oysters within the Chesapeake Bay according to Executive Order 13508 *Strategy for Protecting and Restoring the Chesapeake Bay Watershed*.

We agree to work together to implement the management strategies and actions recommended by this workgroup to restore oyster populations in 20 tributaries of Chesapeake Bay by 2025, further adding to the need to develop clear restoration goals, quantitative metrics and assessment protocols.

We agree to accept this report, which serves to formally adopt success metrics and monitoring protocols for restoring the native oyster resource.

October 17, 2011

Sustainable Fisheries Goal Implementation Team Executive Committee

FOR NOAA ____________________________________________

FOR MD-DNR ____________________________________________

FOR DC-DDOE ____________________________________________

FOR PRFC ____________________________________________

FOR VMRC ____________________________________________

FOR ASMFC ____________________________________________

FOR USAC ____________________________________________

# Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries

**Report of the Oyster Metrics Workgroup**

**Submitted to the**
**Sustainable Fisheries Goal Implementation Team**
**of the Chesapeake Bay Program.**

**October 2011**

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## 1. Introduction

Concerted efforts over the past two decades to restore oyster reefs to the Chesapeake Bay have met with mixed success (1-4). A recent review of oyster restoration activities in Virginia and Maryland pointed to the lack of clear goals, established metrics of success, consistent sampling protocols and sufficient monitoring as contributing to our uncertainty surrounding their success (5). Monitoring activity has generally not been well coordinated with restoration activity, and different entities involved in the monitoring have used different sampling gear, monitoring approaches and assessment protocols. Despite explicit objectives of restoring ecological functions and ecosystem services provided by oyster reefs, few measures beyond the number of market-sized oysters have been used to judge success.

Executive Order 13508 *Strategy for Protecting and Restoring the Chesapeake Bay Watershed* established a goal of restoring oyster populations in 20 tributaries of Chesapeake Bay by 2025, further adding to the need to develop clear restoration goals, quantitative metrics and assessment protocols. This document represents an effort by state and federal agencies directly involved in oyster restoration in the Bay to develop clear and consistent objectives, definitions, sampling protocols and assessment techniques pursuant to achieving this goal and evaluating success.

To address these issues the Sustainable Fisheries Goal Implementation Team (GIT) established a technical workgroup comprised of representatives from NOAA, USACE, MDNR, VMRC and academic scientists from UMCES and VIMS. The specific charge to the group was to develop common bay-wide restoration goals, success metrics and monitoring and assessment protocols for <u>sanctuary reefs</u> that include progress toward achieving a sustainable oyster population that ultimately will provide increased levels of ecosystem services. The charge for the group specifically excludes fisheries-specific metrics since it is limited to sanctuary reefs, though the oyster population metrics are certainly germane to fisheries management. It is also important to point out that the group was tasked with identifying a minimum suite of metrics that should be measured across all sanctuary reefs, particularly for the purpose of assessing progress toward the Executive Order oyster goal. We recognize that some sanctuary reefs will need to be monitored more intensely to address specific issues (research priorities, ancillary goals, etc.). The minimum suite of metrics laid out herein should in no way be seen as limiting such additional monitoring and research activity. The workgroup recognizes that future research will inform oyster restoration practices, and strongly encourages the use of sound adaptive management practices. We view this report as a step towards a consensus document between the primary governmental agencies involved in oyster restoration in the Bay with respect to restoration goals, thresholds for success, and monitoring protocols. Our recommendations are informed by the best available science, restoration results to date, and the varying missions and resources of the agencies involved. As such, it accommodates the very different restoration approaches and observed success rates across different geographic areas of the Bay. We expect that, as the state of knowledge advances, targets and approaches outlined here will evolve.

## 2. Restoration Goals

The overarching goal of restoring a large oyster population, capable of providing valued ecosystem services and supporting a vibrant fishery, drives specific management actions and targets, such as those set forth in E.O. 13508. The crucial fact remains, however, that oyster populations in the Bay have undergone a dramatic regime shift over the past half century and that high natural mortality rates associated with disease, predation, siltation, and unaccounted harvest (poaching), along with negative shell budgets (i.e. shell loss rates > shell accretion rates) in many areas, pose significant challenges to achieving a greatly expanded oyster population. Implicit in the goal of restoring 20 tributaries is the notion that working on a tributary scale will be necessary to achieve sufficiently large changes in oyster populations. Moreover, the cumulative effects of restoration activities are unlikely to be linear; that is, there is an expectation

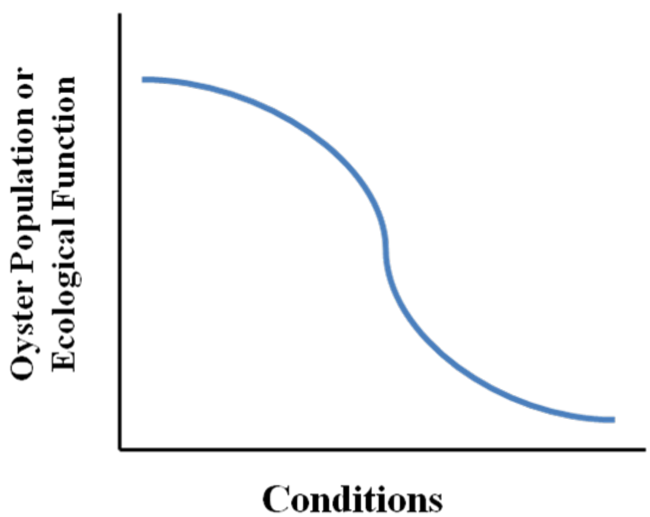


**Figure 1.** Generalized representation of a threshold response in which improvement in conditions (towards the left) must exceed a critical value to return the system to a stable improved state (upward).

that it will be necessary to exceed several threshold values (e.g. in shell volume, larval supply and survival, disease tolerance, etc.) to achieve a regime shift that supports greater population abundance. Figure 1 provides a simplified depiction of this condition graphically and helps to make the point that restoration of oyster populations and the ecological functions they provide may require exceeding threshold improvements in environmental conditions.

*2.1. Tributary-level restoration* – Central to our task of developing clear goals and measures of success is establishing what constitutes restoration at the level of a tributary. Is the end product a population of a certain size? Or, is it a percentage of historical oyster habitats occupied by restored reefs? Are we seeking an operational definition related to the amount of restoration activity (shell, alternative substrate or seed planting) or a functional one in which a tributary is not restored until a greatly expanded, sustainable oyster population is achieved? These are not trivial issues to resolve. The workgroup spent substantial time considering these issues and it is important to review a number of caveats before setting final targets.

The intent of setting a goal of restoring oysters to 20 tributaries by 2025 is to undertake restoration at a sufficiently large scale to dramatically increase oyster populations and realize enhanced ecosystem services at a tributary-wide scale. The workgroup discussed this intent at length, defining it as a functional goal. *Specifically, the goal of oyster restoration at the tributary-level is to dramatically increase oyster populations and recover a substantial portion of the ecosystem functions provided by oyster reefs within the tributary.* In effect the goal is to return to the higher plateau represented in Figure 1. As restoration proceeds, the workgroup believes that it is essential that these functional goals remain the primary target.

Exactly what will be necessary to achieve these functional goals is unknown. Simply stated, it has not been done previously. We lack both an empirical and theoretical basis for knowing how much oyster reef restoration is necessary within a given tributary to reach our functional goals. Our underlying assumption is that achieving this goal will require the *successful functional restoration* of a significant proportion of the historical oyster reefs within a tributary. As discussed in the following section, many years of post restoration monitoring will likely be necessary to determine successful functional restoration at the reef level. Additionally, there are several practical limitations on the scale of restoration that can be undertaken within a given tributary, including available restorable areas, the extent of private leases and designated fisheries bars, the availability of shell, and limits on the amount of spat-on-shell production.

Despite the ultimate goal of functional restoration success, restoration goals at the tributary level will need to include *operational goals*, e.g., the amount of shell planted or the quantity of spat-on-shell or the number of bars planted. The agencies and organizations involved in restoration must set operational targets for planning and staging their work. It is necessary, therefore, to establish target levels for restoration activity within a tributary that constitute operational or intermediate measures of success that facilitate restoration planning and implementation. Unfortunately, there is no clear answer to how much oyster reef habitat within a tributary should be targeted for restoration. Comparing detailed surveys by Winslow in Tangier Sound (6) and by Moore in the James River (7) with the more general Yates (8) and Baylor (9) surveys in Maryland and Virginia, respectively, USACE estimated that approximately 40% of the areas included in the Yates and Baylor surveys were hard oyster habitat. Further, using available information, USACE has projected that 8-16% (40x20% to 40x40%) of historic (Yates and Baylor) habitat needs to be restored in a tributary to effect a significant change. Other significant considerations in setting these targets are observed degradation of historical oyster bottom and practical limits associated with the amount of reef area within a tributary that can realistically be set aside as sanctuaries and restored.

"Restorable areas" have, at a minimum, hard bottom that will support shells or alternative substrates deposited on the bottom in a restoration effort (i.e. they will not sink into mud or silt). Other considerations for restorable areas include availability of public bottom (not leased) and appropriate water quality. The amount of reasonably restorable area varies considerably among tributaries. Surveys of oyster bars conducted during the late 19$^{th}$ and early 20$^{th}$ Centuries provide our base maps for historical oyster distributions (6-9). The most recent comprehensive survey of the condition of the Maryland Bay Bottom was conducted between 1974 and 1983. More recent surveys (11, 12) have attempted to characterize the currently-viable habitat and estimate habitat loss. In Maryland, a recent estimate suggested that less than 10% of the areas formerly classified as supporting oysters currently had suitable substrate for oyster restoration (12). In Virginia, surveys conducted in the 1980s suggested that only about 20% of areas formerly classified as oyster bars were viable (11, 13). These estimates do not necessarily precisely characterize the amount of bottom area that is suitable for restoration, but they do illustrate the point that conditions at many of the historical oyster bars are not currently favorable for conducting oyster restoration. In Virginia, an Oyster Restoration Atlas (14) has been developed by VIMS and VMRC, which incorporates the most recent substrate maps, the boundaries of public and leased oyster grounds, bathymetry and salinity in relation to current and potential restoration sites on a tributary by tributary basis. These maps not only target areas that are suitable for restoration, but make it quite clear that many areas are either not suitable or not available by nature of being privately leased. In Maryland, the Native Oyster Restoration and Aquaculture Development Plan designates some areas to be established as sanctuaries and others for aquaculture development, with other areas open to fishing. It is clear that tributaries will need to be selected for restoration based upon numerous criteria, including the amount of area suitable for restoration and how this area compares to the historic extent of oysters. Those with too little suitable area offer little chance for improvement, and those with too much are likely intractable.

These considerations lead us to recommend that tributaries slated for oyster restoration be carefully selected as those adequate in size to be meaningful, but not so large as to exceed reasonable expectations with available resources. Large-scale, tributary-based oyster restoration is in its infancy. Techniques and methods are only beginning to be identified and are largely untested at this scale. With this in mind, as well as recognized funding and resource limitations, it is recommended that small tributaries (creeks and small rivers) receive initial focus, given the tributaries meet other restoration criteria. (See Appendix A for examples of Chesapeake tributaries that fall into this size category.) It may also be reasonable to target geographically distinct sub-segments of larger tributaries for focused oyster restoration and still be consistent with the E.O. goal. Tributaries need to be further evaluated for the amount of available habitat that is suitable for restoration and the reality of establishing and maintaining the restoration sites as sanctuaries.

*In accordance with this analysis, the workgroup suggests that an operational goal of restoring 50 -100% of currently restorable oyster habitat represents a reasonable target for tributary-level restoration.* In selecting a tributary for focused restoration, it is also important to consider its historic oyster bottom where accurate data exist. As mentioned previously, USACE has projected that 8-16% of historic oyster bottom habitat needs to be restored in a tributary to effect a significant change. *Thus, an ideal candidate tributary is one where 50-100% of the currently restorable bottom is equivalent to at least 8%, and preferably more, of its historic oyster bottom.*

Final judgments about the ultimate success of these activities in catalyzing a regime shift to greatly enhanced, sustainable oyster populations may not come until many years after the actual restoration activities are completed. Functional success metrics for gauging the ultimate success of these efforts are discussed in sections below.

*2.2. Reef-level restoration* – Oyster restoration activity (planting of substrate or spat-on-shell) takes place at the level of an oyster bar (=reef). Again, however, we lack clear definitions of either operational or functional success at this level. Complete failure is easily observed as a lack of recruitment to planted shell, high mortality of planted seed, or the degradation and burial of shell before a population becomes established. Success, on the other hand, can be harder to define and quantify. Do we define operational success in restoring a reef only after 100% of that reef area has been planted with shell, alternative substrate or spat-on-shell? Or, is some lesser coverage sufficient? Is functional success achieved only when a threshold abundance of oysters (e.g., 100 oysters $m^{-2}$) is established, or a target value of an ecosystem service (e.g., 500 kg N removed $hectare^{-1}$ $yr^{-1}$) is reached? And, what is the time course over which this success is to be judged? Each of these requires some resolution if progress towards achieving the goal set forth in the E.O. is to be tracked in a consistent manner. We attempt to provide some clarity on these issues below.

Establishing operational goals and metrics is an imperative. Restoration activity on an individual bar must have a target value at the implementation phase. Do we target planting shell, alternative substrate or spat-on-shell on 100% of the bar before we consider our current activity at that bar complete or do we target planting 50% of the area, for instance? A relevant consideration here is that in their unexploited state oyster beds in the Chesapeake Bay did not exist as vast uniform reefs, but rather varied considerably in shape, size and degree of bottom coverage (6, 7, 15-17) with "hard-rock" and "mud-shell" areas occurring within an oyster bed (18). Practical considerations of planting techniques in current restoration practices also play a role in variable coverage of oysters on a reef. Thus, it seems apparent that restoration of an oyster bar should target planting something less than 100% of the historical bar area.

Unfortunately, we have only limited information on which to base specific recommendations for the amount of coverage that should be targeted with shell, alternative substrate or spat-on-shell plantings. Figure 2A shows a spatial view of intertidal oyster reefs in the coastal bays along Virginia's Eastern Shore. Individual patch reefs, typically 2 – 3 $m^2$ in area are separated by 1 – 4 m and larger scale patterns of reef distribution appear to the reflect flow patterns. We do not suggest that this pattern is typical of all subtidal reefs within Chesapeake Bay, but use it to illustrate that in a natural, seemingly healthy and stable oyster population that oysters do not cover 100% of the bottom within an area that might reasonably be termed a reef. Historical accounts from subtidal reefs in the Chesapeake Bay indicate that "reefs", even during the early phase of heavy exploitation, were not uniformly covered in oysters, but included extensive areas without oysters (6, 7). A lack of complete coverage of the bottom is

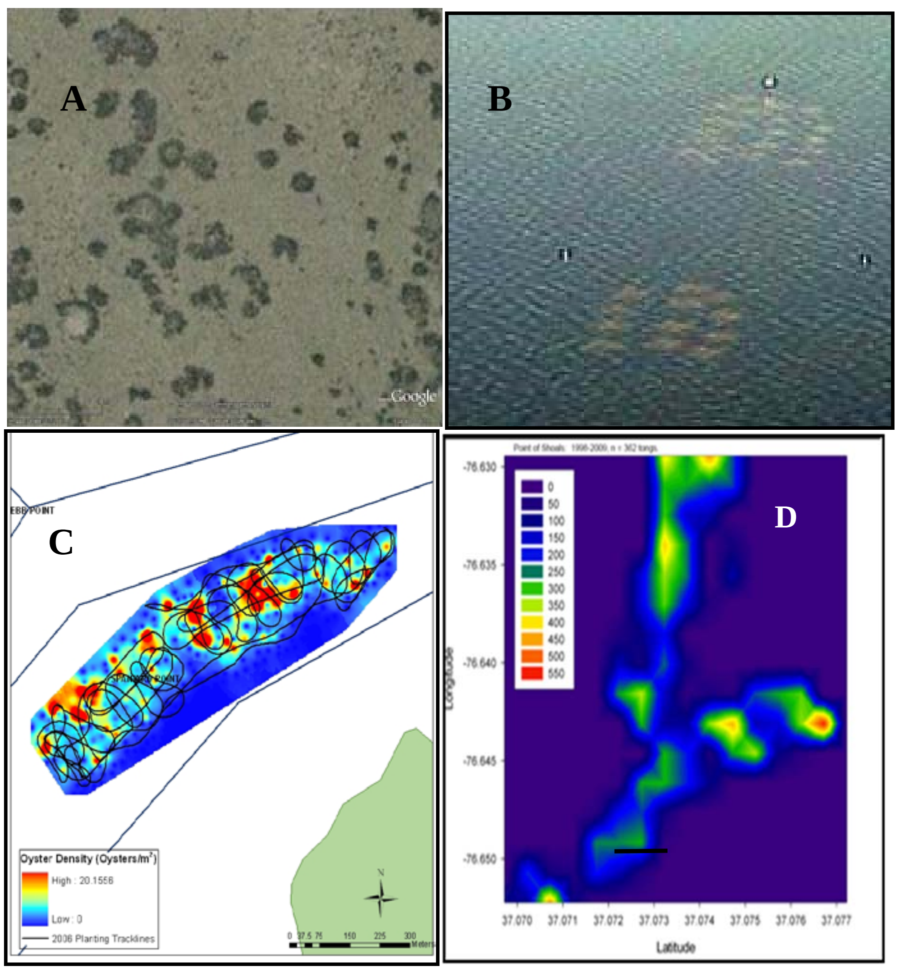


**Figure 2.** Shell and oyster coverage on natural and restored reefs: (**A**) Intertidal patch reefs in the VA coastal bays; (**B**) Shell plants in mounds in the Rappahannock River; (**C**) Track lines from seed planting and oyster densities on a restored reef in the Chester River; (**D**) Map of oyster density on Point of Shoals reef in the James River. (Figure credits: A. Image from VA Base Map Program via Google Maps; B. photo by P.G. Ross; C. figure from Ken Paynter; D. figure from Roger Mann.)

also evident in planting techniques currently in use (Fig. 2B, C) for planting shell and spat-on-shell in Virginia and Maryland, respectively, and on a natural reef in the James River (Fig. 2D).

There are two distinct reasons to establish minimal planting coverage operational targets: (1) to provide guidance on how much planting should be planned for a particular reef and (2) to establish a consistent approach to reporting the spatial extent of operationally restored reefs. In lieu of a more rigorously defined value, we suggest that at this time a minimum target of 30% coverage of a reef area be set as an operational practice. *That is, shell planting and spat-on-shell should result in a minimum of 30% of coverage of the restoration reef*[1]. We emphasize here that, as with the other targets that we are recommending, this minimum value represents a minimum consensus value that can be achieved across the range of restoration techniques and restoration sites in Chesapeake. For instance, it is reasonable that close to 100% coverage can be achieved at some restoration sites which receive shell only; however, areas in upper Bay for which spat-on-shell is the preferred restoration technique, 30% coverage of an oyster bar may be near the upper limited that can be practically achieved.

Operational targets for the oyster population size and structure within these planted areas also need to be established. Again, however, we lack a clear empirical or theoretical basis for setting these targets. We follow a few guiding principles in developing some tentative recommendations in this area. The first, and most compelling, is that our concept of a reef as a biogenic structure is unlikely to be achieved at very low densities of oyster (< 10 and perhaps 20 adult oysters/$m^2$). Indeed, the persistence of the reef itself is dependent upon densities above some minimal level. A positive shell budget will require sufficient numbers of oysters accreting at a rate that exceeds current sediment deposition and shell degradation rates, a condition that Mann and Powell (2) have pointed out is not currently achieved with many restoration efforts. In a successful modeling study of oyster populations in the James River, Mann and Evans (19) assumed, based upon a previous empirical study (20), that at a mean density of 100 oysters/$m^2$ fertilization efficiency was less than 10%. Because oysters are largely protandric

[1] This recommendation is not intended to suggest that restoration activity should select a region of the target area that is only 30% of the total and concentrate shell or spat-on-shell planting only in that region. Rather, it is a recognition that even a natural or fully restored reef is not a monolithic structure fully covered in oysters and shell. 30% is intended only as a minimal acceptable coverage within the area that was actually planted.

hermaphrodites, with most larger, older individuals being females, achieving high reproductive success may require that multiple ages classes are present to ensure adequate numbers of males and females. A second area of guidance in developing oyster density or biomass targets comes from studies of ecosystem services provided by oyster reefs. Though we lack quantitative relationships between oyster density and the various ecosystem services that we are seeking to recover via restoration, the studies to date that have documented such services have, to our knowledge, done so on reefs with mean densities well above 20 adult oysters/m$^2$ (e.g., 21-35).

Though a firm basis for establishing optimal mean density and age structure targets is lacking, *the workgroup recommends that a mean density of 50 oysters/m$^2$ and 50 grams dry weight /m$^2$ containing at least two year classes, and covering at least 30% of the reef area provides a reasonable target operational goal for reef-level restoration.*[2] A mean oyster density of 50 adults/m$^2$ over 30% of the bottom is comparable to the mean oyster density in Maryland 100 years ago, which was 10-15 oysters/m$^2$ over an entire oyster bar (36). The target of having a minimum of two year classes reflects the need in low recruitment-low mortality areas in the upper Bay to ensure that as oysters from initial plantings age and progressively contain more females that a younger year class with more males is present ensure fertilization. Thus, this criterion requires attention to the age and sex ratio of the oysters on restored reefs and may require that additional year classes be added.

We note that reefs with much lower densities than the target above may be on a positive restoration trajectory, be viable, and warrant continued restoration efforts because they provide some level of ecosystem services, and could serve as spat settlement substrate in subsequent years. Thus, for the purpose of consistently tracking progress toward the E.O. goal, the *workgroup recommends a minimum threshold for a successful reef as a mean density of 15 oysters/ m$^2$ and 15 grams dry weight/ m$^2$ containing at least two year classes, and covering at least 30% of the reef area.* Reefs that meet this minimum threshold will be considered minimally successful for the purposes of tracking E.O. goal progress, although the target goal is not achieved. Again, this minimum threshold would require either 15 oysters >3 inches/m$^2$ or a larger number of smaller oysters to achieve 15 g dry weight/m$^2$. Higher coverage with lower

[2] Note that 3 inch oyster has a dry weight of approximately 1 gram, so this target would require 50 adult oysters/m$^2$ or many more small oysters.

mean densities does not qualify. Higher abundances without 15 g dry weight/$m^2$ does not qualify, nor does >15 g dry weight/$m^2$ with fewer than 15 oysters/$m^2$. As with the minimal percent coverage target discussed above, this minimal value reflects a consensus view among the workgroup that accommodates those areas in the lower Bay for which high recruitment occurs, but that few oysters survive to greater than 3 inches. The workgroup believes the literature supports the establishment of a combination of minimum biomass, abundance and coverage for restoration to be deemed successful.

As noted above, a viable oyster reef must maintain a non-negative shell budget (2). Reef structure is itself necessary for the persistence of healthy benthic populations (24, 25), and influences the magnitude and type of ecosystem services provided. The basic tenet here is that structure should at a minimum be maintained, or ideally grow, from a post-restoration baseline to allow for reef sustainability. Restored structure to date generally consists of either shell mounds or alternative substrates (e.g., rock, crushed concrete, reef balls). Tracking the height, spatial extent, and shell budget on these areas over time is critical to understanding whether the structure is increasing, unchanged, or decreasing based on these metrics. Factors contributing to reef structural growth include natural spat set, oyster growth, set and growth of other hard-shelled organisms, and maintenance plantings of shell or seed oysters. Factors decreasing reef structure may include subsidence of constructed substrate and/or shell (e.g., post-construction subsidence into soft bottom), sedimentation, shell dissolution in excess of accretion, and illegal harvest activity. Thus, the workgroup recommends as *a structural goal that reef spatial extent, reef height, and shell budget should remain neutral or increase from a post-restoration baseline.*

Meeting operational targets does not, of course, ensure functional success of the restoration. The reality exists, however, that it may not be possible to determine functional success until at least several years after the initial restoration activity. The ultimate goal of restoring a reef is that it will persist as part of a larger *self-sustaining* population, with new substrate accruing or keeping pace with shell loss and providing desired ecosystem services. Limited success at achieving this goal at a greatly enhanced population level on a system-wide basis has led to the new emphasis on a tributary-scale approach to the problem with the hope that this will overcome some of the problems in the past. In the near-term an intermediate goal of *sustainable* reefs (for which some ongoing intervention, such as shell or spat plantings may be repeated every few years) is more realistic than entirely self-sustaining reefs. *On a time horizon of 2 – 10 years following restoration activity, we suggest that a stable or positive shell budget, stable or increasing oyster biomass and multi-year class age distributions represent reasonable goals.* Comprehensive monitoring, employed in an adaptive management approach, can inform the need for additional restoration activity on specific reefs following initial restoration activity to meet this intermediate goal. Likewise, timely monitoring data will allow managers to make the less desirable decision to cease restoration activities on a particular reef if the minimum restoration thresholds are not being achieved. The workgroup recommends that a technical panel with representatives from each of the organizations be convened to explore a joint database for all monitoring data collected toward tracking the reef-level and tributary-level goals laid out herein as a mechanism of tracking progress toward the E.O. goal of restoring 20 tributaries. The Comprehensive Oyster Database being developed by NOAA's Chesapeake Bay Office may serve this purpose.

*2.3. Ecosystem services and ecological function* – Oyster restoration efforts in the Chesapeake Bay and elsewhere in the U.S. have been motivated over the past two decades as much by the desire to recover lost ecological functions and ecosystems services provided by oysters and the reefs they build as by the desire to rebuild fisheries. Several studies over the past few years have demonstrated that healthy or restored oyster reefs provide enhanced ecosystem services over unrestored or non-reef habitats, including the growth rate of seagrasses (28), the abundance, biomass and diversity of reef resident organisms (24, 25), the abundance, biomass and diversity of nekton (22, 29-34), water quality improvement (26, 37, 38), nutrient cycling (27, 38, 39) and shoreline stabilization (35). Setting specific targets for any of these ecosystem services or ecological functions as quantifiable goals for oyster restoration poses several practical constraints. First, we lack both a historical basis and appropriate current reference sites to set targets for most ecological functions of interest. We currently do not know, for instance, how much fish production or denitrification was associated with historical oyster reefs in the Chesapeake Bay or how much would be associated with fully restored reefs in the present. Second, we cannot quantify the level of any of these services provided by a restored reef by sampling on reefs alone. The quantity of an ecosystem service (e.g., increased water clarity or enhanced blue crab populations) provided by a reef or a series of reefs in a tributary cannot be determined from sampling only on restored reefs, but requires comparisons to appropriate references areas in a well conceived BACI (Before-After-Control-Impact) design. Even in the uncommon situation when appropriate reference sites are available, the effects of restored oyster reefs on ecosystem services may be confounded by many other factors in the watershed and water body. We nevertheless appreciate the importance of evaluating the ecosystem services provided by oyster restoration activities and including these in our determinations of success. Thus, we outline an approach in the sections below on Assessment Protocols for estimating the ecological services provided by restored oyster reefs based upon combining the findings from experimental and/or modeling studies with routine reef monitoring.

## 3. Assessment Protocols

Evaluating reef-level restoration success minimally requires the determination of several parameters: (1) structure of the restored reef (reef spatial extent, reef height, and shell budget), (2) population density (as individual abundance and biomass) and (3) a total reef population estimate (biomass). Although measurement of the first two and calculation of the third parameters are straightforward, they have been the source of some consternation in the past, so we will first clarify the issues before making specific recommendations.

*3.1. Reef area, height, shell budget* **–** Original reef boundaries in the Chesapeake were mapped in the late 19$^{th}$ Century by using techniques such dragging a chain or probing the bottom with a pole (6-9). These techniques were adequate for coarse identification of broad areas with shell and oysters; however, it was recognized at the time (6, 7) and has been subsequently verified that these approaches did not accurately represent either the boundaries of the reefs or the heterogeneity within a reef. The practical implication of this today is that neither the Yates nor the Baylor surveys serve as appropriate benchmarks for scaling restoration targets.

Current-day techniques for assessing reef structural metrics include acoustic mapping, direct benthic sampling, under water video and aerial imagery. Acoustic mapping is a powerful tool for obtaining detailed bathymetric and textural information about bottom habitats, and may provide for simultaneously mapping reef boundaries and measuring reef spatial extent and reef height (as well as structural complexity). Acoustic mapping cannot be used in intertidal areas and must be combined with groundtruthing to distinguish shell from live oysters or shell under thin layers of sediment. For shallow water reefs where acoustic mapping may be inefficient or impossible, aerial photography may provide an accurate means of assessing reef area (see Fig. 2B or the Google Earth image of the Hume Marsh reefs in the Lynnhaven River at 36°53'26.47"N, 76° 5'6.15"W), though this approach requires groundtruthing as well. Direct sampling coupled with high resolution GPS data can be used to map reef perimeters, but large sample numbers are required to accurately define the reef perimeter. On these shallow water reefs, height can be obtained using a rod and level method.

Quantitative samples taken for oyster population measures by patent tong or diver can be used to measure volume. Recommended assessment methodology for measuring and tracking shell budget on subtidal reefs is by patent tong. During surveys for oyster populations, retrieved shell volume can be measured in each tong grab. Shell quality can also be subjectively judged in several ways including an estimation of ‘anoxic’ or black shell vs. ‘oxic’ or brown shell. It should be noted that acoustic mapping techniques cannot determine shell quality. Expectations would be that shell volume surveyed in this way would reflect general decline, maintenance or increase over time.

The accurate determination of total reef area is critical to estimating the amount of restored area, oyster population abundance, and ultimately the quantity of ecosystem services provided by oyster restoration. The most appropriate method or combination of methods for assessing reef area will vary by region and reef types. The majority of the subtidal restoration activities will occur in depths where acoustic mapping technologies can be applied; in these areas, acoustic mapping with groundtruthing appears to be the most accurate and efficient method for assessing the structural characteristics of a reef, including reef spatial extent and should be pursued as the standard wherever possible. We stop short, however, of recommending this approach as a minimal monitoring requirement on all restoration projects. The important point is that accurate determination of total reef area is, in particular, critical to estimating the amount of restored area, oyster population abundance and ultimately the quantity of ecosystem services provided by oyster restoration. *Determination of reef area, height, and shell budget should be an integral part of the assessment of restoration success on sanctuary reefs*.

*3.2. Quantitative density estimates* – There is historical precedent in portions of Chesapeake Bay for estimating oyster abundance based upon timed dredge tows and there are widely recognized limitations to this approach including unknown sample area and the dependence of gear capture efficiency on sample volume (40, 41). Density estimates obtained in this manner are usually expressed as numbers of live oysters per bushel of shell, but conversion to numbers of live oysters per unit bottom area have also been developed by Rothschild and colleagues (42). It was not in the purview of this workgroup to design sampling protocols for oyster fisheries assessment, so we will leave it to others to determine the appropriate sampling technique for that use. *However, we recommend oyster density estimates on sanctuaries and other protected reef restoration sites be obtained from quantitative grab samples*. These samples may be obtained from quadrate samples excavated by divers or by patent tongs or, in shallow-water and intertidal sites, by direct access. We point out, however, that the capture efficiency of quadrate grabs and tongs is less than 100% and that there is the need for careful calibration of these techniques.

Monitoring costs by any of the methods above can be high, especially when there are large areas to be assessed. Thus, there is often pressure to keep sample replicates to a minimum. Accurate and precise estimates of mean abundances in highly patchy populations nevertheless may require large sample sizes. The sample size required to obtain a desired level of precision in the estimated mean or total abundance can be determined by plotting the relationship between the relationship between the standard error of the mean and sample size. We recommend that monitoring programs employ this approach and optimize sample allocations.

Confusion has occurred in recent years regarding the inclusion of grab samples that contain no oysters into estimates of mean density. This uncertainty arises because oyster reefs (even natural healthy ones) are not monolithic structures with oysters distributed uniformly within what we would define as the reef perimeter (see Fig. 2 and discussion in Section 2.2). Thus, as we assess progress towards restoring (and conserving) reefs, we need to come to grips with the fact that restored area does not precisely match the area with oysters. This situation is particularly well illustrated in Figure 2A which shows an area with natural intertidal patch reefs. The currently available information suggests that this represents a fully developed reef complex that is comparable in spatial extent and density (though perhaps not oyster size and biomass) to historical reefs in the region. Estimating the mean density of oysters on these individual patch reefs (which average 2 – 3 $m^2$ in area) is straightforward, requiring only that we obtain adequate numbers of quantitative samples from randomly selected individual patch reefs over the area. The point of disagreement that has arisen is over how one determines either the total population size or the total area of restoration from these samples.

*3.3. Oyster population assessment* – In the intertidal situation represented in Figure 2A, the total population size of oysters in the reef complex is easily estimated as the product of the mean density on patch reefs and the total area of the individual patch reefs, because we can clearly count and measure the individual patch reefs within the area. The challenge emerges in subtidal reefs were obtaining a clear picture of the distribution of oysters prior to sampling is more difficult and costly. High-resolution side-scan sonar, coupled with extensive groundtruthing samples may provide such information precisely and reliably. *If current, validated maps of fine-scale reef distribution are available prior to quantitative density sampling, then sample allocation may be directed at those locations only and total population size estimated as in the intertidal example above*. In the more generalized case in which predetermined, high precision maps of oyster density or habitat quality are available, Wilberg (pers. com.) has shown that when underlying habitat strata explain a portion of the overall variance, stratified random sampling (STRS) provides a more precise estimate of total oyster abundance than simple random sampling (SRS) *for a given number of samples*. In the STRS scenario, regions within the reef of high, medium and low habitat quality are sampled in a stratified random design (see Fig. 2 C&D for maps of reefs exhibiting these conditions). This approach can provide a much more precise estimate of the true population abundance with far fewer samples than SRS (Wilberg, pers. com). This method is dependent upon the availability of high resolution maps reflecting the current reef conditions prior to sampling. Ideally these maps would be available and should be developed wherever possible; however, in the past such detailed knowledge about the underlying distribution of oysters on a reef has not always been available to guide sampling. When the underlying distribution of oysters (or even oyster habitat) within a restored reef is unknown or not known with sufficient accuracy, then a stratified sampling design is not possible. In this case two approaches have generally been used: systematic and simple random sampling (SRS). The systematic approach involves gridding out the sampling area and taking one sample from the centroid of each grid. The SRS approach has generally involved also gridding the sampling area, but taking samples from a random subset of grids. This type of systematic survey will provide information on both the population and its distribution across the target area. If distribution is not important, an SRS will suffice for population estimate and coverage. The number of samples required will be determined by the variance among samples and should be adjusted to reduce the variance of the population estimate to the point where additional samples will only minimally affect the variance.

The data from either systematic or SRS surveys can be used to estimate population size (total abundance) within the target restoration area. Specifically, the mean density of oysters in all samples (including zeros) taken within the target restoration area is multiplied by the entire target area. This approach, however, may not provide a valid estimate of density on the actual reef(s) resulting from the restoration activity. Such an estimate requires that the actual extent of the reef be defined, either via pre- or post-stratification, and that samples only from the reef strata be used to determine density. The committee recommends that a stratified random survey design be used whenever data on strata are available. All restoration projects should collect pre-construction data in order to assess the project's success and cost-effectiveness by comparing post-construction data. When stratification is possible, restoration efforts should be surveyed considering the strata rather than using SRS. We note, however, that determining failure rate of a restoration activity is equally as important as determining success rate. Consequently, sampling in areas that received restoration activity, but did not result in the formation and persistence of a reef is a critical requirement of the evaluation process. We note that there are at least two ways in which such "failures" can occur—(1) operational errors in which shell or spat-on-shell planting took place outside of the target area and (2) burial of planted materials within the target area. Both have occurred in various restoration efforts in Chesapeake Bay. Thus, those strata should be sampled as well but perhaps not with the frequency of the 'successful' strata. The important point here is that monitoring programs should sample in a manner that allows several questions to be answered: *How successful was the restoration activity? What is the oyster abundance and biomass within the target area? What is the density and abundance of oysters on the resultant reef?*

Although a stratified random sampling design requires fewer samples than either a simple random sampling or systematic sampling design to achieve the same level of precision in estimating population size under the conditions specified above, we stop short of recommending that all population assessments on restoration reefs employ a pre-sampling STRS design for two reasons. First, we are not in a position affirm that the technical resources (side-scan sonar or video imagery) will always be available to parties conducting these assessments in a timely fashion. More importantly, we have not evaluated the cost effectiveness of the various approaches. That is, it might be more cost effective for an agency to take many SRS than to conduct acoustic bottom surveys and take fewer STRS to achieve the same level of precision in estimating oyster population size. The important point here is that it is incumbent upon each monitoring program to employ a sample design that provides oyster population estimates with good accuracy and precision.

We emphasize that accurate and precise estimates of the total population size on a restored reef require that the actual extent of the reef be determined during post-restoration monitoring. Actual extent of the restored reef may differ from the target restoration area, both in the extent within the target area and expansion outside of the target area.

3.4. *Assessment Frequency*- The question ‘At what point in time can we call a reef restored?’ is not an easy one to answer, but the workgroup believes it is an essential part of our initial charge to come to consensus on this for the purpose of tracking progress toward the E.O. goal.

*The recommended minimum assessment intervals for reef-level goals is established at 1) post-restoration activity to establish baseline (within 6 to 12 months of restoration activity); 2) again at three years post-activity; and 3) again at 6 years post-activity.* The group recognizes that there is additionally a need for basic pre-construction monitoring to support site selection and gauge the accomplishments of restoration actions. Pre-construction monitoring should be designed based on the goals of the restoration project and the resources available. This, however, is not purview of this workgroup.

More frequent and intensive monitoring will likely be required, and is highly encouraged, on some restoration projects to facilitate, for example, research projects or ancillary goals. The above intervals are established only as *minimum* frequencies for assessment, and are in no way meant to preclude more frequent monitoring. The initial post-restoration assessment is essential for establishing a baseline against which to evaluate future project success. The three-year point is critical to allow for adaptive management. If, for example, a project shows at this point signs of needing additional seed or shell, a management decision can be made to do so to increase the likelihood of success. Conversely, the decision may be made that the project was poorly constructed, poorly sited, used inappropriate materials, etc., and that continued investment is ill advised. Determining the *causes* of failure is, of course, essential to adaptive management. Measuring parameters such as dissolved oxygen, pH, temperature, salinity, disease levels and sedimentation rates can help determine why failure occurred, allow for adaptive management, and avert recurrence.

By consensus, this workgroup establishes the six-year assessment as a reasonable point at which to determine whether a reef is 'successful' for tracking progress toward the E.O. goal.

*Ecosystem services and ecological function* – In Section 2.3 we indicated that monitoring alone would not be sufficient for assessing the level of ecosystem services provided by a restored oyster reef. Because this is an important concept, we will explain this assertion further and then recommend an assessment strategy that we believe is appropriate.

Most of the ecological functions and ecosystem services that we desire from a restored oyster reef are affected by a great many other factors. For instance, water clarity is affected by atmospheric and terrestrial inputs, phytoplankton dynamics and meteorological conditions, among other things. Thus, measuring changes in water clarity in a tributary and attempting to link those changes to oyster restoration success is highly problematic. Indeed, even as an increasing oyster population filters more water, changing land use practices could cause water clarity to decline. Similarly, measuring utilization of a restored reef by finfish does not account for numerous other factors (e.g., recruitment, natural mortality and fishing mortality) that may be affecting regional fish population size. Comparisons to a nearby non-reef control sites may overcome some of these uncertainties; however, such a monitoring scheme quickly becomes intractable to do at all restoration sites.

A much more tractable approach is to make use of the results from targeted monitoring programs, controlled experiments and modeling studies to develop generalizable relationships between characteristics of an oyster reef (e.g., reef size, oyster abundance, oyster biomass, reef complexity or other measures) and the quantity of various ecosystem services. For instance, if a carefully designed study was to estimate:

$$\text{Biodeposition} = f\,(\text{reef size, oyster biomass, total suspended solids [TSS] and temp.}),$$

then routine monitoring of reefs at other sites together with measurements of TSS could be used to estimate biodeposition provided by those reefs. Similarly, if a controlled, replicated experiment was used to generate a relationship between the numbers (or biomass) of oysters on a reef and the resulting amount of additional finfish production, then routine monitoring of oyster population characteristics described above could be used to estimate potential finfish production associated with restored reefs in varying conditions. As a final example, if controlled, replicated experiments were employed to quantify nitrogen fluxes from the sediment as a partial function of oyster biomass (as well as temperature and seston concentrations), then routine monitoring data could be used to estimate nitrogen fluxes attributable to a particular restored reef.

Apart from the obvious benefits of feasibility, this approach towards evaluating success of reef restoration relative to ecosystem services provides a means of estimating the amount of ecosystem services provided by restored reefs that vary in their success. That is, hypothetically, a reef with 100 g dry weight biomass $m^{-2}$ may provide 20-times the nitrogen removal capacity of an unrestored reef, while a reef with only 10 g dry weight biomass $m^{-2}$ may provide only 5-times the removal capacity.

Determining such relationships will require carefully designed monitoring, experimental or modeling studies conducted over the next several years. We are careful here not to identify specific ways in which these relationships should be determined acknowledging that it will require creative studies by various investigators. As long as those studies equate absolute or relative values of ecosystem services to quantitative metrics related to the oyster population or reef characteristics that are being measured as part of a routine monitoring program, then they will provide the best means available of assessing success in this area. *Funding these types of studies will be neither cheap nor politically popular, but we emphasize that they are the only reliable means of quantitatively assessing the ecosystem services associated with reef restoration* *and they are <u>much less expensive</u> than attempting to directly measure ecosystem services on all restored reefs.*

## 4. Evaluating Success

As stated previously, success in oyster restoration efforts will need to be evaluated on several levels over varying spatial and temporal scales. Targets and metrics of operational success are required to guide restoration activity, such as what percentage of a historical bar or other area should be planted with shell or spat-on-shell. Monitoring of individual reefs following initial restoration activity will be required to determine success at various stages by evaluating recruitment success, early post-settlement or post-planting survival, natural mortality, disease status, growth, reproduction and shell accumulation. Evaluating success at the tributary level likewise will need to involve operational definitions about the amount of area within the tributary that needs to be rehabilitated and functional measures of the status of those areas several years after the restoration activity. Table 1 summarizes the goals, assessment protocols and success metrics that we have discussed above.

**Table 1.** Summary of goals, assessment protocols, assessment frequency and success measures

| Goal | Success metrics (targets and/or thresholds) | Assessment Protocol | Minimum Assessment Frequency (assumes pre-restoration survey) |
|---|---|---|---|
| ***Operational Goals:*** Defined programmatic and planning outcomes for reef construction and tributary level restoration | | | |
| **Reef-level**<br>1. Appropriate amount of substrate and/or spat-on-shell was planted.<br>2. Presence of substrate and/or spat-on-shell within the target area. | Shell, alternative substrate, or spat-on-shell should cover a minimum of 30% coverage throughout the target reef area. | Patent tong or diver grabs | Within 6-12 months of restoration activity |
| **Tributary-level target**:<br>1. Appropriate amount of area within the tributary has met reef-level operational goals. | A minimum of 50% of currently restorable area that constitutes at least 8% of historic oyster habitat within a given tributary meets the reef-level goals defined above. | GIS-based analysis of restoration activity within the tributary | Annual |
| ***Functional Goals:*** The desired ecological outcomes at reef and tributary scales | | | |
| **Reef-level goals** | | | |
| Significantly enhanced live oyster density and biomass | Target: An oyster population with a minimum mean density of 50 oysters and 50 grams dry wt/$m^2$ covering at least 30% of the target restoration area at 3 years post restoration activity. Evaluation at 6 years and beyond should be used to judge ongoing success and guide adaptive management.<br>Minimum threshold: An oyster population with a mean density of 15 oysters and 15 grams dry wt biomass · $m^{-2}$ covering at least 30% of the target restoration area at 3 years post restoration activity. Minimum threshold is defined as the lowest levels that indicate some degree of success and justify continued restoration efforts. | Patent tong or diver grabs | Minimum 1, 3 and 6 years post restoration |
| Presence of multiple year classes of live oysters | Minimum of 2 year classes at 6 yrs post restoration. | Patent tong or diver grabs | Minimum 3 and 6 years post restoration |

**Table 1 (cont.)**

| | | | |
|---|---|---|---|
| Positive shell budget | Neutral or positive shell budget. | Quantitative volume estimates shell (live and dead) per unit area | Minimum 1, 3 and 6 years post restoration |
| Stable or increasing spatial extent and reef height | Neutral or positive change in reef spatial extent and reef height as compared to baseline measurements. | Multi-beam sonar, direct measurement, aerial photography | Within 6 -12 months post-restoration, and 3 and 6 years post restoration |
| **Tributary-level goals** | | | |
| Expanding oyster population beyond the restored reefs | Will need to be determined as restoration proceeds. | Quantitative assessment of oyster populations throughout the tributary. | Will need to be determined from future assessments. |
| Return of the oyster population within a tributary to an enhanced stable state. | Specific targets will need to be developed on a tributary-specific basis as restoration proceeds. | Quantitative assessment of oyster populations throughout the tributary. | Will need to be determined from future assessments. |
| Enhanced ecosystem services in the tributary | Currently unknown. Specific targets will likely be informed by the results of experiments relation ecosystem services to structural metrics. | Determine relationships between structural reef characteristics (e.g., reef size, oyster abundance, or oyster biomass) and the quantity of various ecosystem services via controlled experiments and modeling studies. Use measured values of structural metrics to estimate levels of specific ecosystem services. | Currently unknown |

## 5. Applying Adaptive Management

Throughout this document we refer to applying adaptive management principles to restoration techniques and activities (e.g. placing subsequent additions of shell or spat-on-shell as informed by monitoring data). But, adaptive management means more than simply adjusting techniques. It means gathering data to answer specific questions at known decision points. For instance, in areas with only intermittent recruitment, it may mean monitoring shortly after the potential recruitment period to make a decision about the need to use spat-on-shell at that location. More fundamentally, fully adaptive management makes use of knowledge gained through data collection to refine both targets and metrics in route to meeting its ultimate goal. This will almost certainly be the case for oyster restoration in Chesapeake Bay. We have suggested restoration targets in this document that reflect the experiences not only of the workgroup members, but their organizations and the consulting scientist. There was seldom unanimity of opinion and in some cases our recommendations represent compromises between organizations; in others; they can be described as informed guesses. We strongly encourage those organizations involved in efforts to restore oyster populations and the ecosystem services that they provide in Chesapeake Bay to a higher stable state (Fig. 1) to rigorously evaluate and reassess the targets and the metrics established here as more data becomes available.

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## Appendix A

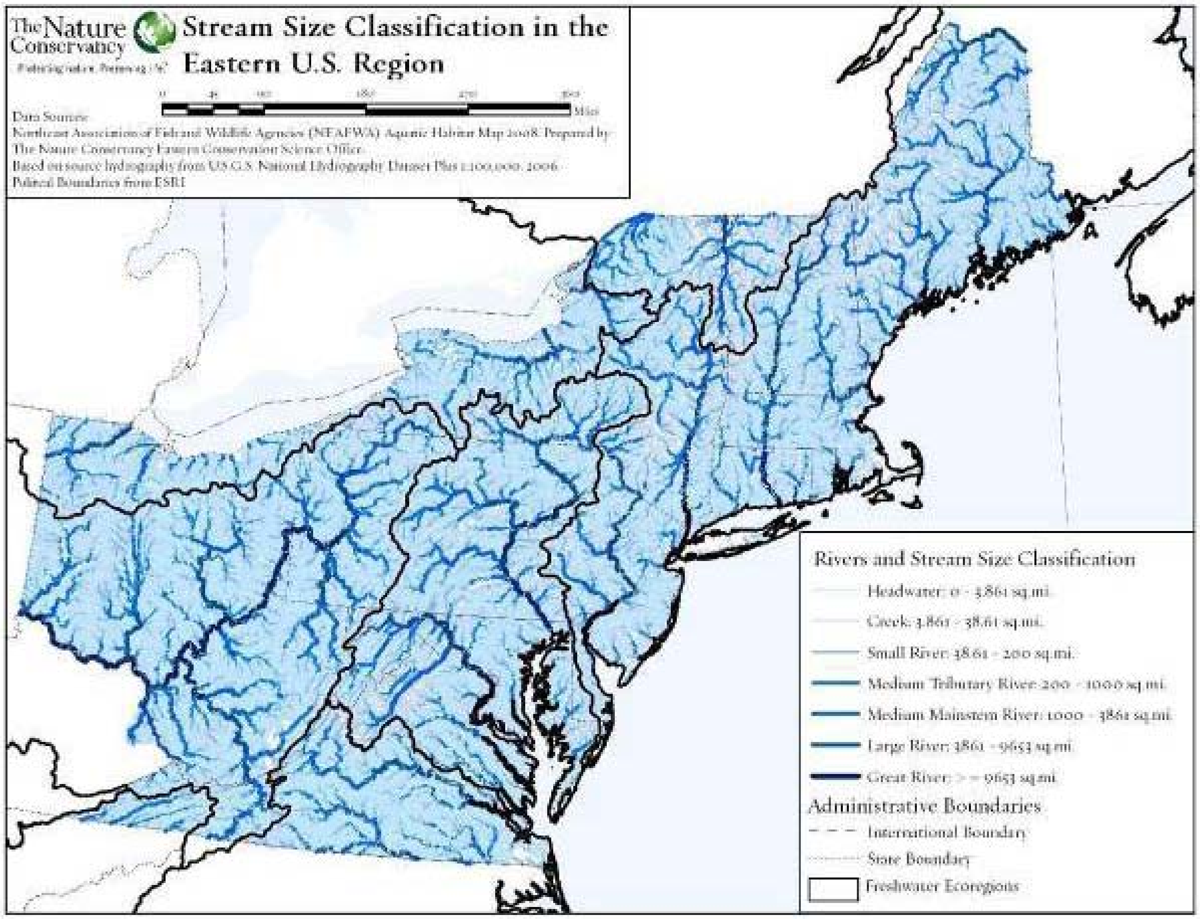
The Nature Conservancy River Size Classification

The Nature Conservancy has developed a stream size classification for the eastern U.S. based on watershed size (upstream drainage area in square miles) as listed below:

Headwaters (<3.861 sq.mi.)
Creeks (>= 3.861<38.61 sq.mi.)
Small Rivers (>=38.61<200 sq. mi.)
Medium Tributary Rivers (>=200<1000 sq.mi.)
Medium MainstemRivers (>=1000<3861 sq.mi.)
Large Rivers (>=3861 < 9653 sq.mi.)
Great Rivers (>=9653 sq.mi.)

The size breaks were initially developed as part of TNC's Northeast Aquatic Stream classification project for the Northeast Association of Fish and Wildlife (NEAFWA) (http://rcngrants.org.spatialData, see map below). The stream classification is regional and is appropriate to apply across the northeast region and within the Chesapeake Bay watershed. All 13 northeast states participated and contributed to its development. According to TNC, the classification has been used in a number of regional projects for planning and reporting. The table below shows the application of the stream classification to some of the tributaries of the Chesapeake Bay.

| Tributary | TNC classification | | Tributary | TNC classification |
|---|---|---|---|---|
| ***MARYLAND*** | | | ***VIRGINIA*** | |
| **Chester River** | medium trib | | **James River** | great river |
| Corsica River | Small river | | Elizabeth River | small river |
| **Choptank River** | medium mainstem | | Nansemond River | medium tributary |
| Broad Creek | Creek | | **Pocomoke Sound** | (medium tributary) |
| Harris Creek | Creek | | **Rappahannock River** | medium mainstem |
| Little Choptank | Small river | | Corrotoman River | small river |
| **Eastern Bay** | Small river | | **York River** | medium mainstem |
| **Patuxent River** | medium trib | | Back River | small river |
| **Potomac River** | great river | | Cherrystone Inlet | small river |
| St. Mary's River | small river | | Cockrell Creek | creek |
| **Tangier Sound** | (small river) | | Great Wicomico R. | small river |
| Big Annemessex River | small river | | Hungars Creek | creek |
| Fishing Bay | medium trib | | Little Wicomico R. | creek |
| Little Annemessex River | small river | | Lynnhaven Bay | small river |
| Manokin River | small river | | Mobjack Bay | (small river) |
| Monie Bay | (small river) | | Nandua Creek | creek |
| **Honga River** | small river | | Nassawaddox Creek | creek |
| **Magothy River** | small river | | Occohannock Creek | creek |
| **Rhode River** | creek | | Old Plantation Creek | creek |
| **Severn River** | small river | | Onancock Creek | creek |
| **South River** | small river | | Piankatank River | small river |
| **West River** | creek | | Poquoson River | small river |
| | | | Pungoteague Creek | small river |
| | | | Severn River | small river |


The Nature Conservancy
Stream Size Classification in the Eastern U.S. Region
Data Sources:
Northeast Association of Fish and Wildlife Agencies (NEAFWA) Aquatic Habitat Map 2008. Prepared by The Nature Conservancy Eastern Conservation Science Office.
Based on source hydrography from U.S.G.S. National Hydrography Dataset Plus 1:100,000. 2006.
Political Boundaries from ESRI
Rivers and Stream Size Classification
Headwater: 0 - 3.861 sq.mi.
Creek: 3.861 - 38.61 sq.mi.
Small River: 38.61 - 200 sq.mi.
Medium Tributary River: 200 - 1000 sq.mi.
Medium Mainstem River: 1000 - 3861 sq.mi.
Large River: 3861 - 9653 sq.mi.
Great River: >= 9653 sq.mi.
Administrative Boundaries
International Boundary
State Boundary
Freshwater Ecoregions

2011 Chesapeake Bay Blue Crab Advisory Report
CBSAC Meeting Date: Sept. 19-20, 2011
Beaufort, NC
Report Approved by the Fisheries Goal Implementation Team: XXXXX



# 1. INTRODUCTION

## 1.1 Background

The Chesapeake Bay Stock Assessment Committee combines the expertise of scientists from the Chesapeake Bay region, with that of Federal fisheries scientists from the Northeast and Southeast Fisheries Science Centers of the National Marine Fisheries Service. This group meets each year to review the results of annual Chesapeake Bay blue crab surveys and harvest data, and to develop management advice for the Bay jurisdictions: Maryland, Virginia and the Potomac River Fisheries Commission.

With support from the Virginia Marine Resources Commission, Maryland DNR, and the NOAA Chesapeake Bay Office, benchmark stock assessments of the Chesapeake Bay blue crab have been conducted every 3-7 years since 1992. The most recent assessment, completed in 2011, generated new reference points for the female component of the blue crab population. These MSY-based female reference points are recommended as replacements for the current Maximum Spawning Potential overfishing reference points (Table 1.1). Similarly, the 2011 stock assessment recommends replacing the empirical overfished age 1+ (both sexes) abundance threshold and interim target with an MSY-based threshold and target based solely on female age 1+ crabs.

## 1.2 Terms of Reference

With the completion of the 2011 benchmark blue crab stock assessment, the Chesapeake Bay Sustainable Fisheries Goal Implementation Team has requested that CBSAC address the following terms of reference within this report:

1) Provide guidance for the management agencies on:
    a. Implementation of the biological reference points developed within the 2011 assessment.
    b. Methods for determining appropriate reference points for the male component of the population.
2) Provide a description of how the reference points recommended under task one differ from the current reference points.
3) Prioritize research needs and science gaps – as identified in the 2011 assessment and Center for Independent Experts (CIE) review.

The second term of reference requesting a comparison of current and recommended reference points is addressed below and stock status is updated according to both sets of reference points. Within this report and future reports, annual updates of population size and exploitation fraction will be calculated directly from the annual results of the winter dredge survey (WDS) and from annual estimates of harvest and compared to the new reference points. CBSAC has adopted the WDS as the primary indicator of blue crab population health because it is the most comprehensive and statistically robust of the blue crab surveys conducted in the Bay[2]. The WDS measures the density of crabs (number per 1,000 square meters – Figure 1) at approximately 1,500 sites around the Bay. The measured densities of crabs are adjusted to account for the efficiency of the sampling gear and then are expanded to reflect the area of Chesapeake Bay, providing an annual estimate of the number of over-wintering crabs by age and gender[2].

Table 1.1: A comparison of the current (sexes combined) and recommended female-specific biological reference points for Chesapeake Bay blue crab. The exploitation fraction is the percentage of all crabs removed from the population by commercial and recreational fisheries. Under the current framework, annual estimates of exploitation fraction are calculated as the annual harvest of crabs divided by the total number of crabs (age 0+) estimated in the population at the start of the season. The population estimate is derived from the winter dredge survey. When calculating female-specific exploitation, the annual female harvest is divided by the total number of female crabs (age 0+) estimated in the population at the start of the season. The recommended, female-specific target and threshold abundance refer to the number of female crabs age one and older estimated to be in the population according to the winter dredge survey. The 2011 exploitation fraction cannot be calculated until the completion of the 2011 fishery and estimation of harvest.

| | | Target | Threshold | 2010 Stock Status | 2011 Stock Status |
|---|---|---|---|---|---|
| Exploitation Fraction | Current | 46% | 53% | 39% | *To be determined* |
| | Recommended female-specific | 25.5% | 34% | 18% | *To be determined* |
| Abundance (millions of crabs) | Current | 200 | 86 | 315 | 254 |
| | Recommended female-specific | 215 | 70 | 251 | 190 |

## 2. CONTROL RULES

### 2.1 Recommended Control Rule from 2011 Benchmark Assessment

The 2011 Benchmark assessment recommends a new framework (control rule) based on biological reference points for the female component of the population (Figure 2). The recommended targets and thresholds for exploitation (U) and abundance (N) were developed using the concept of maximum sustainable yield (MSY). $U_{MSY}$ is defined as the annual rate of exploitation by the fisheries that achieves the largest average catch that can be sustained over time without risking stock collapse. Following Federal guidelines, the 2011 assessment recommended a target exploitation rate that is associated with 75% of $U_{MSY}$ and a threshold set equal to $U_{MSY}$. The female-specific, age 1+ abundance target and threshold were set accordingly at abundances associated with fishing levels at 75%

$N_{MSY}$ (target) and 50% $N_{MSY}$ (threshold). Annual exploitation was calculated as the number of female crabs removed by the fisheries divided by the total number of age-0 and age-1+ female crabs estimated to be in the Bay at the beginning of the fishing season. Within this calculation, the juvenile component (age 0) of the total estimated number of crabs was scaled up by a factor of 1.6 to achieve the best fits of the model to the observed data. The recommended target and threshold reference points are presented in Table 1.1 of this document.

## 2.2 Former Control Rule

The fomer control rule was adopted by the Bi-State Blue Crab Advisory Committee in 2001[3] and updated in the 2005 Benchmark Stock Assessment[4] (Figure3). This control rule represents the relationship between removals by fisheries (exploitation fraction) and the number of spawning-age crabs (both sexes combined), compared with established target and threshold reference points for exploitation and abundance. In 2006, the CBSAC defined the minimum safe number (overfished threshold) of spawning-age crabs to be 86 million crabs. This threshold value was applied based on a lack of historical evidence that a sustainable fishery can be maintained at lower abundances than the minimum observed abundance in the WDS, which occurred in 1999. A threshold or maximum level of exploitation was determined to be 53%, based on the consensus that a minimum of 10% of the spawning potential of an unfished population must be preserved to minimize the risk of recruitment failure and stock collapse. Therefore, if more than 53% of crabs were removed in a given year, overfishing would be occurring. The established target exploitation fraction of 46%, maintained over several years, represents an exploitation fraction that would preserve 20% of the unfished spawning potential.

In January 2008, CBSAC established an interim target of 200 million spawning-age (1+) crabs. This target was established based on analyses suggesting that 200 million age 1+ crabs is the lowest abundance associated with consistently higher levels of recruitment.[5,6] The target level of 200 million was meant to be a goal for initial rebuilding of the stock.

# 3. POPULATION SIZE (ABUNDANCE)

## 3.1 Spawning-age Female Crabs: Recommended Reference Points

The 2011 benchmark assessment recommends replacing the current interim target of 200 million total spawning-age crabs with a target of 215 million female spawning-age crabs. Approximately 190 million female age 1+ crabs were estimated to be present in the Bay at the start of the 2011 crabbing season. This number is below the recommended target but more than twice the recommended threshold number of 70 million female spawning-age crabs (Figure 4). CBSAC notes that, according to the recommended female-specific abundance threshold of 70 million crabs, the blue crab stock would have been classified as overfished for three years between 1999 and 2002 (Figure 4), whereas based on the former control rule the blue crab stock has not been overfished within the last two decades (Figure 5). CBSAC also notes that the estimated abundance in 2011 was lower than observed in 2010. This decline in abundance of age 1+ was the result of substantial over-winter mortality, particularly in Maryland. Approximately 30% of adult crabs estimated to be in the Maryland waters of Chesapeake Bay perished due to a precipitous drop in December water temperature, followed by sustained below-average temperatures for the remainder of the 2010-2011 winter (Figure 6).

### 3.2 Spawning-age Male and Female Crabs: Current Reference Points

The number of spawning-age crabs (age 1+) is a key indicator of population health and is used to determine if the population abundance is too low (i.e., is overfished - see section 4 – Control Rules). Approximately 245 million spawning-age crabs (sexes combined) were estimated to be in the Bay at the beginning of the 2011 crabbing season (Figure 5). This represents a 19% decrease from the 2010 estimate of 315 million. Despite the mortality event noted above, the number of spawning-age male and female crabs remained above the former interim target of 200 million for the third consecutive year.

### 3.3 Age 1+ Male and Age 0 Crabs

In 2011, the number of age 1+ male crabs (greater than 60 mm or 2.4 inches carapace width) estimated to be present in the Bay was approximately 63 million crabs (Figure 7). Although this represents a 70% increase from male abundance in 2008, the number of male crabs remains below the survey average of 87 million crabs. CBSAC notes that male abundance has not increased proportionally to female abundance because the recent management actions promoted recovery and conservation of the female spawning stock. Recruitment, as measured by the number of age 0 crabs (less than 60 mm or 2.4 inches carapace width) appears to have increased, since the female-specific conservation measures were implemented (Figure 8). The number of recruits dropped from 345 million in 2010 to 207 million in 2011 (Figure 8), which was not unexpected given the vagaries of recruitment.

## 4. HARVEST

### 4.1 2010 Commercial and Recreational Harvest

The 2010 Maryland commercial crab harvest from the Bay and its tributaries was estimated as 53.4 million pounds. The 2010 commercial harvest in Virginia was reported to be 26.9 million pounds (Figure 9). An additional 4.5 million pounds were reported harvested from the jurisdictional waters of the Potomac River Fisheries Commission. Recreational harvest is assumed to be 8% of the total Bay wide commercial harvest.[7a, b, c] Therefore, the 2010 Bay-wide recreational harvest was estimated to be 6.8 million pounds. Combining these categories, approximately 91.6 million pounds were harvested from Chesapeake Bay and its tributaries during the 2010 crabbing season. This is the highest harvest since 1994, and is 22% above the long-term (1990-2010) average of 75 million pounds.

Based on continued evidence of inflated harvest reports, Maryland's 2010 commercial harvest was estimated from fishery-independent data sources including the Maryland commercial reference fleet and an annual survey of crab pot effort in the Maryland portion of Chesapeake Bay[8]. The difference between Maryland's 2010 estimated harvest of 53.4 million pounds and reported harvest of 57.7 million pounds was less than in the two previous years. However, Maryland's 2010 harvest represents a departure from the historic proportion of each jurisdiction's harvest. In recent years, Maryland's commercial harvest has accounted for approximately 53%, by weight, of the Bay-wide harvest. In 2010, that fraction was 59.7%, affected more so by males, whose catch increased by 92.8% from 2009.

### 4.2 Exploitation Fraction: Recommended and Current Reference Points.

Despite the elevated 2010 harvest, the percentage of female crabs removed by fishing (exploitation fraction) in 2010 was approximately 18%, well below both the new recommended target of 25.5% and threshold of 34% (Figure 10). When considering the former reference points, the percentage of crabs removed by fishing (exploitation fraction) was approximately 39%, compared to the former target of 46% and threshold of 53% (Figure 11).

## 5. STOCK STATUS

The Chesapeake Bay blue crab stock is currently not overfished and overfishing is not occurring. This is true according to both the new recommended female-only framework developed in the 2011 Benchmark assessment and the former management framework.

## 6. TERMS OF REFERENCE

### 6.1 Provide Guidance for the Management Agencies on Implementation of the Biological Reference Points Developed within the 2011 Assessment.

The CBSAC recommends that the jurisdictions place primary management focus on the female-specific target exploitation fraction. If the annual female exploitation fraction is, on average, equal to the target of 25.5%, the assessment model predicts that female abundance should vary around the target level of 215 million crabs. However, given the uncertainty in the abundance component of the model, jurisdictions should focus primarily on the exploitation fraction when deliberating on management strategies, as long as the abundance of age 1+ female crabs is not substantially lower than the target for consecutive years.

The CBSAC recommends that the jurisdictions adopt the female-specific target and threshold reference points developed in the 2011 Benchmark Blue Crab Stock Assessment. The CBSAC suggests that the recommended female-specific reference points be reviewed in the 2012 CBSAC report, relative to model refinements that were recommended by the CIE peer review panel, and which will be undertaken during the coming year.

Finally, the CBSAC stresses the importance of updating benchmark assessments every four to six years. This is necessary to fully evaluate the newly adopted reference points relative to stock status and to incorporate important new data and science into the assessment.

In implementing female-specific reference points, annual estimates of spawning-age female abundance and female exploitation fraction can be derived directly from results of the winter dredge survey and annual estimates of harvest. These calculations can be compared to the new framework to determine stock status, thereby eliminating the need to run the full assessment model each year.

The CBSAC notes that overall crab abundance was 30% lower at the beginning of the 2011 crabbing season than it was at the start of the 2010 season. Although this decrease in abundance was due to lower recruitment and higher winter mortality, rather than elevated fishing pressure during the 2010 crabbing season, having fewer crabs at the start of the 2011 season elevates the risk that the 2011 harvest will exceed the recommended female harvest target of 25.5%. If the 2011 Bay-wide harvest of female crabs is equal to the 2010 female harvest of 27.9 million pounds, the resulting exploitation fraction will be near the target level of 25.5%. Given this, the CBSAC recommends that the jurisdictions closely monitor the 2011 harvest prior to adjusting management measures.

### 6.2 Provide Guidance for the Management Agencies on Methods for Determining Appropriate Reference Points for Male Blue Crabs

In order to ensure that male abundance does not drop below a critical level relative to female abundance, the CBSAC recommends development of threshold reference points for male crabs that would provide management with a trigger for male conservation. One possibility to explore is a ratio of male to female abundance, which could be derived from annual winter dredge survey results. To properly define a threshold based on an abundance ratio, several key analytical issues need to be addressed and the results of ongoing research on crab reproductive biology need to be reviewed. These issues include: estimation procedures of winter dredge survey gear efficiency, estimation of winter dredge survey gear selectivity for differing sizes of crabs, crab reproductive biology (sperm limitation) and estimation procedures for over-wintering mortality. The CBSAC suggests addressing these issues and to explore appropriate male reference points during a workshop that could be convened in late May or early June of 2012.

In the near term, the CBSAC recommends that management jurisdictions monitor the ratio of the number male crabs greater than 60 mm in carapace width to the number of immature female crabs greater than 60 mm, as calculated from the dredge survey, to ensure that annual ratios stay within the range observed since 1990 (Figure 12). This represents the best estimate of an operational sex ratio, which refers to the relative numbers of sexually mature male crabs (greater than 110 mm) and pre-molt female crabs who are actively seeking mates. Because there is no current evidence of sperm limitation in the population, maintaining the sex ratio within observed values should ensure maintenance of sufficient males for reproduction. Refining this ratio should be a primary topic during the proposed workshop mentioned above.

Finally, to ensure that male reproductive capacity is not compromised in the face of female conservation measures, CBSAC recommends maintaining current male conservation measures such as size limits. Size limits are important in that they ensure that males have an opportunity to mate prior to being harvested.

### 6.3 Prioritize research needs and science gaps – as identified in the 2011 assessment and Center for Independent Experts (CIE) review.

The Center of Independent experts thoroughly reviewed the 2011 blue crab benchmark stock assessment with positive results. Dr. Cathy Dichmont, whose comments were consistent with the panel, said in her review: "*This assessment is a valid approach and an improvement on the previous assessments and therefore should be adopted as the basis for management advice.*" However, several gaps in the current knowledge of the blue crab and the fisheries were noted by the CIE review panel. The CBSAC has prioritized the review panel's findings.

**The three highest priorities for research and surveys are:**

1. Implement monitoring to characterize the sex, size, and life-stage composition of the commercial harvest Bay-wide. This is of the highest priority given the sex-specific nature of the current management framework.

2. A recreational survey is high priority as it is likely that recreational effort may be increasing with improved stock status.

3. Continue the winter dredge survey and work to refine gear efficiency and over-winter mortality calculations as this could impact reference point values. The CBSAC recommends a workshop is held to address issues such as gear efficiency, selectivity of the dredge gear and dredge survey sex ratios as a reference point.

Other important research projects would include:

- Analysis of existing reported effort data to get at spatial and temporal patterns in CPUE for specific gears and fishery sectors.
- Design a shallow-water complement to the winter dredge survey to estimate the fraction of crabs that are not vulnerable to the winter dredge survey due to their shallow water residence. Pilot studies are ongoing.
- Sex-specific natural mortality rates (research based).
- Variations in fecundity based on season and size (ongoing).
- Determine threshold sex ratio when sperm limitation becomes a problem (research - ongoing).

In addition to recommending research areas to improve critical knowledge of the blue crab population and fisheries, all three peer reviewers had specific concerns that they felt needed to be addressed within the model as a high priority. Therefore, CBSAC recommends that, within the next 12 months, the assessment team explore the impacts of the following modifications to the model:

1) Incorporate an internal correction factor for the time series of commercial harvest from Virginia and Maryland. In both jurisdictions, there have been significant changes to the reporting systems, which appear to have artificially impacted reported harvest. Currently, the time series of harvest is corrected for changes in reporting procedure externally to the model. Although the method appears reasonable, the very large effect on the resultant harvest time series should be validated. Ideally, a reporting change parameter (with variances) should be included in the model so that the sensitivity of the parameter on results can be explored and error can be accounted for within the model.
2) Provide probability distributions around the recommended reference points. This will provide a clear picture for managers and stakeholders of the model-based uncertainty surrounding the recommended reference points and will be important for managers when crafting decision rules and deliberating on adjusting management strategies.
3) Include a sensitivity analysis for various levels of recreational harvest. Given the poorly quantified recreational harvest, it is essential that managers understand a range of potential impacts from recreational harvest. This will assist in crafting management actions including the design of recreational crabbing licenses.
4) Modify the stock-recruitment relationship that is used in the model to include a penalty for male-biased abundance sex ratios.

In addition, the CBSAC recommends that the following modifications to the assessment occur in the longer term:

1) Incorporate gear-specific harvest and partial recruitment.

## 7. Management Advice – Short Term

**1) Monitor fishery performance and stock status relative to recommended reference points before adjusting regulations:**

Management actions since 2008 continue to be effective at rebuilding the spawning component of the population. Empirical estimates of 2011 age 1+ female abundance are close to the recommended target level of 215 million crabs. The female exploitation fraction in 2010 was below the recommended target of 25.5% for the 3rd consecutive year. Management jurisdictions should carefully consider the performance of 2011 fisheries relative to the recommended female-specific reference points and the outcome of the 2011-2012 winter dredge survey before making regulatory adjustments. The CBSAC notes that overall crab abundance was 30% lower at the beginning of the 2011 crabbing season than it was at the start of the 2010 season. Although this decrease in abundance was due to lower recruitment and higher winter mortality, rather than elevated fishing pressure during the 2010 crabbing season, having fewer crabs at the start of the 2011 season elevates the risk that the 2011 harvest will exceed the recommended female harvest target of 25.5%. If the 2011 Bay-wide harvest of female crabs is equal to the 2010 female harvest of 27.9 million pounds, the resulting exploitation fraction will be near the target level of 25.5%.

**2) Catch Reports:**
If management based on exploitation fraction continues, the CBSAC recommends that the jurisdictions implement procedures that allow accurate accountability of all commercial and recreational catches. If the jurisdictions continue with a sex-specific regulatory strategy, CBSAC recommends greater efforts to characterize the biological characteristics of all catch.

**3) Recreational Catch and Effort:**
Recreational catch and effort remains poorly quantified in Chesapeake Bay. The jurisdictions should consider methods for more precisely calculating recreational catch and effort, possibly through licensing systems.

4**) Latent effort:**
In both states, significant numbers of commercial crabbing licenses are unused. An increase in the blue crab population will likely increase the use of licenses that have, for some time, been inactive. During 2009 and 2010, both Maryland and Virginia have made headway addressing the amount of latent effort in the blue crab fishery. Federal fishery disaster relief money was used by both states to buy back commercial licenses.

**5) Effort Control:**
Controlling effort has been the foundation of crab management in recent years. The principal tools used by managers have been limited entry, size limits, catch limits, and seasonal closures. However, the total amount of effort expended in the fishery remains poorly quantified. Thus, the effectiveness of management actions remains difficult to quantify. Effort monitoring programs could be improved by incorporating pot tagging so that pot effort is measurable and enforceable.

## 8. Management Advice – Long Term

**1) Catch Control:**
A management strategy that sets annual catch levels based on estimates of abundance from the winter dredge survey could potentially balance annual harvests with highly variable recruitment. The CBSAC recommends that jurisdictions evaluate the benefits of quota-based systems. Allocating annual quotas to each jurisdiction would improve performance of a Bay-wide quota and lead to jurisdictional accountability of harvest relative to the Bay-wide exploitation target.

## 9. Critical Data and Analysis Needs

Blue crab management now employs sex-specific regulatory strategies. Given this, the lack of data describing sex ratio and size composition of the harvest will impede efforts to develop effective management strategies. CBSAC recommends that jurisdictions sample for biological characteristics in proportion to the magnitude of harvest from each harvest sector. A collaborative and coordinated Bay-wide, fishery-independent survey focused on the spring through fall distribution and abundance of blue crabs remains important, especially if agencies are considering regional or spatially-explicit management strategies. Finally, an assessment of the magnitude of incidental mortality due to various sources such as discarding female sponge crabs, the peeler fishery, predation effects and gear effects, would potentially improve reliability of exploitation estimates, and inform future assessments.



**CBSAC Members:**

| | |
|---|---|
| Lynn Fegley (Chair) | Maryland Department of Natural Resources |
| Derek Orner | NOAA Chesapeake Bay Office |
| Tom Miller | UMCES, Chesapeake Biological Laboratory |
| Daniel Hennen | NMFS, Northeast Fisheries Science Center |
| Alexei Sharov | Maryland Department of Natural Resources |
| Rob O'Reilly | Virginia Marine Resource Commission |
| John Hoenig | Virginia Institute of Marine Science |
| Rom Lipcius | Virginia Institute of Marine Science |
| Amy Schueller | NMFS, Southeast Fisheries Science Center |
| Eric Johnson | University of North Florida |

**Other Attendees:**

| | |
|---|---|
| Glenn Davis | Maryland Department of Natural Resources |
| Doug Vaughn | NMFS, Southeast Fisheries Science Center |

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7c. Ashford, J. R., and C. M. Jones. 2005. Survey of the blue crab recreational fishery in Maryland, 2005. Final Report to the Maryland Department of Natural Resources. Annapolis, MD. 31p.
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# CBSAC

# 2011 Blue Crab Advisory Report

# Figures

Figure 1. Winter dredge survey index of total blue crab abundance (density of males and females, all sizes combined) in Chesapeake Bay, 1990 through 2011. Error bars represent 95% confidence intervals.

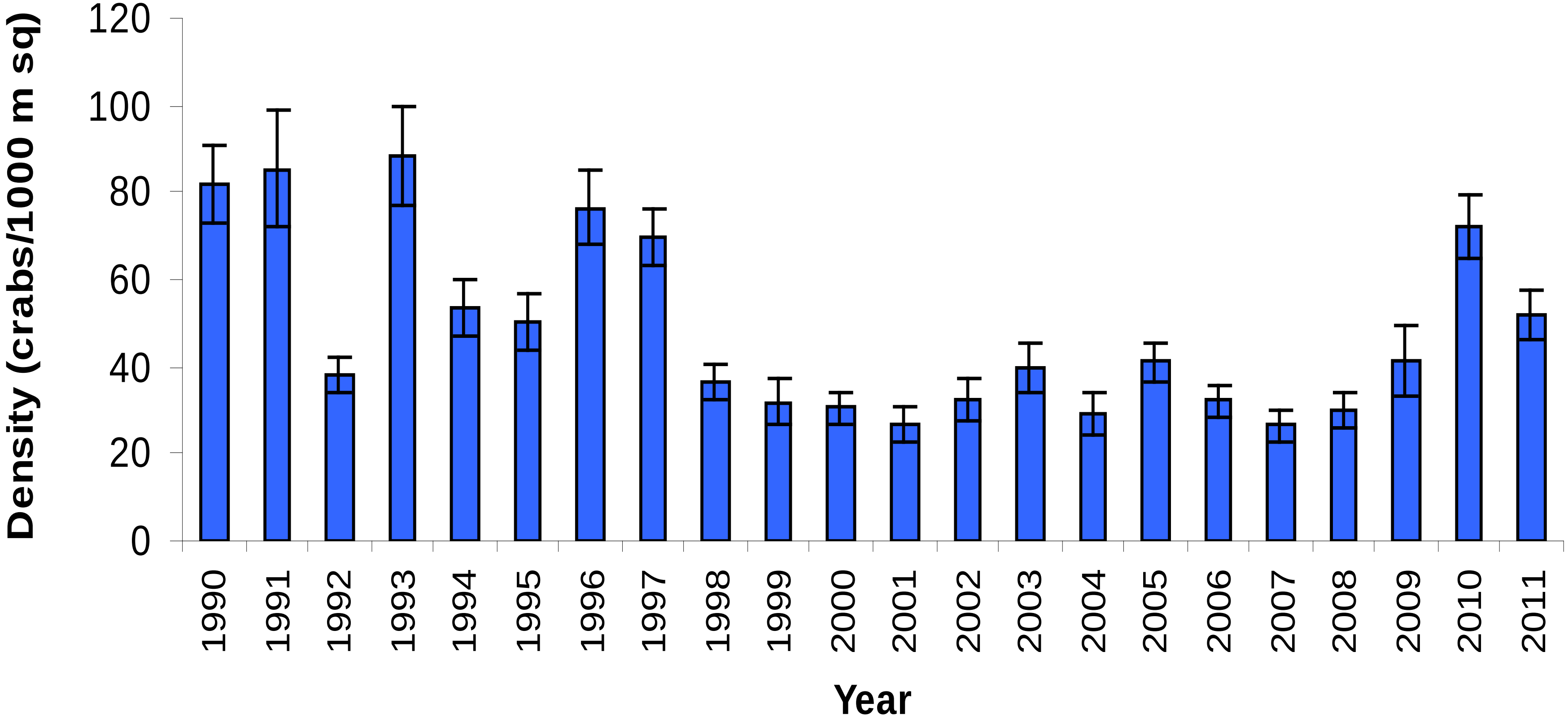

Figure 2. The recommended control rule for the Chesapeake Bay blue crab fishery. An abundance of 70 million age 1+ female crabs represents the overfished threshold. In 2010, abundance was above the overfished target and the exploitation rate was below the overfishing target. Reference points were derived from a statistical assessment model incorporating multiple surveys. Please see text for explanation of terms.

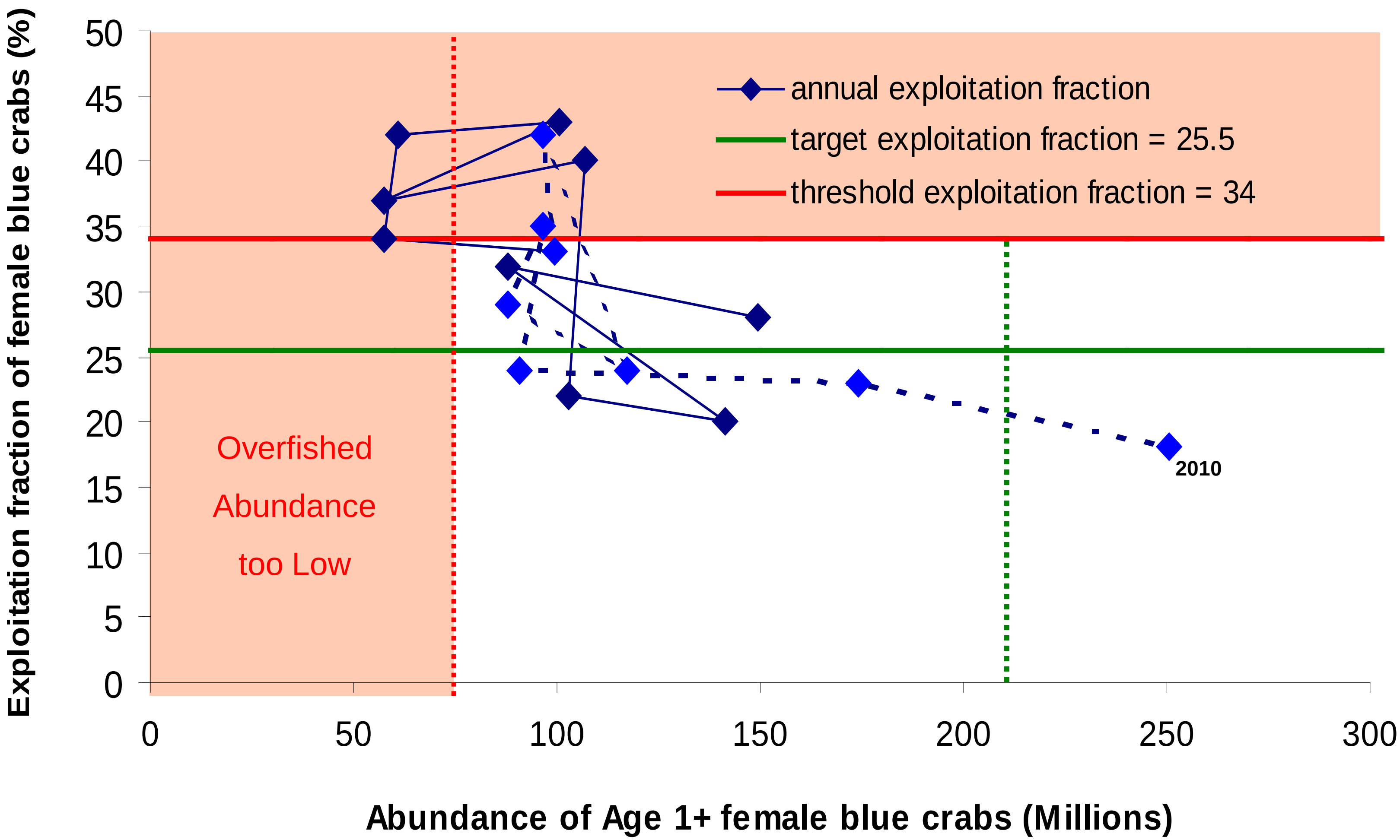

Figure 3. The former control rule used to manage the Chesapeake Bay blue crab fishery. An abundance of 86 million age 1+ (male and female) crabs represents the overfished threshold. In 2010, abundance was above the overfished target and the exploitation rate was below the overfishing target.

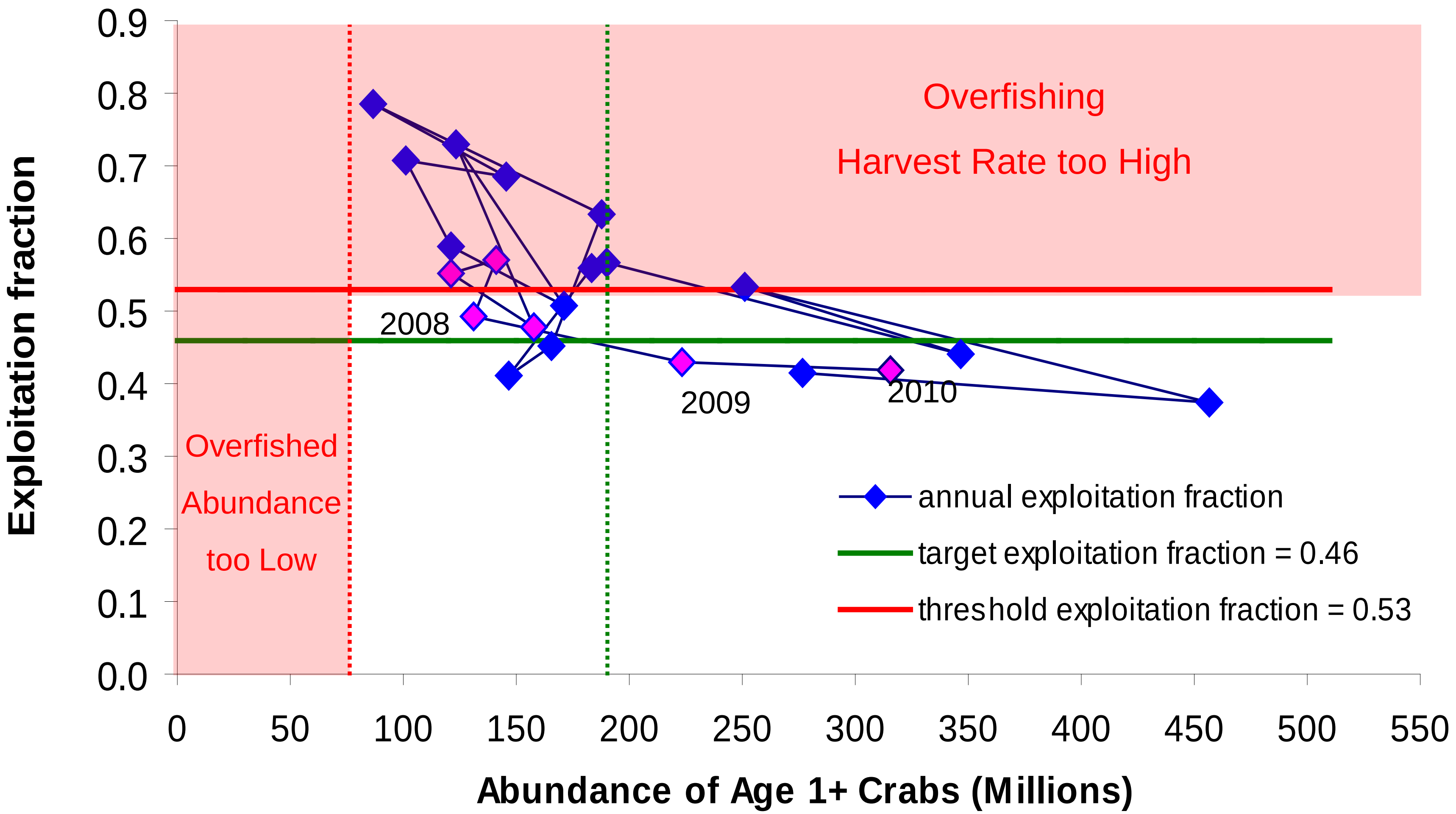

Figure 4. Winter dredge survey estimate of **abundance of female blue crabs age one year and older** (age 1+) 1990-2011 with recommended reference points. These are female crabs measuring greater than 60mm across the carapace and are considered the 'exploitable stock' that will spawn within the coming year.

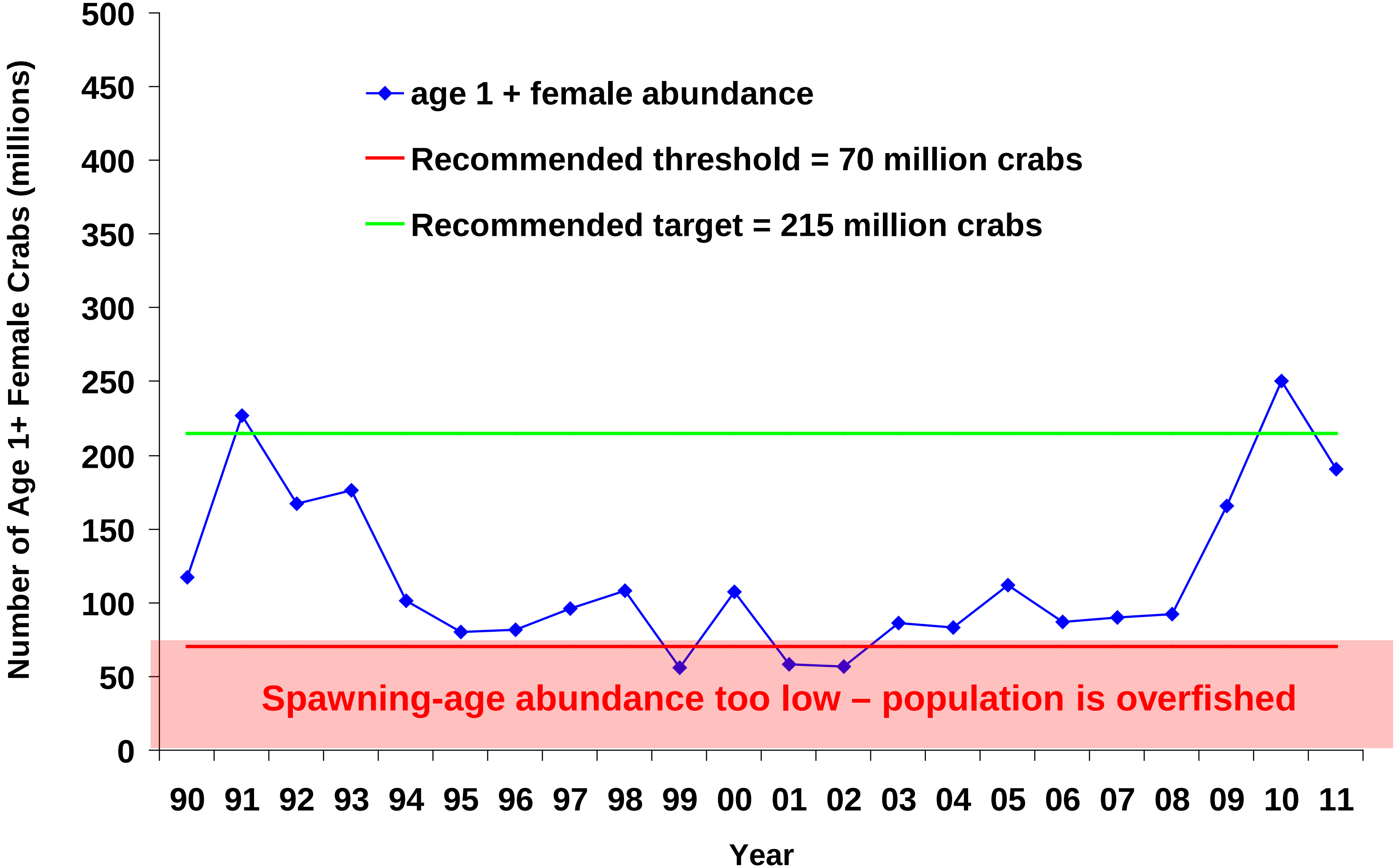

Figure 5. Winter dredge survey estimate of **abundance of male and female blue crabs age one year and older (age 1+) 1990-2011.** These are crabs measuring greater than 60mm across the carapace and are considered the 'exploitable stock' that will spawn within the coming year. The lowest abundance of 86 million crabs was observed in the 1998-1999 survey and is considered the overfished threshold. The interim target abundance was 200 million crabs.

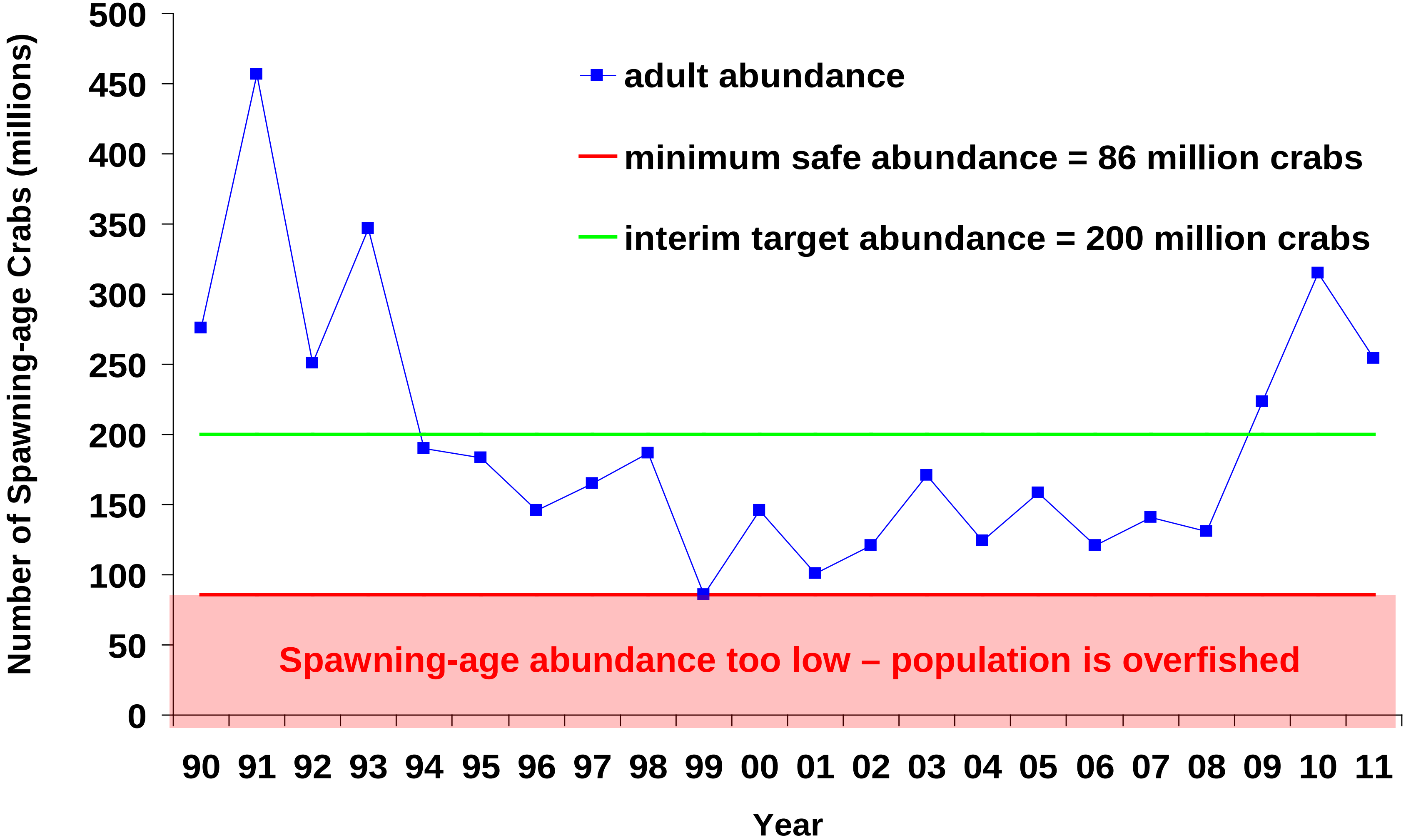

Figure 6. Beginning in December 2010, water temperature during winter in Chesapeake Bay declined to the coldest temperatures observed since 1996. Temperatures remained below average from January through February, causing high mortality of large crabs.

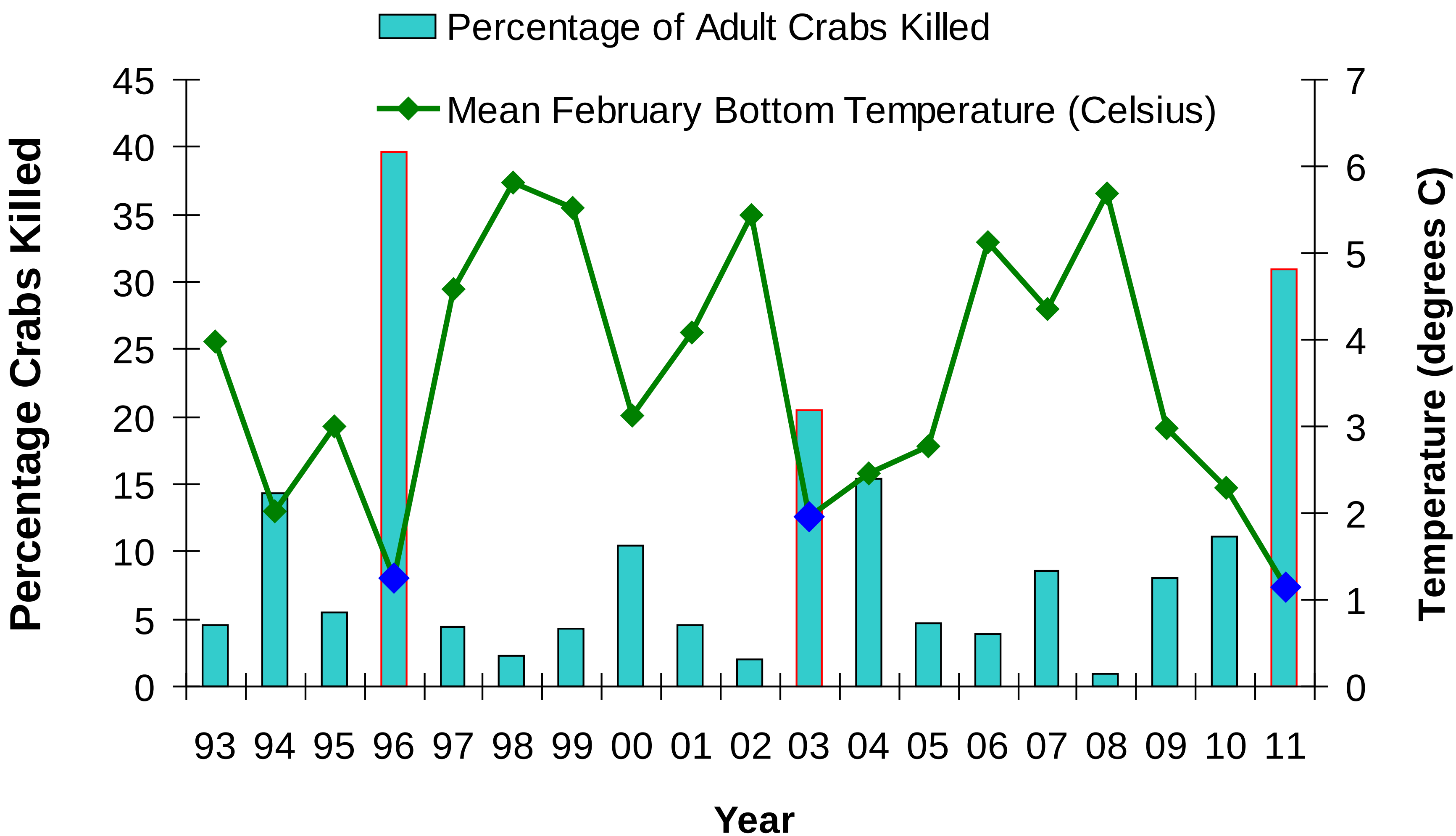

Figure 7. Winter dredge survey estimate of **abundance of male blue crabs age one year and older (age 1+)** 1990-2011. These are male crabs measuring greater than 60mm across the carapace and are considered the ‘exploitable stock’ that will spawn within the coming year.

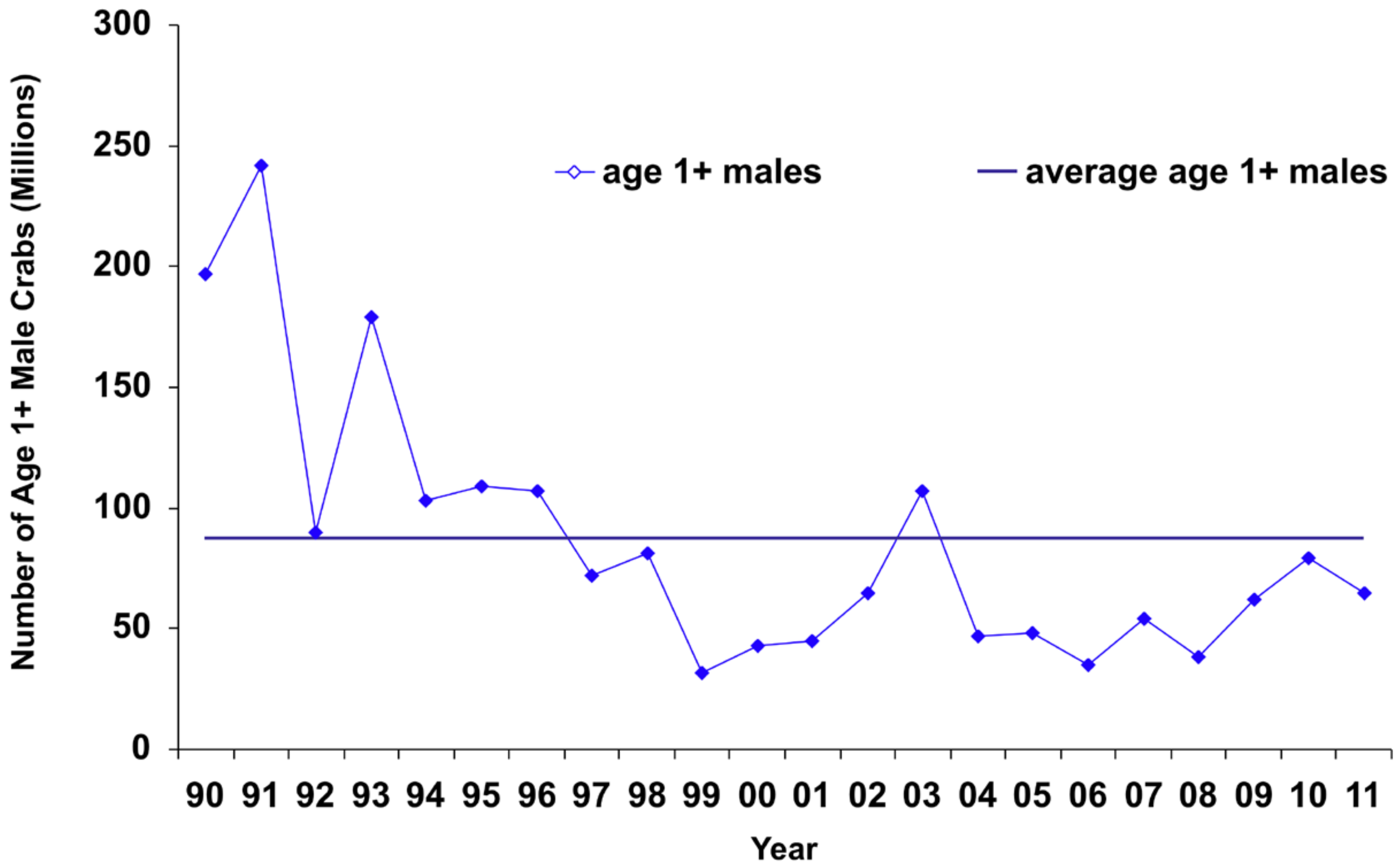

Figure 8. Winter dredge survey estimate of **abundance of age 0 crabs,** 1990-2011. These are male and female crabs measuring less than 60mm across the carapace.

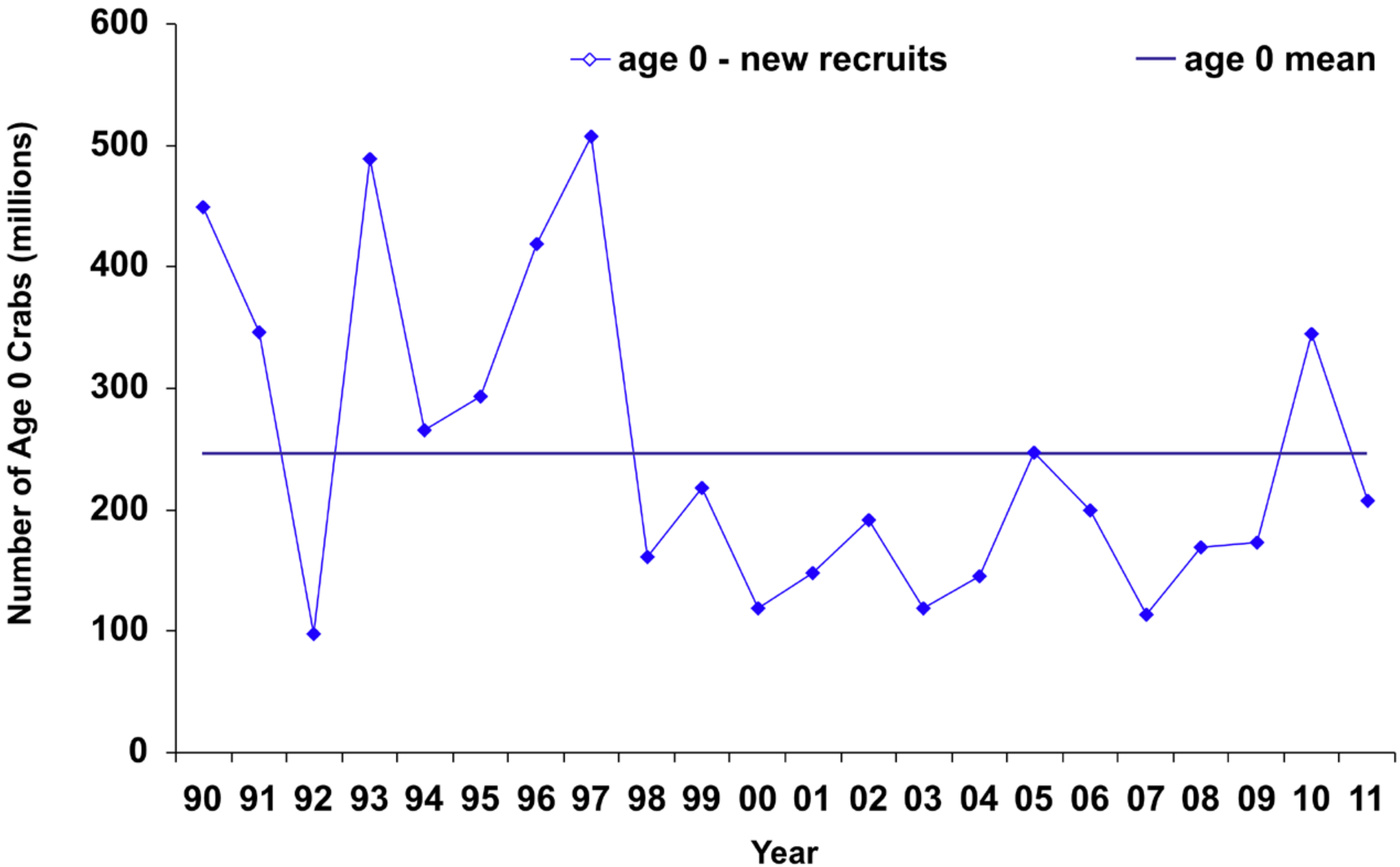

Figure 9. Maryland and Virginia Chesapeake Bay commercial blue crab harvest 1993-2011.

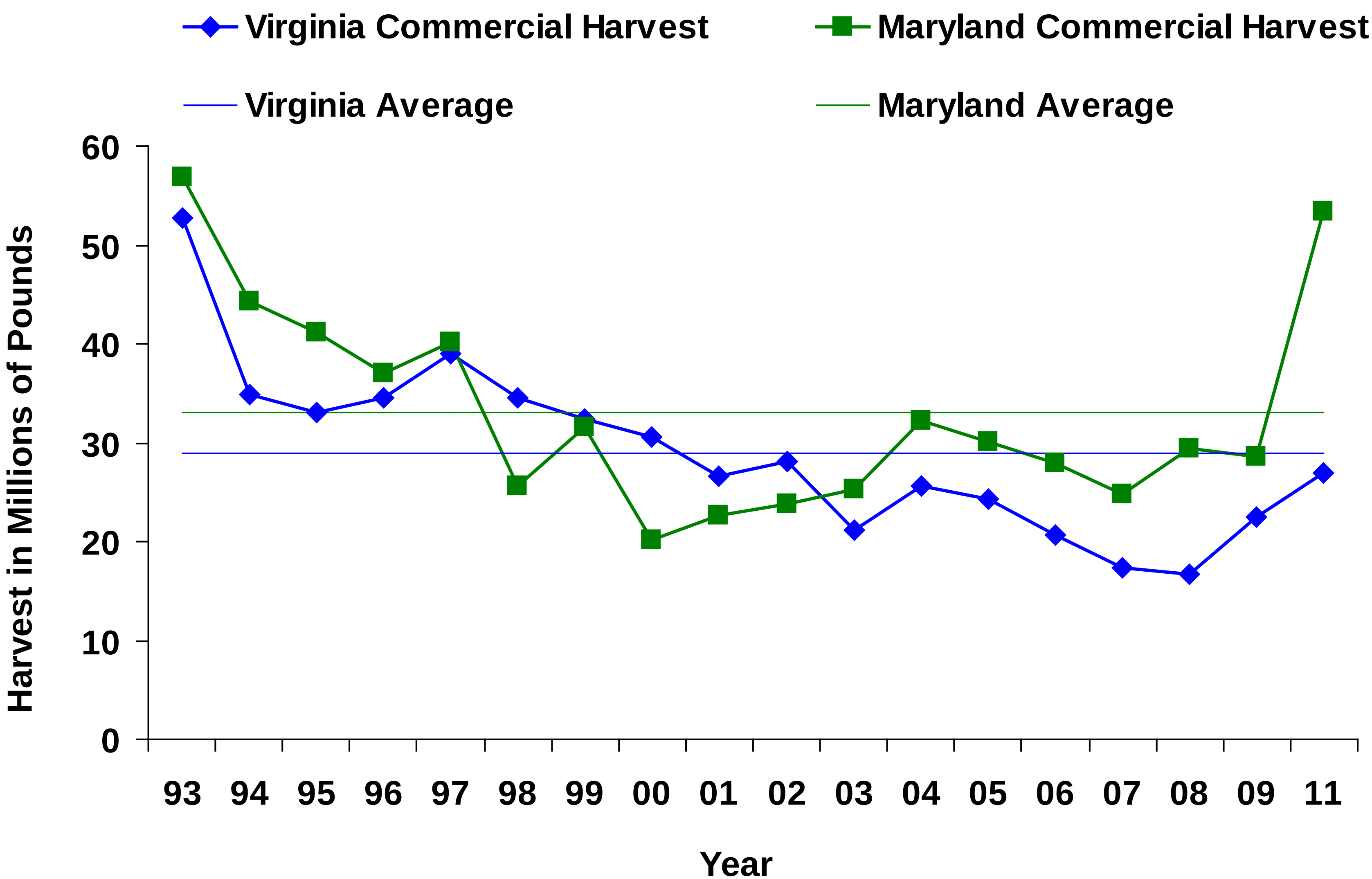

Figure 10. The percentage of female crabs removed from the population each year by fishing relative to recommended female-specific target and threshold levels 1990 through 2010.

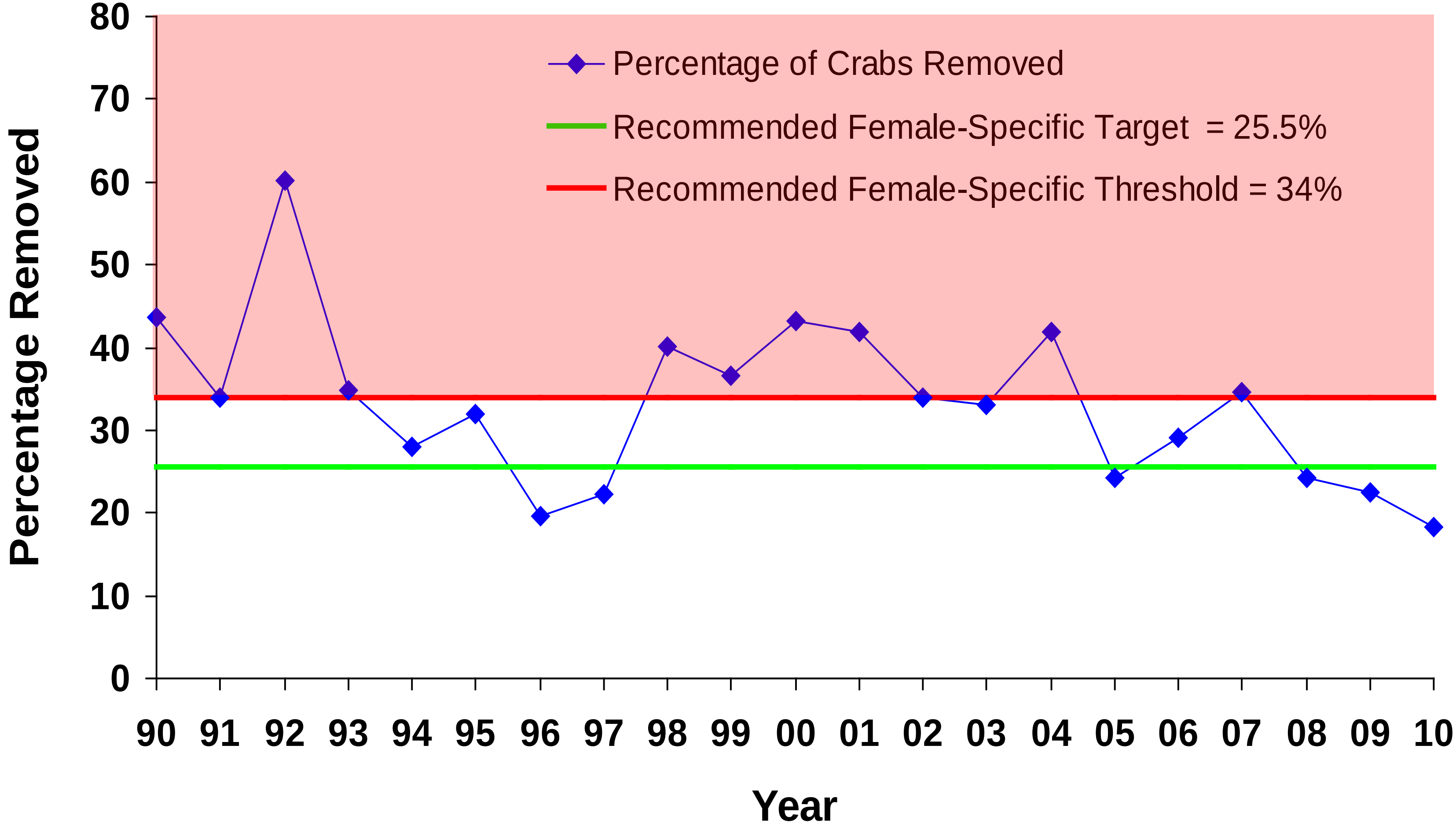

Figure 11. The percentage of male and female crabs removed from the population each year by fishing relative to target and threshold levels 1990 through 2010.

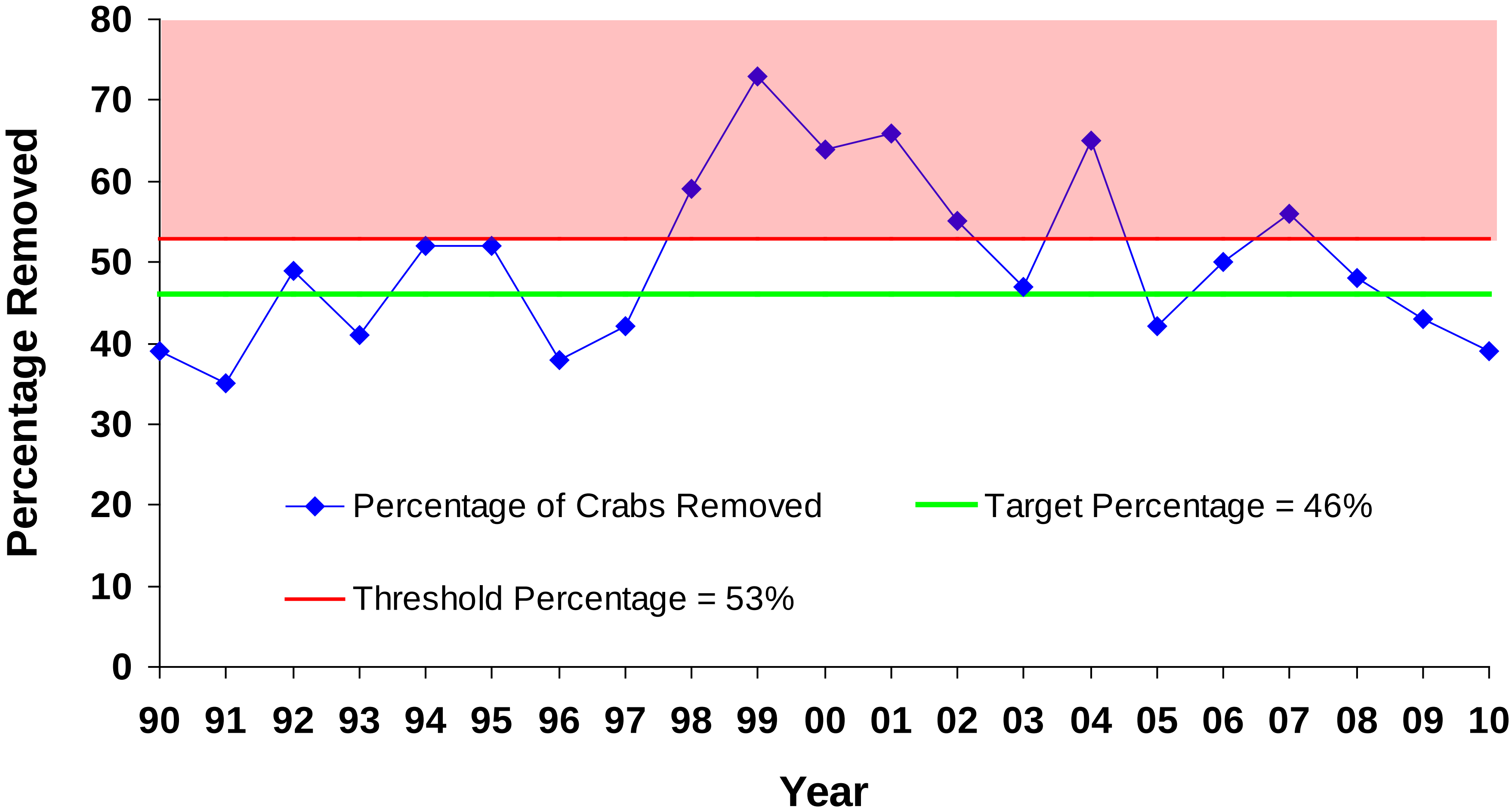

Figure 12.  An ‘operational’ sex ratio for blue crab in Chesapeake Bay based on abundance estimates from the Winter Dredge Survey.  The ratio is the density reproductive males (greater than 60 mm across the carapace) divided by the density of female crabs which would actively be seeking mates (immature female crabs greater than 60 mm across the carapace).