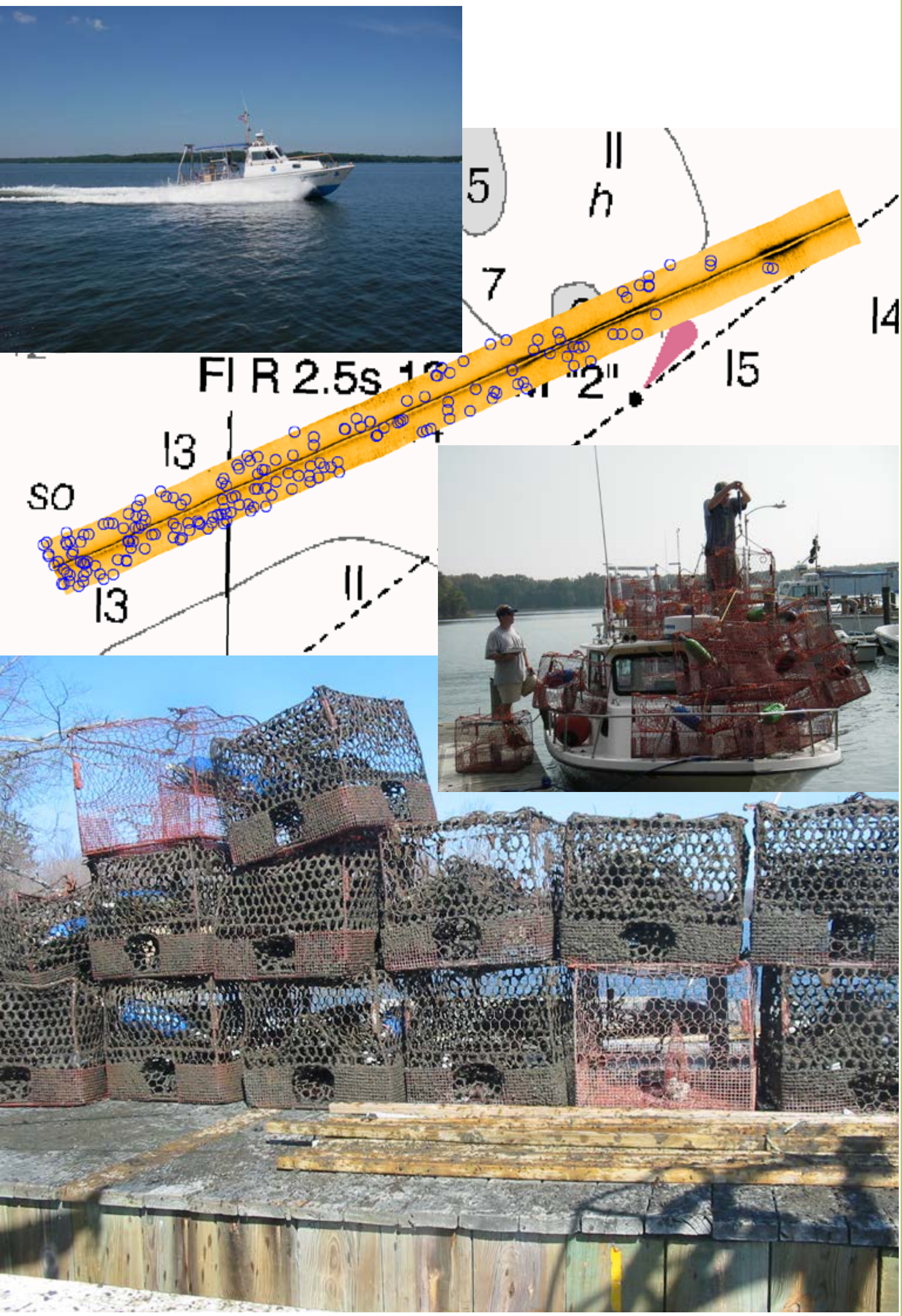
# 2006-2009

# Quantifying the Effects of Derelict Fishing Gear in the Maryland Portion of Chesapeake Bay




## Final Report

**Submitted to:**
**NOAA Marine Debris Program**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# EXECUTIVE SUMMARY

In 2005 the NOAA Chesapeake Bay Office (NCBO) established the Derelict Fishing Gear Program (DFGP) to address concerns that derelict crab traps may be negatively affecting blue crab and other estuarine species in Chesapeake Bay. With support from the NOAA Marine Debris Program, the NCBO DFGP developed a research approach and the methodologies to determine the effects of derelict crab traps Bay-wide. The primary objectives of the program were to (1) quantify the number of derelict traps throughout Chesapeake Bay, and (2) to evaluate the direct effects of derelict traps on blue crabs and other estuarine species. To meet the program objectives the research priorities were divided by State and the Center for Coastal Resource Management (CCRM) at VIMS conducted research in Virginia waters and NCBO and partners conducted work in Maryland waters. This report describes work focused on quantify the effects of derelict crab traps in the Maryland portion of Chesapeake Bay using a combination of side-scan sonar surveys, derelict trap ground-truthing, and in situ crab trap experiments.

The densities of derelict crab traps were successfully quantified and examined using side-scan sonar, ground-truthing surveys, and a diver based survey. In the winter of 2007 a stratified random side-scan sonar transect survey was conducted throughout the Maryland portion of Chesapeake Bay. The main objective of the side-scan sonar transect survey was to quantify the density and distribution of derelict crab traps. Major elements of this survey included developing the survey design, conducting a stratified random survey, and developing specific image analysis protocols to aid with the detection and enumeration of derelict traps in side-scan sonar imagery and to assess the accuracy of detecting derelict traps during the review. The survey results indicate that derelict crab traps appear to be ubiquitous throughout areas where the commercial hard crab trap fishery is active in the Maryland Bay. In addition, the survey also uncovered identifiable spatial patterns of derelict traps. The total number of derelict traps in the Maryland Bay is estimated to be 84,567 traps based on a total of 285 side-scan sonar transects.

To simulate actively fishing derelict traps in the Maryland Bay, a set of experimental crab traps was deployed and monitored across all four seasons between October 18, 2006 and March 6, 2008. The purpose of this study was to determine the overall effects that derelict blue crab traps have on fisheries resources in the mesohaline portion of Chesapeake Bay. Specifically, the objectives of this study were to (1) document what species enter derelict traps, (2) determine trap retention rate by species, (3) determine how those rates change as a function of "deployment time", and (4) determine overall mortality to all species caught in the traps. Trap monitoring revealed that both blue crab and other by-catch species continue to be captured and killed after bait from the trap is gone. Traps that were not lost or vandalized during the study continued to capture species for the entire study time-frame indicating that derelict traps last for at least 14 months. White perch had the highest mortality of all by-catch species and seem to be highly susceptible to derelict traps. Blue crab mortality is estimated to be 20 crabs/trap/year.

Taken together, these results indicate that ghost fishing by derelict traps is widespread and a measurable source of unaccounted fishing mortality for the blue crab and also negatively effects other species in the Maryland portion of Chesapeake Bay. Although there are currently no management regulations in place to reduce ghost fishing by derelict traps, there are options to reduce the effects and potentially reduce the numbers of derelict traps in the Bay. These include modifications to the traps to aid in escapement of organisms, developing management strategies to reduce crab trap losses, and retrieving traps once they become derelict. The management options and mitigation measures based on our findings represent just a few approaches to reduce the effects of derelict crab in the Maryland portion of Chesapeake Bay. We recommend that scientists and managers work with industry to determine the best combination of approaches to reduce the loss of crab traps in the Maryland portion of Chesapeake Bay.

# ACKNOWLEDGEMENTS

This work was partially funded by the NOAA Marine Debris Program through internal grants to the NOAA Chesapeake Bay Office. We thank Dr. Holly Bamford, Director of the Marine Debris Program for her support on every aspect of this project. We also acknowledge the Smithsonian Environmental Research Laboratory (SERC) for the use of their facilities during survey operations. We are grateful to Lynn Fegley of the Maryland Department of Natural Resources for her support of this project. We are also grateful to Dr. Jon Vølstad for his help with survey design. We thank Rick Younger and Steve Suttles for conducting the diver survey used to enhance derelict trap detection. We also thank Dr. Howard Townsend, Dr. Hongguang Ma, and Dr. Xinsheng Zhang for their assistance and helpful discussions with multiple aspects of this project. We are grateful to Dr. Don Strebel for his assistance with accuracy assessment techniques and to Gail Lucas for her help with formatting and production of this final report.

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# 1.0 INTRODUCTION

Marine debris is one of the most widespread pollution problems facing the world's oceans and coastal environments (The Ocean Conservancy 2003). The federal government recognized the need to address this issue by passing the Marine Plastic Pollution Research and Control Act in 1987. This legislation provided much needed research prioritization and funding for this growing problem in the U.S. It also facilitated the creation of the Marine Debris Research, Protection, and Reduction Act of 2006, which legally established the National Oceanic and Atmospheric Administration's Marine Debris Program (NOAA Marine Debris Program 2009). The Marine Debris Program (MDP) supports national and international efforts to prevent, identify, and reduce the occurrence of marine debris to protect and conserve our nation's natural resources, oceans, and coastal waterways. Specifically, the activities undertaken by MDP and its partners research the locations and sources of marine debris and its impacts on the environment, reduce debris occurrence, and create educational campaigns to help people understand the threats marine debris poses locally, regionally, and to the nation as a whole.

Generally defined as any type of man-made object that unintentionally enters the coastal or marine environment (e.g., plastic bottles, lumber, fishing gear), marine debris largely (80%) originates from the terrestrial environment, while smaller but still significant amounts originate from at-sea activities (DOC 1999). As marine debris has become more common, its deleterious effects have become more evident and more quantifiable. Negative impacts to several marine taxonomic groups have been documented. For example, organisms have been known to ingest or become entangled in or entrapped by various types of marine debris (Laist 1996). Because many types of marine debris (e.g. plastics) degrade very slowly, such effects could potentially increase over time as debris accumulates in the marine environment.

One of the most persistent and damaging types of marine debris is lost or "derelict" fishing gear (FAO 2009). Derelict fishing gear can damage habitat, interact with threatened and endangered wildlife, and can introduce synthetic materials into the marine food web. However, the most deleterious aspect of derelict gear is that it can continue to catch and kill target and non-target species, through what is widely known as "ghost fishing". Although marine debris and its negative impacts have only recently received widespread attention, ghost fishing by derelict gear has been recognized as a problem by North American fisheries researchers for over 35 years.

Much of the earliest work on derelict gear focused on determining the impacts of derelict traps and gill nets on target and non-target species rather than identifying causes or quantifying the amount or loss rates of derelict gear (FAO 2009). Both gill nets and traps are proven to be detrimental to living resources and can persist in the environment for years and even decades after they become derelict (FAO 2009). Many trap fisheries are susceptible to greater gear loss because they typically span over large areas and require high densities of traps to remain productive. This can cause significant deleterious effects to target and non-target species because derelict gear is continuously be resupplied in high densities.

The Chesapeake Bay blue crab (*Callinectes sapidus*) fishery is one of the most extensive trap fisheries in the world. The fishery is jointly managed by the states of Virginia and Maryland, together with the Potomac River Fisheries Commission. Although the population has declined substantially over the past several decades, the Chesapeake Bay remains the nation's largest source of blue crab (Miller 2005). The fishery occurs from early spring through November in Virginia and the Potomac and until mid-December in Maryland. The primary gear for harvest is a trap locally known as the "crab pot". This trap was introduced into the fishery in 1928 and is essentially the same design used in the fishery today (Van Engel 1962). These traps are deployed in the mainstem of the Bay in Maryland and can be fished in the tributaries and mainstem of the Virginia Bay and in the Potomac River. Traps are generally fished attached to a single line and float, but multiple traps can also be fished on trotlines with just two buoys attached to the ends (Slacum et al. 2008). The number of traps fished throughout the Bay annually is unknown, however in Maryland monthly estimates of traps fished during the season have been as high as 183,000 at any one time (Slacum et al. 2008). Although fishing effort is not as extensive in Virginia or in the Potomac, the numbers of crab traps being fished in Virginia and in the Potomac can also be quite large considering the number of license holders and the number of traps allowed under each license (Rhodes et al. 2001, Havens 2008). Thus, at any one time during the open season there could be an enormous amount of traps being actively fished in Chesapeake Bay.

The rate at which traps are lost can be difficult to assess because trap loss is infrequently reported. A portion of crab traps become derelict in Chesapeake Bay due to losses from storm activity, inferior gear, vandalism, or abandonment. Currents may also roll the trap or move them deeper so buoys are submerged and therefore undetectable. Vessel propellers can also sever buoy lines. While the number of traps lost annually is still unknown, existing information suggests the number of ghost fishing derelict traps could be very high in Chesapeake Bay. Casey (1990) interviewed local fishers in Chesapeake Bay and determined annual losses of a fisher's gear could be between 10 and 30%. In the Gulf of Mexico, Guillory et al. (2001) roughly estimated that 250,000 crab traps could become derelict assuming a 25% annual loss rate. The percentage of annual loss for these fisheries corresponds to what has been suggested in other trap fisheries. Early work by Smolowitz (1978) estimated trap losses in the American lobster (*Homarus americanus*) fishery at 20 to 30% annually. Breen (1987) estimated the loss of traps in the Frazer River Dungeness crab (*Cancer magister*) fishery in British Columbia to be 11% each year. High and Worlund (1979) reported a 10% seasonal loss of gear in the Alaskan King crab (*Paralithodes camtschatica*) fishery. The lack of accurate estimates for the rate of trap loss has precluded accurate estimates of the number of derelict traps present in the Chesapeake Bay.

Derelict crab traps have the potential to be a significant source of unaccounted fishing mortality (Van Engel 1982, Guillory et al. 2001, Haddon 2005). For blue crabs, estimates of annual capture rates by derelict traps have been variable across ecosystems (Gulf of Mexico, 47.7 crabs/trap/year, Guillory 1993; Lower Chesapeake Bay, 50.5 crabs/trap for April-November and 13.6 crabs/trap for May-August, Havens et al. 2008). Once entrapped, crabs are believed to suffer mortality at annual rates ranging from 20-60 crabs/trap in South Carolina (Whitaker 1979), to 25.8 crabs/trap in coastal Louisiana (Guillory 1993), to 50.6 crabs/trap for lower Chesapeake

Bay (Havens et al. 2008), and 53.8 crabs/trap averaged across several ecosystems (Poon 2005) as a result of starvation, cannibalism, infection, disease, and prolonged exposure to poor water quality (i.e. low dissolved oxygen). On the other hand, escapement studies suggest that blue crabs may escape derelict traps at a rate of 34% (Guillory 1993) and 56% (Arcement and Guillory 1993) in the Gulf region.

In addition to crabs, numerous non-target species have also been indentified in derelict blue crab traps (Guillory et al. 2001, Havens et al. 2008). Although all of these rates may be mitigated with trap modifications (cull rings, Ruderhausen and Turano in press; mesh size or escape panels, Guillory 1998, Smolowitz 1978), it is becoming clear that the impact of derelict traps depends strongly on system-specific, local factors such as water quality and target and non-target population sizes (Guillory 1993, Guillory et al. 2001, Havens et al. 2008). While Upper Chesapeake Bay is home to one of the most intensive blue crab fisheries in the world (Van Engel 1962, Cronin 1998), nothing is known about how derelict traps affect its living resources.

Two pieces of information are required to determine the overall effects of derelict traps in Chesapeake Bay; the mortality and injury associated with continued capture, and the number of derelict traps that reside in the system. Taken together, these data can be used to determine the impacts of derelict crab traps. The design of in situ experiments to determine the effects of derelict traps to blue crabs and bycatch is relatively straightforward and there are many examples of successful studies (Guillory 1993, Sean McKenna (NCDMF), personal communication 2006, Havens et al. 2008). However, quantifying the distribution and densities of derelict traps throughout the Chesapeake Bay is much more challenging considering the size of the system and the limitations for direct observational research.

Traditional research designed to gather detailed observations from the seafloor have typically relied upon divers or crude sampling devices to gather data (Eleftheriou and McIntrye 2005). Diver surveys provide superior observational acuity and precision over crude methods in that a wealth of information can be collected through visual counts or in situ observations. In a recent example, Chiappone et al. (2004) used divers to assess the impacts and extent of derelict fishing gear throughout a portion of the Florida Keys National Marine Sanctuary. This survey was successful because divers could identify specific derelict gear and determine their immediate impacts to benthic habitat through direct visual observations. Unfortunately, observations from divers are limited by the condition of the water column (water clarity) precluding some surveys from using divers as a means of data gathering; therefore other methods of observation have to be explored.

Remote sensing techniques used to quantify and map substrate are capable of sampling micro-scale habitat features accurately over large areas at minimal expense. Devices such as multi-beam and side-scan sonar have proven to be useful tools for mapping the seafloor (Able et al. 1993, Cutter et al. 2002, Kenny et al. 2003). This technology is not restricted by water clarity and is a useful alternative where observations of the seafloor are required. Side-scan sonar has been used effectively to identify and enumerate marine debris in several surveys (NOAA Marine Debris Program 2009). For example, a recent survey using side scan sonar to locate and retrieve derelict blue crab traps estimated a one year loss rate of 22% for traps fished in a tributary of the York River, Virginia (Havens et al. 2008).

In 2005 the NOAA Chesapeake Bay Office (NCBO) established the Derelict Fishing Gear Program (DFGP) to address concerns that derelict crab traps may be negatively affecting blue crab and other estuarine species in Chesapeake Bay. The primary focus of this program was to develop research and methodologies that could be used to determine the effects of derelict traps Bay-wide. The DFGP developed a step-wise scientific approach to,

1) Quantify the number of derelict traps throughout Chesapeake Bay, and

2) Evaluate the direct effects of derelict traps on blue crabs and other estuarine species.

In collaboration with its partners, the NCBO DFGP, used a combination of side-scan sonar surveys, derelict trap ground-truthing, and in situ crab trap experiments to quantify the effects of derelict crab traps in Chesapeake Bay. This report summarizes the work undertaken to quantify the effects of derelict crab traps in the Maryland portion of Chesapeake Bay between 2006 and 2009. Section two of the report summarizes work related to ground-truthing derelict traps detected in side-scan sonar imagery. Section three presents the Maryland Bay-wide side-scan sonar transect survey conducted to quantify trap densities in the Maryland Bay. Section four presents the in situ trap experiment designed to quantify effects of derelict traps on target and non-target species. Section five summarizes the major conclusions from this work and presents management recommendations and future research objectives. The methodology and rational used to assess accuracy of derelict trap detection in side-scan sonar imagery is presented in Appendix A, and the Virginia side-scan sonar transect survey design is presented in Appendix B.

# 2.0 DERELICT TRAP GROUND-TRUTHING SURVEYS

## 2.1 GROUND-TRUTHING SURVEY OBJECTIVES

One of the main objectives of the Derelict Fishing Gear Program was to quantify the densities of derelict traps in Chesapeake Bay using side-scan sonar. Preliminary surveys indicated the potential for side-scan sonar to be effective at imaging derelict traps. However, without knowledge of the range of marine debris types occurring in the system or what those debris signatures might look like in a side-scan sonar image, errors in derelict trap detection could be significant. To increase precision of identifying derelict traps and to differentiate suspected derelict traps from other marine debris seen in sonar imagery, several types of image validation or "ground-truthing" surveys were conducted. Each survey employed sonar data acquisition, in situ validation, and image review. The objective of these surveys was 1) to enhance and refine our ability to detect derelict traps in sonar imagery, and 2) to gather information on the condition of derelict traps and the organisms found in those traps. Three separate surveys were conducted to meet these objectives, including a derelict trap retrieval survey using grapples, a survey using a diver, and a directed survey to ground-truth individual traps detected in the imagery.

## 2.2 MATERIALS AND METHODS

### 2.2.1 Derelict Trap Retrieval Survey

Specific objectives of the derelict trap retrieval survey were to 1) evaluate the amount of effort required to retrieve traps from the bottom using grappling devices, 2) document derelict trap condition, and 3) document organisms found in derelict traps. The design of this directed approach included mapping the bottom of an area adjacent to the Rhode and West Rivers that was approximately 450 m long x 300 m wide where the concentrations of derelict traps was suspected to be high (Figure 2-1).

The survey was conducted between 15 March and 30 March 2007 when the fishery was not active in order to prevent confusion between derelict and actively-fishing traps, and so that retrieval efforts did not interfere with fishing operations. Sonar data collected within the specified study area were collected and processed using the same acquisition settings that were used in the broad-scale transect survey (section 3.0). The locations of potential derelict traps were identified and enumerated by two reviewers using Chesapeake Technology Incorporated (CTI) SonarWizMap software® 4.03.0010 (Figure 2-2, Table 2-1).

Derelict traps were retrieved from the survey area using grappling devices deployed from the stern of two research vessels; the R/V Bay Commitment and the R/V Integrity. The locations of potential traps and the corresponding image files were transferred onto the navigational systems (Hypack Max®) of each vessel to direct the trap retrieval efforts. The Grappling

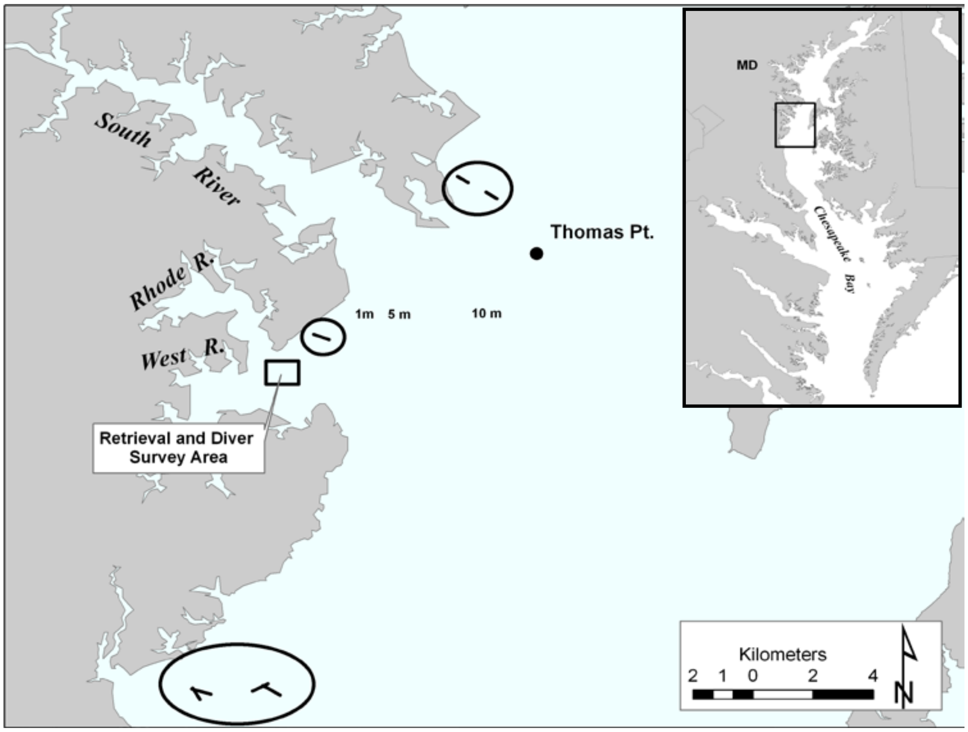



Figure 2-1. Map showing areas on the western shore of Maryland where derelict trap retrieval and diver surveys were conducted between 15 March and 30 March 2007. Circles represent areas where directed side-scan sonar transects and trap retrievals were conducted between 18 March and 28 March 2008 to ground-truth derelict traps.

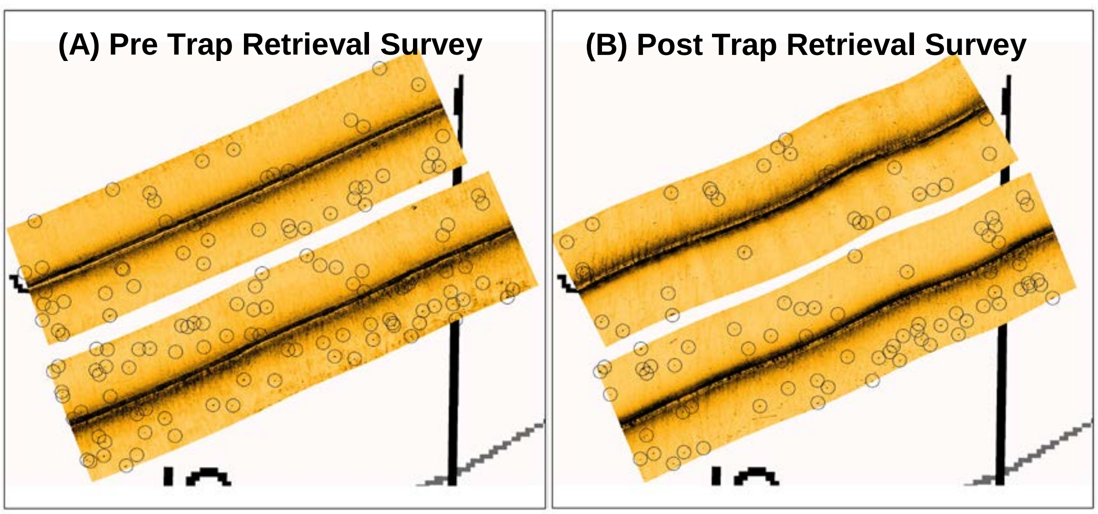



Figure 2-2. Side-scan sonar transects conducted in an area adjacent to the Rhode River, MD with high densities of derelict traps. Caption A depicts suspected derelict traps that were identified and counted before retrieval efforts. Caption B depicts the suspected derelict traps that were counted after retrieval efforts were completed.

Table 2-1. Table showing the counts of potential derelict traps detected in side-scan sonar imagery prior to the trap retrieval survey and after the trap retrievals had completed.

| Date | Side-scan Sonar Survey | Target Counter | |
|---|---|---|---|
| | | Reviewer 1 | Reviewer 2 |
| 14-Mar-07 | Pre | 131 | 131 |
| 29-Mar-07 | Post | 97 | 105 |
| | Difference | 34 | 26 |

devices consisted of five large grappling hooks attached to a five-foot heavy gauge aluminum or steel pipe (Figure 2-3). Both vessels were equipped with stern A-frames from which the grappling devices were deployed to the Bay bottom and towed within the retrieval area to collect derelict traps. When a trap was hooked, the grappling device was retrieved and the trap was brought up to the vessel. Information gathered from each trap is shown in Table 2-2. All species collected in the traps were released and all derelict traps collected during the retrieval event were kept and recycled at a local land fill (Figure 2-4).

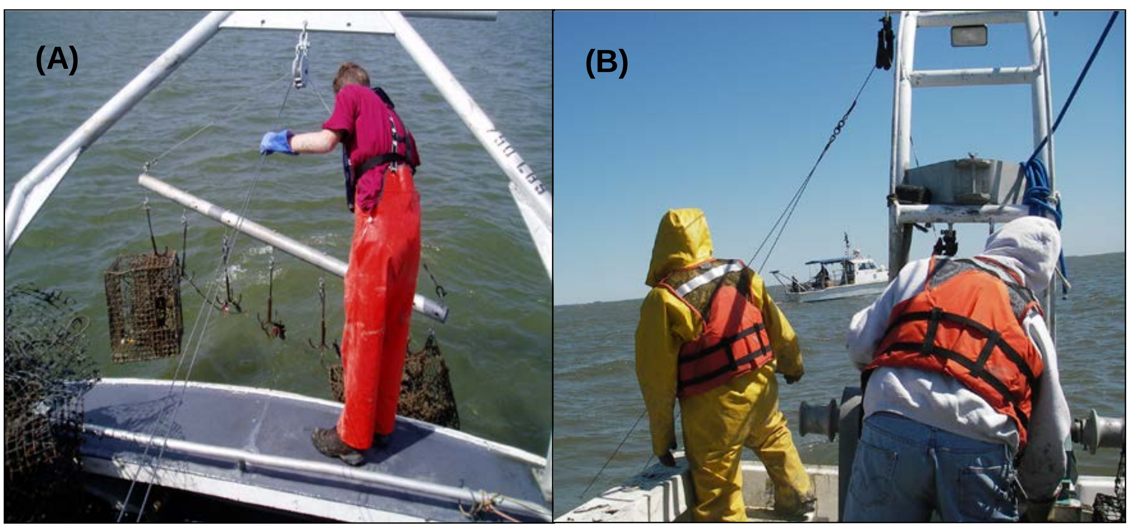



Figure 2-3. Photos of the derelict crab trap retrieval survey that was conducted between 15 March and 30 March 2007.

After the retrieval efforts were completed, a post side-scan survey was conducted to compare the initial distribution of derelict traps with those left following the retrieval. Sonar data acquisition and processing were conducted following the same methods and settings used in the initial survey. Once the post survey was completed, locations of derelict traps were identified and enumerated by two reviewers using Chesapeake Technology Incorporated (CTI) SonarWizMap software® 4.03.0010 (Figure 2-2, Table 2-2).

Table 2-2. Types of data collected from retrieved traps during the derelict trap in situ, diver, and directed in situ surveys.

| Parameter | Level |
|---|---|
| Fouling Condition | Light (<25%) |
| | Medium (26-50%) |
| | Heavy (51-75%) |
| | Extreme (76-100%) |
| Attached Float Line | Present/Absent |
| Bait Status | Present/Absent |
| Organisms | Species ID |
| | Size |
| | Count |
| | Alive/Dead/Injured |

Figure 2-4. Representative derelict traps from all ground-truthing and retrieval efforts and the condition of the organisms trapped within them.

Potential derelict traps (counts and locations) identified during pre and post retrieval surveys were compared to determine the accuracy of identifying derelict traps using sonar imagery. Qualitative data describing the condition of remaining traps and the organisms in the traps were collected. In addition, the daily rate of trap collection was determined to assess the efficiency with which the grappling method retrieved traps.

### 2.2.2 Diver Survey

A one-day diver survey was conducted on 31 March 2007 to provide additional information about the accuracy with which derelict traps could be identified, located, and retrieved using sonar imagery. To this end, potential derelict traps were identified in the sonar imagery and a diver was deployed to retrieve those specific traps. This survey was conducted in two small areas adjacent to the retrieval survey described above (Figure 2-1). These areas were mapped using the same sonar data acquisition and processing methods used in the grappling retrieval survey. Once the side-scan sonar data had been processed, potential derelict traps were identified in the imagery for validation. We purposely choose imagery that depicted a range of target pixel intensities and object configurations which were suspected to be derelict traps. This provided information on the spectrum of shapes, sizes, and pixel intensities that could be encountered and thus allowed us to hone our detection ability.

Once the potential derelict traps of interest were identified, the sonar imagery was loaded onto the vessel navigational system (Hypack Max®). The diver survey was conducted from the R/V Integrity by anchoring the vessel down-current of a group of potential derelict traps of interest. Several groups of traps in two adjacent areas were identified for verification. Because of poor visibility, the diver survey was conducted following a common limited visibility search and rescue pattern, i.e. a line was attached to the vessel's anchor and then the diver proceeded to swim in consecutively larger circles around the anchor until a suspected trap was encountered by either the diver or the line (Figure 2-5). Upon locating a derelict trap, the diver attached a buoyed line to the trap so that a separate vessel could retrieve the trap once the diver was out of the water. This methodology was then repeated at the second site. Information gathered from each trap is shown in Table 2-2. All species collected in the traps were released and all derelict traps collected during the retrieval event were kept and recycled in a local land fill (Figure 2-4).

### 2.2.3 Directed In-situ Ground-Truthing Surveys

Several other small-scale directed surveys were conducted 1) to determine the accuracy of identifying derelict traps in sonar imagery by attempting to retrieve suspected derelict traps immediately while in the field, and 2) to quantify the contents of derelict traps in varying environments. Four areas in the Maryland Bay were chosen for the survey, including areas in the three strata where the trap experiment occurred (Section 4.0, Figure 2-1), as well as an area adjacent to the Little Annemessex River on the eastern shore (Figure 2-6). Specific locations within these areas were chosen because they represented areas where derelict traps were expected to occur in low densities on the bottom. Surveying areas of low density allowed crews to focus on identifying and retrieving individual targets so that a successful retrieval could be verified.

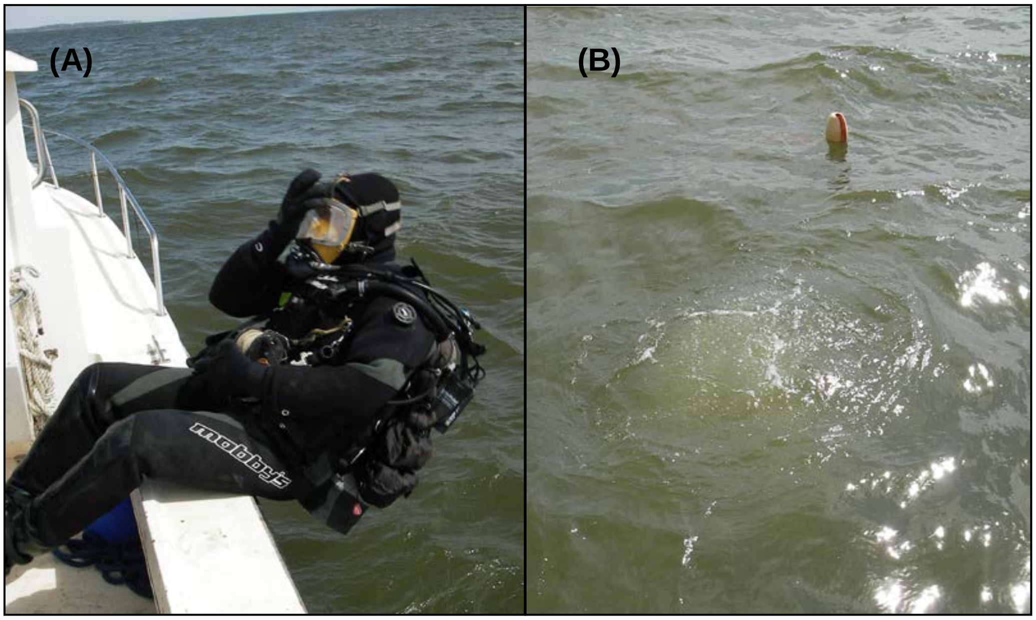



Figure 2-5. Photos showing diver survey operations conducted on 31 March 2007 to verify derelict crab traps in side-scan sonar imagery.

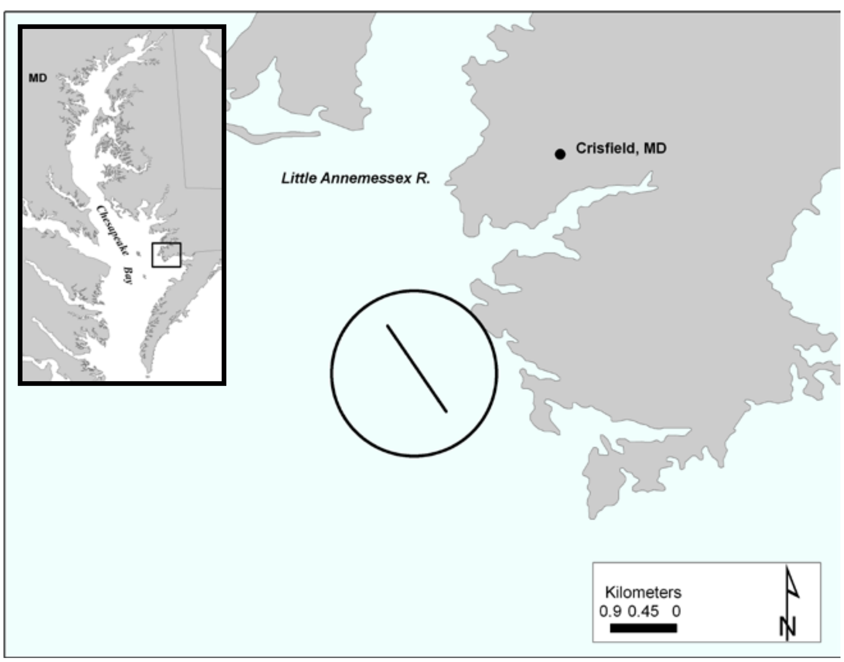



Figure 2-4. Map showing an area in Tangier Sound where a directed side-scan sonar and trap retrieval survey was conducted between 18 March and 28 March 2008 to ground-truth derelict traps.

Side-scan sonar surveys were conducted between 18 March and 28 March 2008 using the same field and sonar acquisition methods used in the transect survey. The surveys consisted of conducting six-minute side-scan sonar transects in specified areas. The sonar imagery was then reviewed aboard the vessel and suspected derelict traps were identified for immediate recovery.

Validation of suspected derelict traps was accomplished using grappling methods identical to those used in the trap retrieval survey. Grapples were deployed just off the bottom and towed over suspected traps. When a trap was hooked, the grappling device was retrieved and the trap was brought up to the vessel. Information gathered from each trap is shown in Table 2-2. All species collected in the traps were released and all derelict traps collected during the retrieval event were kept and recycled in a local land fill (Figure 2-4).

Retrieval attempts were complete once all traps within a transect were either retrieved or were determined to be irretrievable. A post side-scan survey was then conducted to gather information on suspected traps remaining in the transect after the retrieval and to verify derelict trap identification success. Sonar data acquisition and processing were conducted following the same methods and settings used in the initial survey. Initial and post survey sonar imagery was reviewed using Chesapeake Technology Incorporated (CTI) SonarWizMap® software 4.03.0010. All species collected in the traps were released and all derelict traps collected during the retrieval event were kept and recycled in a local land fill (Figure 2-5).

## 2.3 GROUND-TRUTHING RESULTS

### 2.3.1 Derelict Trap Retrieval Survey

A total of 102 derelict traps were collected in the retrieval survey. Seventy-four of those traps were still intact, and 41 (40.2%) of those contained a total of 180 organisms. Blue crabs were the second most abundant organism in the traps, representing 37% of the total number of individuals caught (Figure 2-7). Of the 58 blue crabs found in the traps, 64% were dead, and the remaining individuals were either alive (31%) or injured (5%) (Figure 2-8). Blue crab size ranged from 90-200 mm with an average size of (152 ± 2.2) (Figure 2-9). Mature females (154 ± 2.7 mm) were similar in size to males (151 ± 3.1 mm). No immature females were present in any cages.

Several species of bycatch were also present in the traps. White perch were the most common species, representing 37% of the total individuals caught (Figure 2-7). Fifty-six of the 66 white perch found were alive and the remaining 10 were dead. White perch ranged in size from 160-280 mm with an average size of 212 ± 2.6 mm (Figure 2-10). Pumpkinseed (26%) was the next most abundant bycatch species, with 47 individuals caught in traps. Ranging in size from 120-200 mm, the average pumpkinseed was 168 ± 2.4 mm in length. The remaining two bycatch species, oyster toadfish (3%) and hogchoker (2%) occurred at a much lower frequency (Figure 2-7). Oyster toadfish in the traps averaged 159 ± 29 mm in length while hogchokers averaged 160 ± 5.8 mm (Figure 2-10).

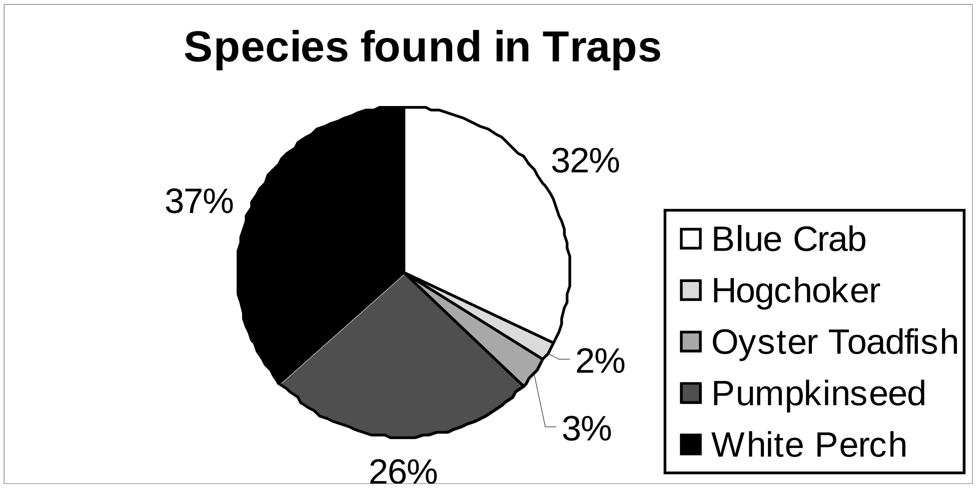



Figure 2-5. The percentage of the total number of individuals (n=180 organisms) representing each species found in derelict traps retrieved using grapples in an area adjacent to the Rhode River, MD.

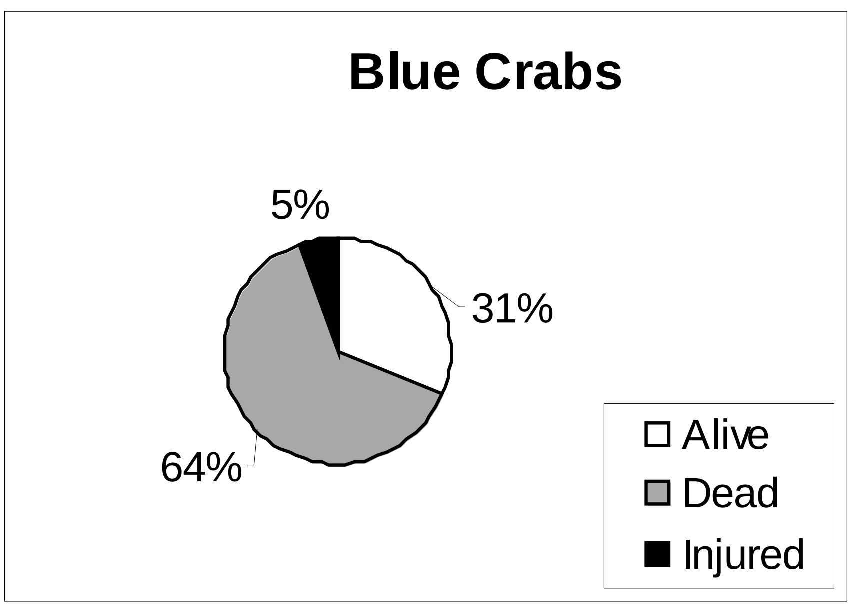



Figure 2-6. The percentage of crabs found in derelict traps that were alive, dead, or injured.

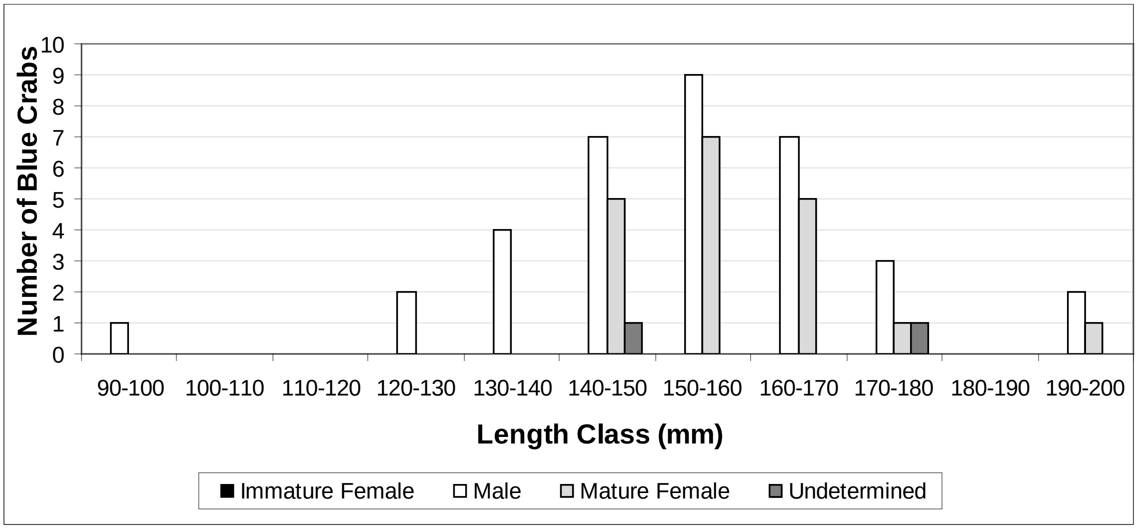



Figure 2-7. Size distribution for all crabs by maturity stage found in derelict traps retrieved using grapples in an area adjacent to the Rhode River, MD.

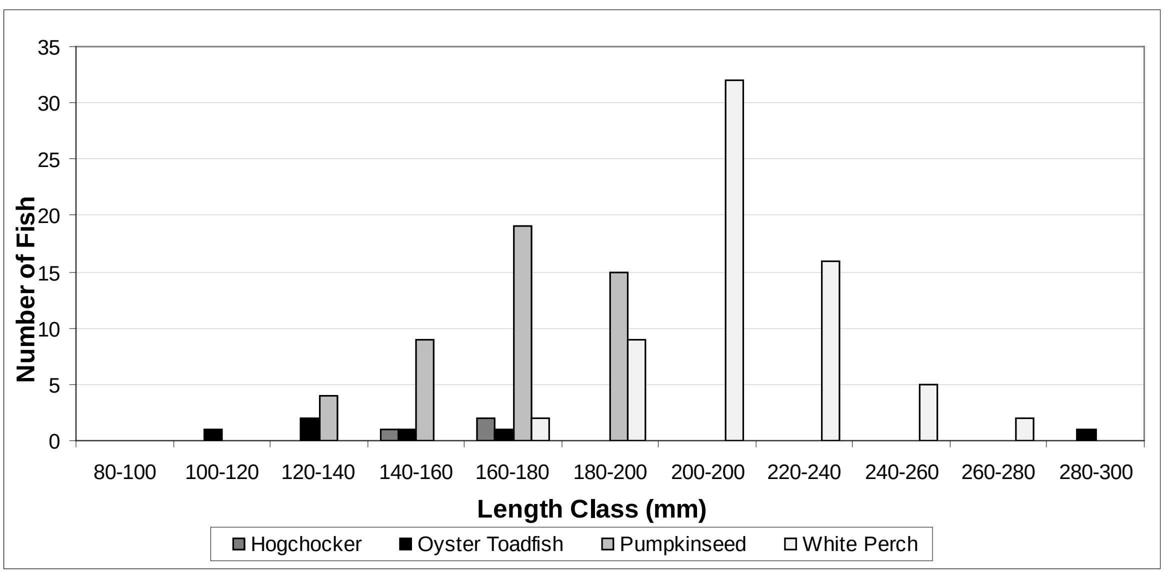



Figure 2-8. Size distribution for bycatch species (hogchoker, oyster toadfish, pumpkinseed, and white perch) found in derelict traps retrieved using grapples in an area adjacent to the Rhode River, MD.

Fouling condition was recorded for all traps that were reported intact. Most traps had light (22 traps) to medium (30 traps) levels of fouling (Figure 2-11). Traps containing organisms had similar levels of fouling compared to all traps collected. Bait status was examined for 45 of the 74 traps; of these 44 contained no bait whereas only 1 trap contained degraded bait. Float lines were attached to 64 of the traps and 3 traps were missing their float line (the remaining 35 traps were not assessed for float line status).

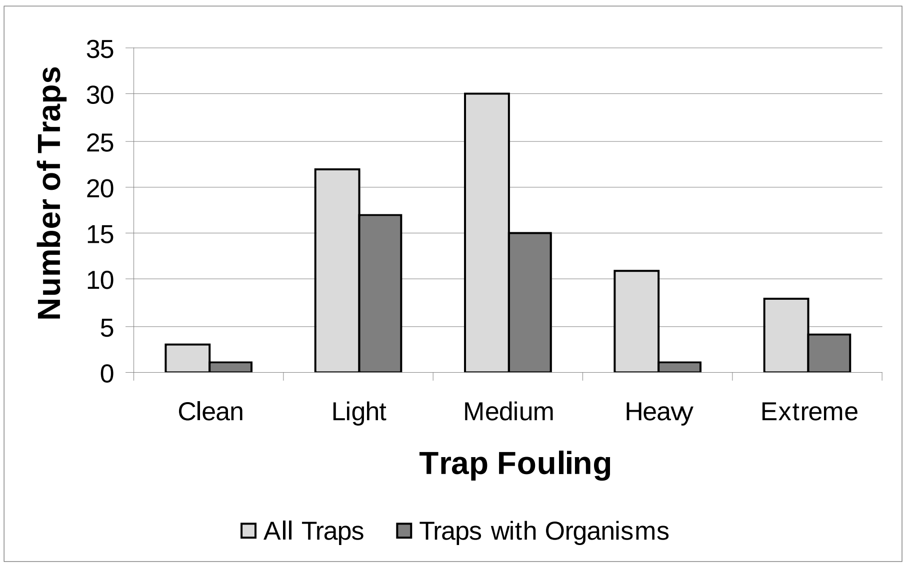



Figure 2-9. Fouling condition of all derelict traps and condition of traps containing organisms which were retrieved in an area adjacent to the Rhode River, MD. Fouling condition was reported for traps that were recorded intact.

The daily "catch per unit effort" of derelict traps (number of traps/the number of hours searched) was consistent over the course of the study with an average of 5.4 ± 0.56 traps retrieved per hour (Figure 2-12).

### 2.3.2 Diver Survey

All suspected derelict traps (n=9) identified in the sonar imagery were collected during the diver survey. Four of these (44.4%) contained a total of 21 organisms. Blue crabs were the most abundant species in these traps, with 10 crabs making up 48% of the total number of organisms caught (Figure 2-13). Eight of the 10 crabs found were dead. Average crab size was 147 ± 5.6 mm (Figure 2-14). Mature females were the largest crabs in the traps (161 ± 4.4 mm), followed by males (151 ± 6.3 mm); the sole immature female crab was 133 mm.

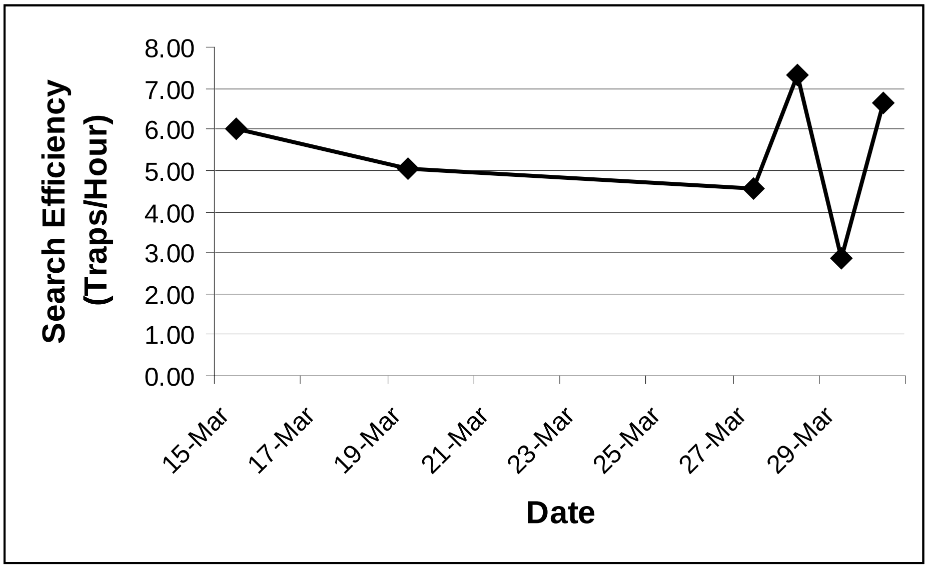



Figure 2-10. The efficiency (number of traps per hour searched) with which derelict traps were collected using grapples in an area adjacent to the Rhode River, MD.

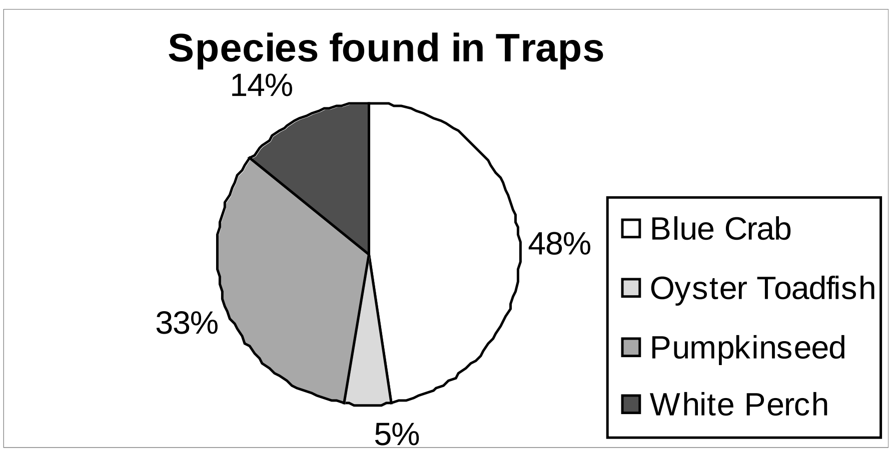



Figure 2-11. The percentage of the total number of individuals (n=21 organisms) representing each species found during the diver survey.

Bycatch species included 7 pumpkinseed (33% of total individuals of all species caught), 3 (14%) white perch, and 1 (5%) oyster toadfish (Figure 2-13). Average length for pumpkinseed in the traps was 156 ± 4.2 mm, for white perch was 222 ± 12.2 mm, and the single oyster toadfish was 245 mm in length (Figure 2-15).

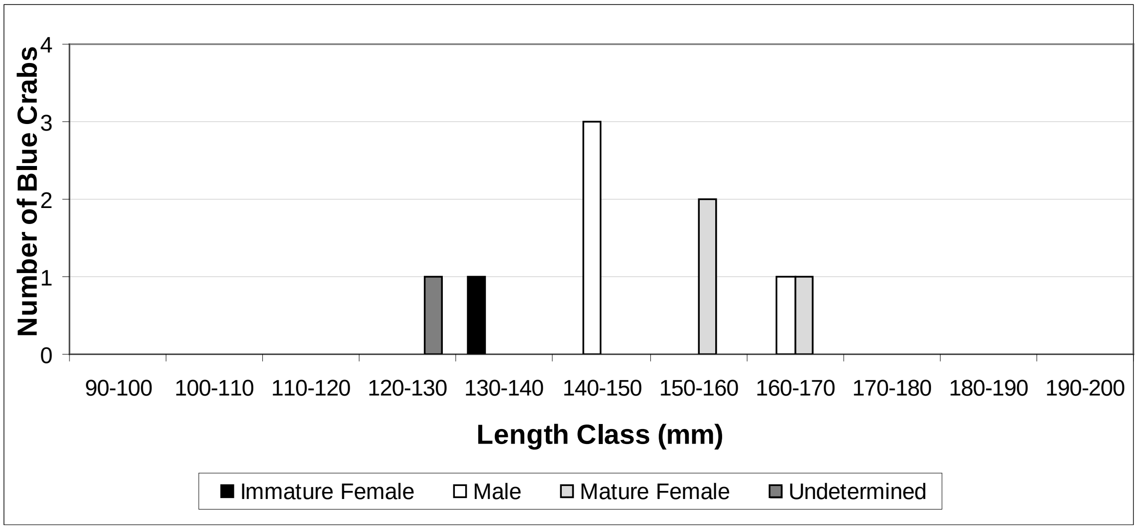



Figure 2-12. Size distribution for all crabs by maturity stage found in traps during the diver survey.

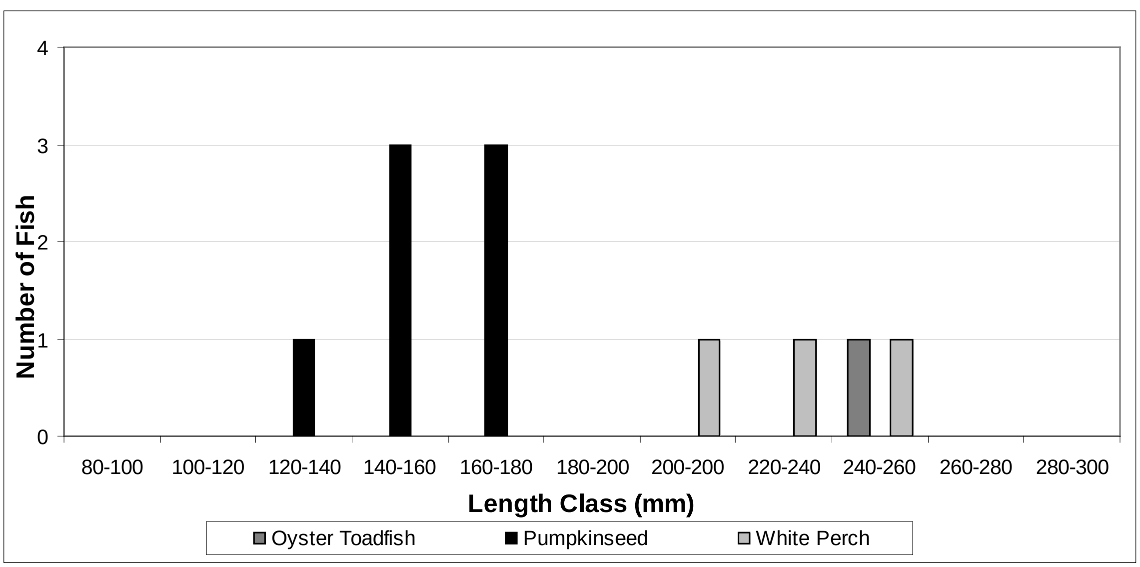



Figure 2-13. Size distribution for bycatch species (oyster toadfish, pumpkinseed, and white perch) found in traps during the diver survey.

The fouling condition for most traps was light (5 traps) to medium (3 traps) while only 1 trap had heavy fouling. All 4 traps containing organisms had light fouling (Figure 2-16). Three traps contained bait, 1 had degraded bait, and the remaining 5 were not examined for bait status. Five traps had their float lines still attached while the other 4 traps were not examined for this parameter.

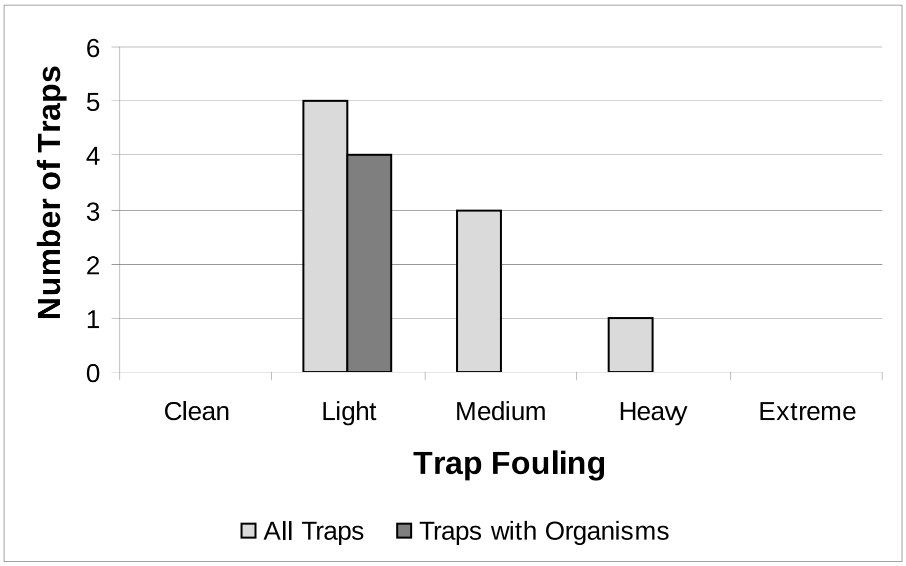



Figure 2-14. Fouling condition of all traps and only those containing organisms collected during the diver survey. Fouling status was reported for all 9 traps collected.

### 2.3.3 Directed In-situ Ground-Truthing Surveys

A total of 25 traps were detected and 14 (56%) traps were retrieved and evaluated at four locations. In the shallow portion of Herring Bay, 2 traps were identified in the side-scan sonar imagery. Both traps were retrieved, and one exhibited no fouling and the other was medium fouled. At the Thomas Point site, seven traps were identified in the sonar imagery, but only two were retrieved after 1.5 hours of retrieval efforts. Both trap exhibited medium fouling. Three traps were detected in the sonar imagery collected at the Rhode/West River site. Two of those traps were retrieved and both exhibited medium fouling condition. At the Tangier Sound site a total of nine traps were detected in the imagery. Of those, 8 traps were retrieved and several pieces of trap were retrieved on grapples while attempting to collect the ninth trap. Two of the traps were in medium fouling condition and the remaining 6 exhibited heavy fouling.

Organisms were only found in traps at the Crisfield site and in the shallow area of Rhode/West River site. Eight organisms were found in traps at the Rhode/West River site of which only 1 was a blue crab (150 mm). Pumpkinseed and white perch were the most abundant organisms in traps at this site with 3 individuals of each species found. One horseshoe crab was also found in the traps at the Rhode/West River site. In contrast, a total of 10 organisms were found in traps at Crisfield, of which blue crabs and oysters were found in equal proportion. Blue crabs ranged in size from 92-150 mm in carapace width; all were alive except for the largest crab. Of the 5 crabs found, 2 were male, 1 was a mature female, 1 was an immature female, and 1 could not be determined.

## 2.4 DISCUSSION

Collecting existing traps in the Bay provided an opportunity to evaluate real traps that had been lost from the fishery and allowed us to establish baseline information for subsequent analyses of side-scan sonar imagery. After being identified as potential derelict traps in the sonar data, 102 traps were collected during the retrieval survey with grapples. This was much more than what was estimated to have been retrieved based on reviews of the pre and post sonar survey (Table 2-2). This discrepancy is most likely from multiple traps being counted as one when they are very close to one another on the bottom and in the imagery. In areas with large high densities of derelict traps this discrepancy would cause reviewers to underestimate trap counts which would result in a conservative estimate of trap densities.

Using the diver, 9 (100%) suspected derelict traps in sonar imagery were identified and validated based on a spectrum of known signatures. Single derelict traps were also verified in side-scan sonar data at several sites by grappling suspected traps immediately after the side-scan sonar surveys were conducted. Fifty-six percent of all traps identified during the directed ground-truthing validations were retrieved with grapples. In addition, there were multiple times when pieces of traps were retrieved or the grapple device hooked on something while targeting a potential trap indicating that these objects were also likely traps that were partially lodged in the sediment, or so degraded that they could not be retrieved with this method.

The retrieval of derelict traps from the Bay also provided an opportunity to quantify what organisms were being trapped and harmed by real derelict traps. Overall, traps collected during surveys generally exhibited light to medium fouling. Blue crabs and white perch were the most abundant species in traps collected with smaller numbers of hogchoker, pumpkinseed, and oyster toadfish also present. Most of the blue crabs found in traps were dead indicating that high levels of mortality are possible in derelict traps. For traps that were examined, about one third were actively fishing (i.e., contained organisms) and contained no bait indicating that the bait was not attracting organisms and that traps were self baiting. Nearly all traps had an attached float line when this variable was recorded. Commercial crabbers are not likely to discard usable materials such as a float line; therefore the presence of a float line attached to the trap suggests that those traps might have been lost due to boat traffic or means other than the crabbers themselves.

In combination, these surveys enhance derelict trap detection sonar technology and provide information on what and how many organisms are being trapped and harmed. Some discrepancies in trap detection was evident when traps are found in high densities, such as with the retrieval survey. However, the ground-truthing surveys were used successfully to enhance detection of derelict traps in side-scan sonar imagery. The information collected from the recovered traps has increased our understanding of how derelict traps are influencing local populations and was used as a baseline to compare to the results of the derelict trap effects experiment discussed in Section 4.0. The final conclusions and recommendations based on this and the other section is presented in Section 5.0.

# 3.0 DERELICT TRAP DENSITIES IN THE MARYLAND CHESAPEAKE BAY

## 3.1 SIDE-SCAN SONAR TRANSECT SURVEY STUDY OBJECTIVES

The main objective of the side-scan sonar transect survey was to quantify the density of derelict crab traps within the Maryland portion of Chesapeake Bay. Major elements of this survey included developing the survey design, conducting a stratified random survey, and developing specific image analysis protocols to aid with the detection and enumeration of derelict traps in sonar imagery and to assess the accuracy of detecting derelict traps during the review.

## 3.2 MATERIALS AND METHODS

### 3.2.1 Transect Survey Design

A stratified random transect survey using side-scan sonar was developed to quantify derelict traps residing in the Maryland portion of Chesapeake Bay. The geographic coverage of the survey was confined to those parts of the Bay where the commercial hard crab fishery occurs (1,785 $km^2$). Following the assumption that trap losses are likely related to the magnitude of fishing effort in a particular habitat, NOAA reporting units were used as the primary level of survey stratification. NOAA reporting units, also known as NOAA codes, are individual geographic regions delineated so that fisheries harvest can be reported and documented spatially. Each NOAA code stratum was further stratified into 3 secondary substrata where commercial crabbing effort was known to be low, medium, or high (Figure 3-1).

Survey substrata were developed using monthly survey data collected by the Maryland Department of Natural Resources (MDDNR) which documents the spatial distribution of commercial crabbing effort during the fishing season (April-December) (Christman and Vølstad 2005). Three years (2002-2004) of survey data were used to classify areas of low, medium, and high fishing effort in Maryland. The classes were based on natural breaks found in the survey data. Data for all seasons and years were combined to delineate the three classes of fishing effort over the course of the fishing season. All seasons were combined to capture overall effort patterns rather than documenting effort within seasons. Once these areas were identified, the effort strata were developed using the Inverse Distance Weighting (IDW) function in ArcView 9.0® software. This process created a continuous map of varying fishing effort within the Maryland portion of Chesapeake Bay (Figure 3-1). Boundaries (contours) were drawn around the three density classes to make individual polygons for random site selection within each class.

Sampling stations were allocated among the primary strata (NOAA code) in proportion to the total fishing effort reported for that NOAA code in the 2004 MDDNR effort survey (i.e. more sampling was allocated to portions of the Chesapeake Bay where greater commercial blue crab fishing effort occurs) (Table 3-1). Within each primary stratum, sampling locations were

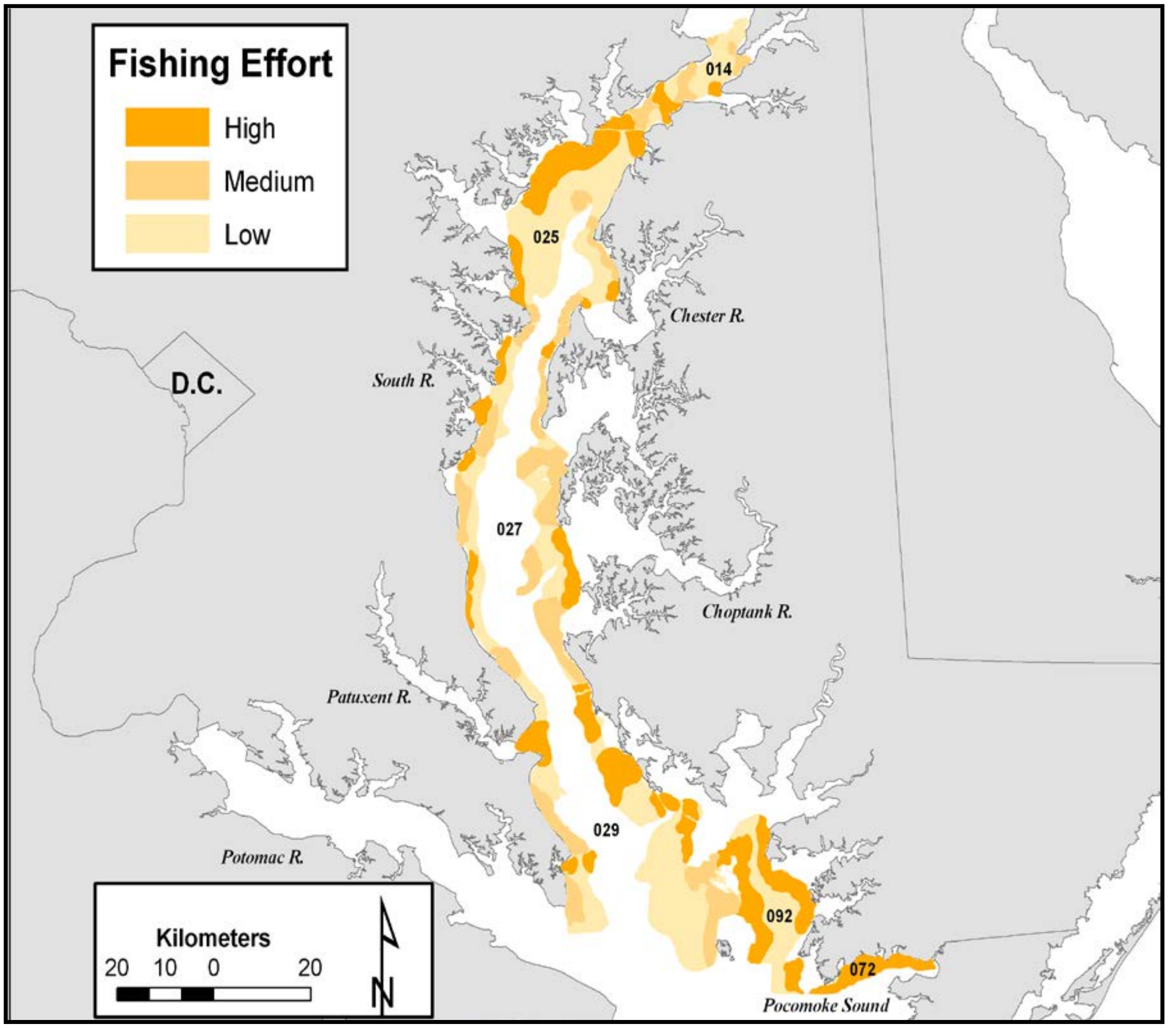



Figure 3-1. Map showing varying degrees of commercial crabbing effort in Maryland state waters. These density estimates were derived from fishing effort data provided by MDDNR and were used to stratify sampling transects in the search for derelict crab traps. Three digit numbers in the map represent NOAA codes.

distributed among substrata (low, medium, and high fishing effort) in proportion to the area covered by that substratum within in the NOAA code (i.e., more sampling was allocated to larger substrata).

Little information existed regarding the number and distribution of derelict traps throughout the MD portion of the Bay; therefore there was no existing approach to determine the overall number of transects required to make a precise estimate of the densities of derelict traps in MD waters. We used the MDDNR annual effort survey as a guide to determine how many side-scan sonar transects to conduct. The annual effort survey samples approximately 150 stations during a month and attains good precision. Since our assumption was that derelict traps would be correlated to fishing effort within certain areas, we chose a conservative approach and doubled the sample size to 300 for the derelict trap survey. Sampling locations were randomly selected using a random sample generator in ArcView GIS 9.0 software®. The numbers of samples allocated to each primary and secondary strata are presented in Table 3-1.

Table 3-1. Aggregated instantaneous crab trap counts during all fishing months of 2004 in Maryland portion of Chesapeake Bay. Proportion of derelict trap sampling transects allocated to each NOAA code. The distribution of transects to each fishing density stratum within a NOAA code as a percentage of NOAA code area.

| NOAA Code | Estimated Fishing Area (Km2) | 2004 Trap Count by NOAA Code | | Number of Transects for Each Fishing Density Stratum | | | |
|---|---|---|---|---|---|---|---|
| | | T^ | % of Total Effort | High | Medium | Low | Total |
| 14 | 137 | 9,829 | 1 | 1 | 1 | 1 | 3 |
| 25 | 401 | 165,690 | 17 | 17 | 6 | 29 | 52 |
| 27 | 439 | 225,654 | 24 | 14 | 34 | 24 | 72 |
| 29 | 544 | 171,156 | 18 | 16 | 7 | 31 | 54 |
| 72 | 51 | 87,852 | 9 | 25 | * | * | 25 |
| 92 | 214 | 298,114 | 31 | 46 | 16 | 32 | 94 |
| Total | 1785 | 958,294 | 100 | 119 | 64 | 117 | 300 |

T^=Aggregated Instantaneous Pot Count
* All fishing effort in Pocomoke Sound was considered high

The following equation was used to allocate sampling stations among NOAA codes:

$$n_i = \frac{\left(NOAA\ Code_i T^{\wedge}\right)}{\left(\sum NOAACode_{i \ldots i} T^{\wedge}\right)} 300$$

where:

$n_i$ = The number of transects allocated to NOAA region code *i*,
$NOAA\ Code_i$ = NOAA Region Code *i*, and
$T^{\wedge}$ = The aggregated instantaneous derelict pot count.

Sampling stations allocated to a particular NOAA code were distributed among substrata within the NOAA code using the expression:

$$s_i = \frac{n_i}{\left(\%s_{1,2,3}\right)}$$

where:

$s_i$ = The number of transects allocated to substratum *i*,
$n_i$ = The number of transects allocated to NOAA region code *i*, and
$\%s_{1,2,3}$ = Proportion of substratum 1 (low), 2 (medium), or 3 (high) in NOAA region code.

### 3.2.2 Side-Scan Sonar Transect Survey Field Methods

Side-scan sonar was used to quantify derelict crab traps throughout the Maryland portion of Chesapeake Bay. Sampling commenced on 26 February 2007 and ended on 28 March 2007. The survey was conducted during the period when harvest was closed to the fishery (15 December through 31 March) to ensure that encountered traps were indeed derelict traps that were not actively being fished. Sampling was conducted using a pool of three research vessels: the R/V Bay Commitment (a 12.5 m aluminum vessel), the R/V In-Situ (a 8.2 m reinforced fiberglass vessel), and the R/V Integrity (an 8 m cuddy cabin vessel). Each sampling station was sampled by navigating to the station and then conducting a six-minute side-scan sonar transect. The heading or direction of each transect was chosen by rolling a 12-sided die in the field, where each number represented a compass direction when multiplied by 30 degrees. For example, if a two was rolled, then the boat would conduct the transect following a heading of 60 degrees NE.

All side-scan sonar data were collected using an Edgetech DF-1000 dual frequency side-scan sonar. The sonar data were collected in the Extended Triton Format (XTF) at both 100 and 500 kHz (nominally 420 kHz) with operational range scales set to 56m, which corresponded to an overall sonar swath width of 112m (Figure 3-2). Side-scan sonar and vessel positioning data were provided using a Differential Global Positioning System (DGPS). Each side-scan sonar transect was collected as an individual file using Chesapeake Technology Incorporated (CTI) SonarWizMap® software 4.03.0010. Additional information collected in the field included the initial starting depth of the transect, the sea state, and weather conditions. Survey data were backed-up daily and archived for the formal analysis.


Figure 3-2. An example of a typical side-scan sonar transect acquired during a six-minute vessel tow at 56 m range scale.

### 3.2.3 Derelict Trap Detection and Enumeration

The main objective of the transect survey were to identify derelict traps in the side-scan sonar imagery precisely so that the densities of derelict traps in the Maryland Bay could be estimated with confidence. The value of using side-scan sonar in a survey approach such as this was that a large volume of data could be collected throughout the Bay in a fairly efficient manner. However, without knowledge of all the types of marine debris occurring in the system or what that debris signature would look like in a side-scan sonar image, errors in derelict trap detection could be significant, creating high levels of uncertainty in the final derelict trap density estimates. Therefore, a specific image analysis protocol was developed to aid with the detection of derelict traps in the sonar imagery and to assess the accuracy of detecting derelict traps during the review. The protocol included 1) repeated training on known derelict traps in side-scan sonar imagery (Section 2.0 for complete details), 2) developing and using a catalog of derelict trap sonar images for reference, 3) applying a standardized method of review on the computer, and 4) adhering to criteria for derelict trap determination. Reviewer accuracy at detecting derelict traps during the review was assessed using mock transects (controls) randomly placed within the reviewers data sets.

#### 3.2.3.1 Image Catalog Development

As part of the side-scan sonar transect review methods, a catalog of derelict trap images was created as a reference to ensure that derelict traps could be differentiated from other marine debris. The catalog was developed by placing a string of known derelict traps in differing states of degradation in two separate areas in the Bay. Traps used in the string were collected during the ground-truthing retrieval survey and were assumed to represent derelict traps present in the Bay. The trap string was imaged at various distances from and angles to the string using the same sonar acquisition settings used in the transect survey. Side-scan sonar transect imagery was then compiled into a reference catalog that was used to train reviewers to discern known derelict trap signatures and to choose the images which best represented the average of derelict trap signatures from the data set (Figure 3-3).

#### 3.2.3.2 Derelict Trap Enumeration

Two independent reviewers quantified the number of derelict traps in the transect imagery by conducting a desktop review. Reviewers were trained on what derelict traps looked like through the ground-truthing efforts (Section 1.0), and by using the image catalog as a reference. All sonar imagery was standardized prior to the review and only the high frequency imagery (400 kHz, Channels 3 and 4) was reviewed using one perspective window in the review software. Three specific criteria guided reviewers in their determination of derelict traps in the imagery. Reviewers were instructed to enumerate high confidence trap-like targets when: 1) the target looked like an intact crab trap similar to the reference catalog images, 2) the target was square in shape and possibly had a following acoustic shadow, or 3) the side dimensions of the

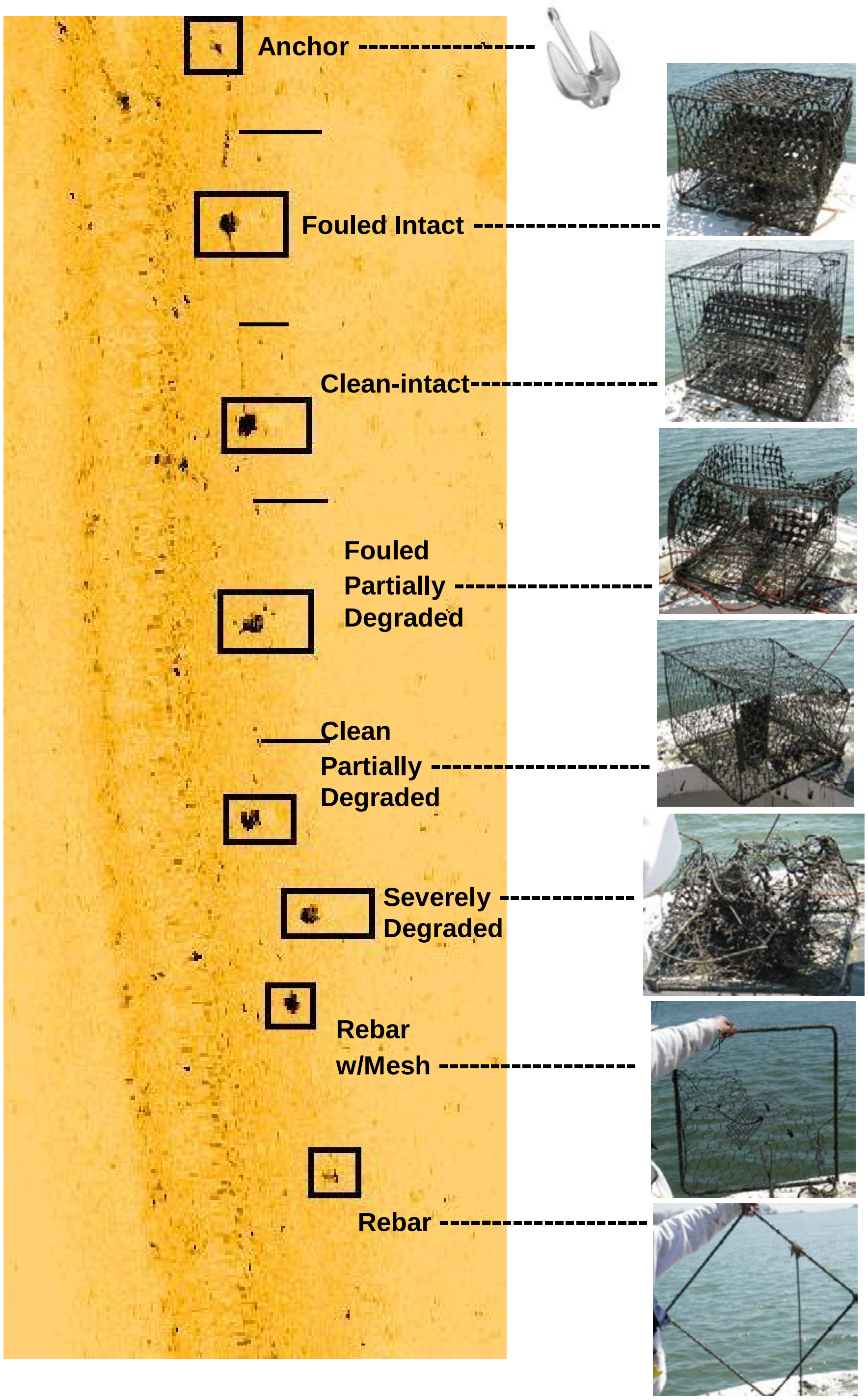



Figure 3-3. A portion of the image catalog that was created from side-scan sonar imagery of a known set of derelict traps.

target was 1m or less. When a derelict trap was identified by a reviewer within an individual transect, its location was saved in a separate spreadsheet file so comparisons between reviewers could be made and a final trap number per transect could be established.

#### 3.2.3.3 Derelict Trap Detection Accuracy Assessment

A set of mock side-scan sonar transects were used as controls during the final side-scan sonar transect review to asses the accuracy of individual reviewers at detecting derelict traps. The mock transects were created by placing a string of known traps in two areas that differed in depth and then conducting a series of side-scan sonar transects in various directions relative to the trap strings. Each individual transect captured the entire string of traps or a subset of the string depending upon the direction of the transect and its orientation to the test string. Sonar data acquisition and processing were conducted following the same methods and settings used in the transect survey. A total of five mock transects from each depth (n=10 transects) was created as controls for the transect survey review and analysis.

The sonar image from each mock transect was placed randomly within the set of images collected during the side-scan sonar transect survey so that the reviewers assumed the mock transects were part of the survey data. The software settings precluded the reviewers from knowing the geographic location of the transects as they reviewed them. This eliminated any bias the reviewers would have toward the mock transects. Each reviewer followed the review criteria developed for the overall review and identified derelict traps in the sonar imagery for all transects in the entire data set.

The mock transects included in the final data set served to establish reviewer accuracy at identifying known derelict traps. The review of each mock transect by each reviewer was compared to quantify how often the reviewers agreed or disagreed on known traps. The analysis of reviewers accuracy at identifying known traps in the mock transects and the correspondence of identifying derelict traps between reviewers within the entire data set, was used to develop the final estimate of the total number of derelict traps per transect. Based on these analysis, the sum of the two reviewers individual counts ($R_1$+$R_2$) minus the number of traps that they both agreed (A) upon or $R_1+R_2-A$ was used for the final derelict trap count per transect. Specific methods and a discussion of the accuracy analysis, including the error associated with the reviews and the rationale behind the final derelict trap counts is presented in Appendix A.

### 3.2.4 Densities of Derelict Traps in the Maryland Bay

#### 3.2.4.1 Total Number of Derelict Traps in Maryland Bay

The instantaneous total number of derelict traps in all NOAA codes was calculated as follows. For each randomly selected station, the number of derelict traps per transect was first converted to number of traps per $km^2$ using the equation:

$$Y_i = \frac{\text{no. of pots per tow i}}{\text{total area (m}^2\text{) of tow i}} * 1{,}000{,}000$$

These values were then averaged over all transects in each substratum (areas of high, medium and low fishing activity) of the NOAA code and multiplied by the area of the substratum (Table 3-1) to obtain an estimate of the total number of traps in that substratum: $\hat{T}_k = \overline{Y} * A_k$ where $A_k$ is the area of the *k*th substratum in the NOAA region (Table 3-1). The substratum results were then combined to obtain an estimate of the instantaneous number of traps in the entire NOAA code. This was repeated for each month of the survey. Standard errors are based on traditional methods for stratified random sampling both for each NOAA codes and for the Bay-wide estimate (Cochran 1977).

Derelict trap density estimates could not be derived directly from transect survey data in the far Upper Bay (NOAA code 014). This was because no transects were conducted in this areas due to significant amounts of ice during the survey period. This area is however an area of high fishing effort during the summer months of the year (Slacum et al. 2008) and was expected there to be derelict traps in this area. To derive an estimate for this NOAA 014, we assumed that fishing effort and the variables associated with crab trap loss would likely be similar to the low density fishing areas in the adjacent region (NOAA code 025). The average density estimated for all transects conducted in NOAA code 025 was applied to the total area of NOAA code 014 to create an estimate of derelict traps in this region. This estimate was added to the overall estimate for Chesapeake Bay.

### 3.2.4.2 Analysis of Spatial Distribution of Derelict Trap Density

One-way analysis of variance (ANOVA) was used to examine differences among NOAA codes, depth categories, fishing pressure levels (high, medium, low). Proximity to river mouths or major shipping channels was also examined. Depth categories were determined for each individual transect using depth contours provided by the National Oceanic and Atmospheric Administration (NOAA) Hydrographic Survey (http://oceanservice.noaa.gov/topics/-navops/hydrosurvey/). Depth categories were shallow (1-3m), medium (3-8m), and deep (>9m) and are ranges of depths where fishing occurs at differing intensity (Slacum et al. 2009).

To determine if there was a relationship between the number of traps in transects that occurred near river mouths or major shipping channels, all transects used in the density analysis were projected in ArcView GIS 9.0 software® and visually inspected for their proximity to these areas. Transects that occurred within an approximate radius of 1 mile from river mouths, major shipping channels, and thoroughfares were compared to all other transects in the data. It was hypothesized that derelict traps seen in this subset of transects would be related to boat traffic occurring between the rivers and the Chesapeake Bay, and also the volume of boat traffic that occurs near the major shipping lanes in the Bay. The dependent variable in all analyses was trap density (number per unit area of a transect, km2). Therefore, the results reflect patterns of trap densities rather than absolute counts. A Wilks-Shapiro test (Proc Univariate, SAS 2009) indicated that the data were non-normally distributed (W=0.70, p<0.0001). Therefore, all statistical analyses were carried out using log (x+1) transformed data to satisfy the assumptions of normality. Duncan's multiple range test was used to test for significant differences.

## 3.3 RESULTS

### 3.3.1.1 Estimate of the Total Number and Spatial Distribution of Derelict Traps

The total number of derelict traps in the Maryland Bay is estimated to be 84,567 traps (Table 3-2 and Figure 3-4) based on a total of 285 transects conducted during the survey. The Upper Bay (code 025) and Mid Bay (code 027) regions had the greatest estimates of derelict traps. Lower Bay and Tangier Sound region had an intermediate number of traps. The smallest estimated number of derelict traps was located in NOAA code 072 which is the smallest NOAA code by area in this study.

The mean number of traps per unit of area of a transect (density) was greatest in NOAA codes 025, 027 and 072 (Figure 3-5, Table 3-3). Trap densities were significantly lower in NOAA codes 029 and 092. There was an overall significant effect of depth, such that greater trap densities occurred in shallow to medium depths compared to deeper water (Table 3-4, Figure 3-6). Derelict trap density was also greater in areas of intermediate to high fishing effort (Table 3-5, Figure 3-7) and in areas that were closer to river mouths or major shipping channels (Table 3-6, Figure 3-8).

## 3.4 DISCUSSION

This study presents the first known estimate of the number of derelict blue crab traps in the Maryland portion of Chesapeake Bay. Estimated at 84,567 traps in 6 regions (NOAA codes), derelict traps appear to be ubiquitous throughout areas where the commercial hard crab trap fishery is active in Maryland. The only other published study of derelict traps in the Bay took place on a much more limited spatial scale and so is not directly comparable to the present study (Havens et al. 2008). However, a similar stratified random transect survey is currently being undertaken in Virginia (See Appendix B). Using a side-scan sonar approach similar to that used here, Havens et al. (2008) estimated that there were 635-676 traps strewn about a 33.5 $km^2$ portion of the mainstem of the lower York River in Virginia. Particularly interested in derelict trap densities in areas of high levels of crabbing effort, Havens et al. (2008) specifically chose a study area to reflect this focus. This contrasts with our study in which sampling stations were proportionally allocated among three strata that differed with regard to known fishing effort. Thus, our approach has quantified derelict traps in a comparable way throughout differing levels of fishing activity occurring in the entire Maryland Bay.

Table 3-2. The estimated number of derelict traps for each NOAA code. RSE=Relative standard error, SE=standard error, N=number of transects. †The estimate for NOAA code 014 is shown was based on data collected in a portion of a neighboring region (low fishing pressure areas of code 025; Section 3.2.4.1 for details). Therefore, the 28 transects used to make this estimate are a subset of the 47 transects conducted in code 025.

| NOAA Code | # Traps | SE | RSE | N |
|---|---|---|---|---|
| 014 | 8,857 | 2,389 | 0.27 | 28 |
| 025 | 29,426 | 5,146 | 0.17 | 47 |
| 027 | 21,635 | 3,172 | 0.15 | 68 |
| 029 | 12,386 | 1,620 | 0.13 | 56 |
| 072 | 3,093 | 641 | 0.21 | 24 |
| 092 | 9,170 | 982 | 0.11 | 90 |
| Total | 84,567 | 6,801 | 0.08 | 285 |

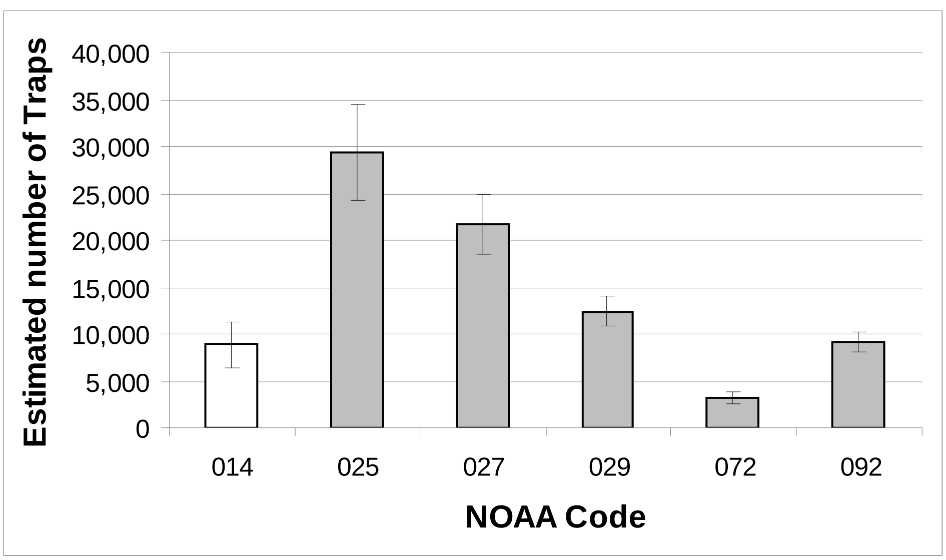



Figure 3-4. Estimated total number of derelict traps per NOAA code. Error bars represent ± 1 se of the total. NOAA code 014 is shown with a white bar to denote that the estimate for this region was based on data collected in a portion of a neighboring region (low fishing pressure areas of code 025; Section 3.2.4.1 for details).

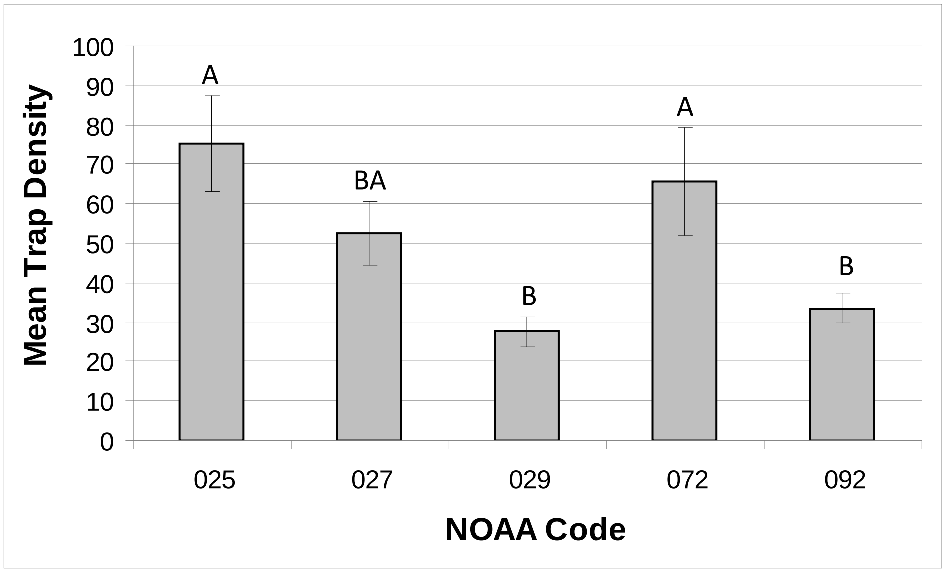



Figure 3-5. Density (mean number of traps per km2 of transect) of derelict traps per NOAA code. Error bars indicate ± 1 se of the mean. Letters indicate significant differences according to Duncan's multiple range test.

Table 3-3. ANOVA results for the effect of **NOAA code** on the density (number per transect area, km2) of derelict traps.

| Source | DF | SS | MS | F-Value | Pr > F |
|---|---|---|---|---|---|
| NOAA code | 4 | 36.14 | 9.03 | 4.59 | 0.0013 |
| Error | 280 | 551.11 | 1.97 | | |
| Total | 284 | 587.25 | | | |

| Table 3-4. ANOVA results for the effect of **depth** on the density (number per transect area, km2) of derelict traps. | | | | | |
|---|---|---|---|---|---|
| **Source** | **DF** | **SS** | **MS** | **F-Value** | **Pr > F** |
| Depth | 2 | 13.21 | 6.61 | 3.25 | 0.0404 |
| Error | 282 | 574.04 | 2.04 | | |
| Total | 284 | 587.25 | | | |

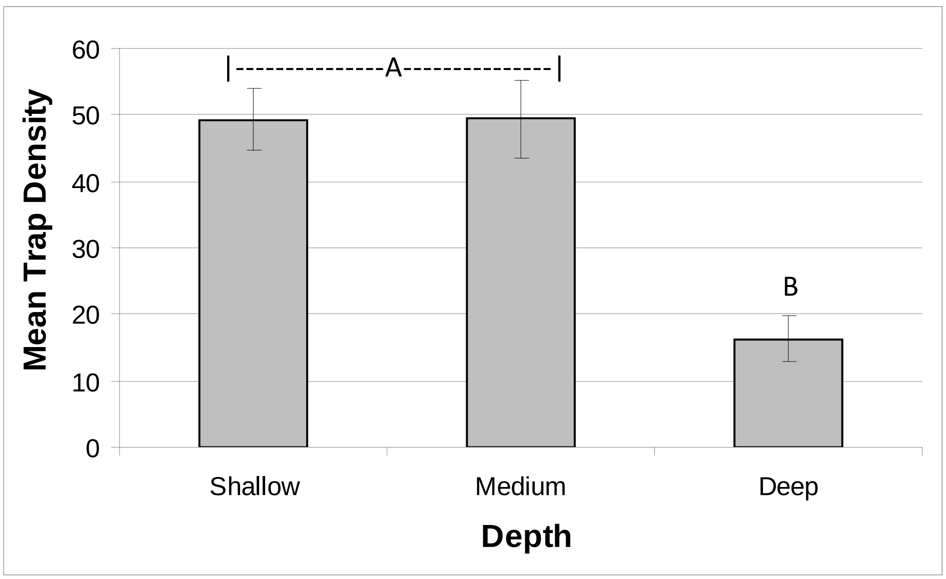



Figure 3-6. Density (mean number of traps per km2 of transect) of derelict traps per depth category. Error bars indicate ± 1 se of the mean. Letters indicate significant differences according to Duncan's multiple range test.

| Table 3-5. ANOVA results for the effect of **fishing pressure** on the density (number per transect area, km2) of derelict traps. | | | | | |
|---|---|---|---|---|---|
| **Source** | **DF** | **SS** | **MS** | **F-Value** | **Pr > F** |
| Fishing Pressure | 2 | 22.90 | 11.45 | 5.72 | 0.0037 |
| Error | 282 | 564.35 | 2.00 | | |
| Total | 284 | 587.25 | | | |

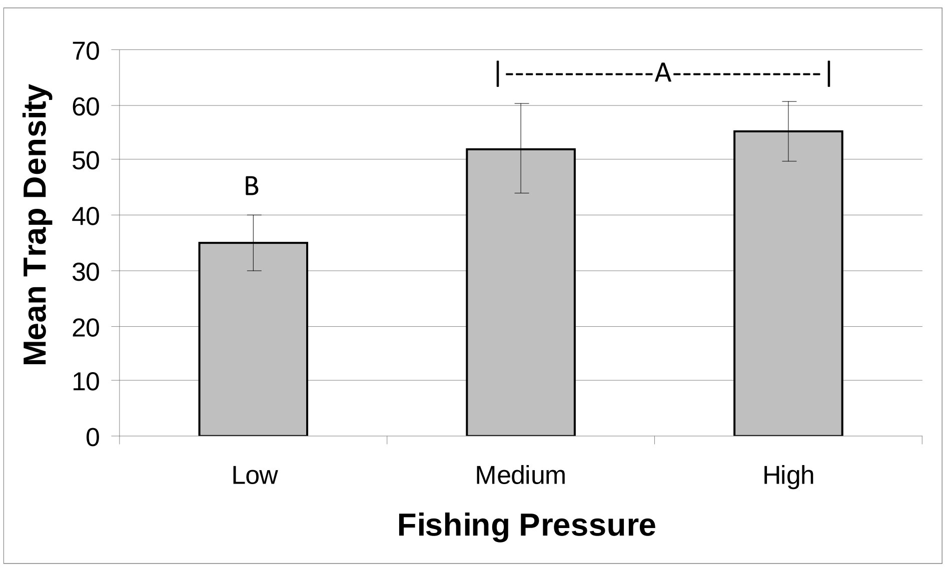



Figure 3-7. Density (mean number of traps per km2 of transect) of derelict traps per fishing pressure category. Error bars indicate ± 1 se of the mean. Letters indicate significant differences according to Duncan's multiple range test.

| Table 3-6. ANOVA results for the effect of **proximity to river mouth or major shipping channel** on the density (number per transect area, km2) of derelict traps. | | | | | |
|---|---|---|---|---|---|
| **Source** | **DF** | **SS** | **MS** | **F-Value** | **Pr > F** |
| Proximity to Mouth | 1 | 70.62 | 70.62 | 38.69 | <.0001 |
| Error | 283 | 516.63 | 1.83 | | |
| Total | 284 | 587.25 | | | |


Figure 3-8. Density (mean number of traps per km2 of transect) of derelict traps per fishing pressure category. Error bars indicate ± 1 se of the mean. Letters indicate significant differences according to Duncan's multiple range test.

The density and estimated number of derelict traps varied among NOAA codes. Both the density and estimated number of traps were greatest in NOAA code 025. NOAA code 072 had the second highest density of traps but due to its relative small size, the estimated number of traps in that code was the smallest of all examined. The relationship of trap densities and estimated number of derelict traps for the remaining NOAA codes were more similar to that of NOAA code 025. For the most part, the spatial variability in derelict traps among NOAA codes is a reflection of the level of fishing effort that takes place in each region. However, when compared to a spatial interpretation of commercial effort throughout the Maryland Bay (Slacum et al. 2008), there is some mismatch that indicates other factors are influencing trap losses.

Among depth strata, derelict trap density in Maryland Bay was nearly 3 times greater in shallow (1-3m) and intermediate depths (4-8m) compared to deeper areas. This association with depth is also attributable to the greater levels of crabbing effort and thus the greater number of traps that could potentially become derelict occurring in this depth range (Slacum et al. 2008). Shallower depths are also areas adjacent to rivers which can have high densities of recreational boat traffic. Proximity to a river mouth or major shipping channel was also associated with greater densities of derelict traps based on a subset of transects. This finding suggests that there is a greater rate of trap loss in areas of high shipping and recreational boat traffic where trap lines may be accidentally severed by the boat or its propeller. Boat traffic has been cited previously as a leading cause of trap loss (Breen et al. 1990).

Fishing effort was also directly found to have an effect on derelict trap density; more derelict raps were found in substrata defined by high fishing effort. This indicates that all other things being equal, areas where more traps are deployed are expected to contain greater densities of derelict traps on the bottom.

While fishing effort is an important variable for the distribution of derelict traps, our study suggests that other factors also play a role. For example, the high levels of fishing effort in Tangier Sound (NOAA code 092) did not translate into high densities of traps in this region. One explanation for this is the variation in the spatial distribution of effort among years (Slacum et al. 2008). The fishing pressure strata designed for this study was based on effort data from 2002-2004; however, derelict traps surveyed were lost over many years and would be present in varying degrees of density based on other factors influencing trap loss. For example, this area is also somewhat secluded, thereby reducing the amount of vessel traffic compared to other areas in the survey. In addition, Tangier Sound is a large shallow sound with well defined channels for navigation. Mariners are likely to adhere to navigational channels more readily in an unfamiliar area, keeping them away from the majority of fishing effort which occurs over the expansive shallow areas adjacent to well known channels (Slacum et al. 2008).

Previous studies of the distribution and effects of derelict fishing gear have used a stratified random design similar to that used here. In the Florida Keys, Chiappone et al. (2004, 2005) carried out a stratified random survey of derelict gear with respect to geographic region, habitat type, and level of fishing restriction (fishing, catch and release, and no-fishing zones) in order to optimize sampling effort. Using divers, approximately 25,200 m2 was surveyed and

300 pieces of derelict gear, including hook-and-line gear and lobster traps, were recovered. Using a stratified random approach allowed Chiappone et al. (2004, 2005) to characterize and compare the spatial patterns of derelict gear among strata. Using a similar design we could also compare the spatial patterns of derelict traps, but in addition, we could also make an estimate of the total number of traps in the system because we have detailed information where the fishery occurred annually.

The use of side-scan sonar also overcame the significant obstacle of turbidity and allowed the study to collect imagery of the Bay bottom. Although side-scan may not provide the quality of data required to document significant details from the bottom when compared to diver observation, for this study merely detecting derelict traps was sufficient to satisfy the study objectives. Therefore, side-scan sonar offers a reasonable method by which large areas can be surveyed with quantifiable levels of accuracy.

A synthesis of final conclusions and recommendations based on all sections of this report is presented in Section 5.0.

# 4.0 DERELICT TRAP SIMULATION STUDY

## 4.1 STUDY OBJECTIVES

The purpose of this study was to determine the overall effects that derelict blue crab traps have on fisheries resources in the mesohaline portion of Chesapeake Bay. Specifically, the objectives of this study were to (1) document what species enter derelict traps, (2) determine trap retention rate by species, (3) determine how those rates change as a function of "deployment time", and (4) determine overall mortality or injury attributed to all species caught in the traps. To simulate actively fishing ghost traps in the Bay effectively, a set of experimental crab traps was deployed and monitored across all four seasons between October 18, 2006 and March 6, 2008. To mimic as closely as possible the real function of ghost traps in the Bay, we limited the amount of interaction between the researchers and the experimental traps in the study. A suite of environmental observations data was also collected during sampling events. This report presents the methods and results of this study.

## 4.2 MATERIALS AND METHODS

### 4.2.1 Sampling Design

Three general locations in the mesohaline (10-20 ppt) portion of Chesapeake Bay were chosen to conduct the study. These locations were on the western shore of the Maryland portion of Chesapeake Bay. The southern most site was located in Herring Bay (HB) and the other two sites were located just north and south of the South River (Rhode-West and Thomas Point) (Figure 4-1). These sites were selected to represent a range of natural variation in blue crab habitat and fishing effort in this region of the Bay. These were important considerations because retention rates of species in derelict traps and resulting mortality rates were expected to vary as a function of these factors. Our study locations represented a range of blue crab habitat characteristics (e.g., salinity, sediment type, proximity to shore, proximity to river mouths) and blue crab abundance. Fishing effort (Christman et al. 2005) and landings reports from Maryland DNR were used to evaluate local blue crab abundance during the site selection process. Each sampling location was divided into two depth strata, shallow (1m-3m) and deep (5m-10m), to account for seasonal variation in blue crab distribution and water quality.

The traps used in this study were standard crab traps, similar to those used by commercial fishers in Chesapeake Bay. External dimensions of each trap were 60 cm long and wide and 60 cm tall. Each trap was constructed of 3.8 cm hexagonal mesh wire and was weighted on the bottom by a 1.3 cm rebar frame. Traps had two 680 g anti zinc anodes and two cull rings attached on opposite sides of the upper chamber (Figure 4-2). Cull rings were of the standard size required by the state of Maryland, 5.57 cm and 5.87

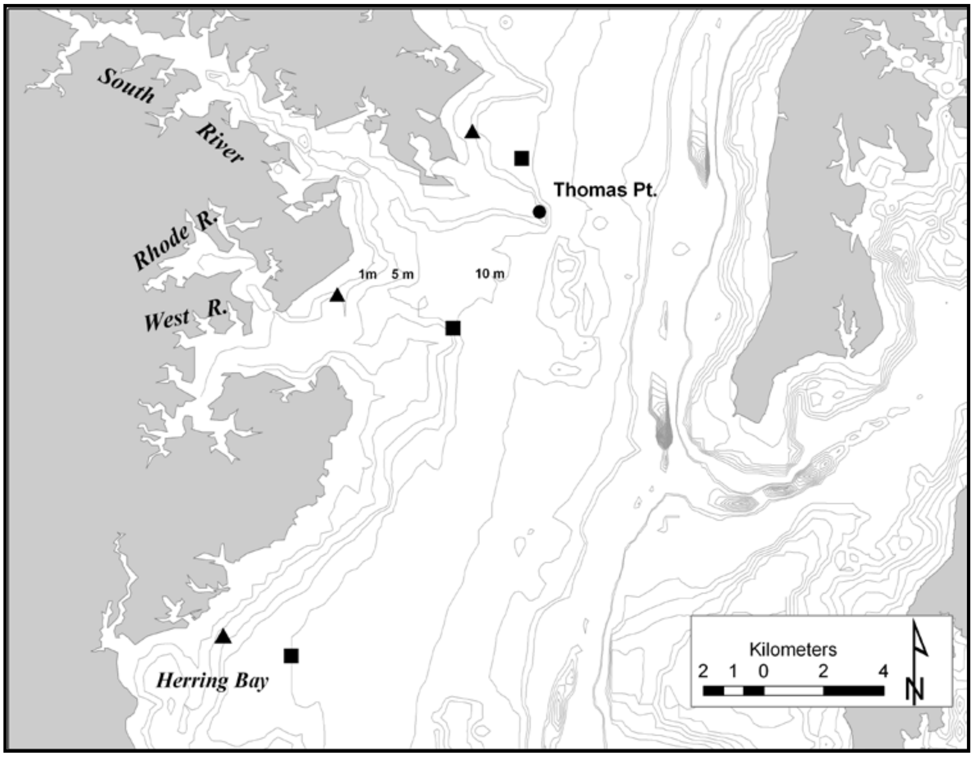



Figure 4-1. Map of three primary sampling locations in the Maryland Chesapeake Bay where experimental crab traps were deployed and sampled in two depth strata from October 2006 March 2008. Triangles represent sites in 1-3 m depths and squares represent sites in 5-10 m.

Figure 4-2. Picture of an experimental crab trap used in this study.

cm diameter. Not all of the cull rings on the experimental traps were functioning (some were blocked by mesh) because Maryland law requires only that a cull ring be attached to traps, but does not explicitly require them to be functional. Some fishers do not cut the trap mesh to allow the cull ring to function. Therefore, a randomly chosen subset (35 traps, 44% of total) of experimental traps had open cull rings in order to mimic the types of derelict traps lost in the local fishery, while the remaining 56% (45 traps) had the cull rings closed. Traps were also retrofitted with an additional 1.0 cm square wire mesh covering the bottom and 15 cm up all sides of each trap. The finer mesh was attached so that all material in the trap including dislodged across-the-back carapace tags would remain in the traps during sampling events (Figure 4-2). The traps were dipped (painted) with antifouling paint similar to methods used by commercial fisherman to inhibit fouling growth and deterioration of trap structure. Each trap had an individual line and buoy attached to it so that it could be retrieved periodically from the bottom and sampled. A bridle was constructed on the top of each trap and the buoy lines were attached to the center of the bridle. This was done to ensure that traps would be retrieved in an upright position and any materials in the trap would not fall through the large mesh and so that organisms were not piled and crushed on one side of the trap as it was being retrieved.

The initial deployment of the experimental crab traps occurred on 18 October 2006 and sampling concluded on 6 March 2008 for a total of 42 sampling events. All traps were pre-baited with previously frozen whole Atlantic menhaden (*Brevoortia tyrannus*), which are commonly used in the Chesapeake Bay commercial blue crab fishery. Traps were deployed during either fall (October-December), spring (April through June), and summer (July through September) to simulate the effects of traps lost from the fishery during each of these time periods. During the fall, 5 to 17 experimental crab traps were deployed at each of the three primary sites within each depth stratum. Additional traps were also deployed in the spring and summer of 2007. Experimental traps were also lost and vandalized during the study and those traps were replaced as part of these additional seasonal deployments. A total of 80 traps were sampled during the study, with an average deployment time per trap of 125 days with a range of 8 days to 505 days. The total number of traps sampled at each site is presented in Table 4-1.

Table 4-1. Total number and type of experimental crab traps in each depth stratum at each of three locations.

| | | **Original Trap** | **Additional Traps** | **Reference** |
|---|---|---|---|---|
| Herring Bay | Deep | 11 | 4 | 4 |
| | Shallow | 11 | 4 | 4 |
| Rhode/West | Deep | 13 | 3 | 4 |
| | Shallow | 13 | 9 | 4 |
| Thomas Point | Deep | 5 | 0 | 0 |
| | Shallow | 7 | 0 | 0 |

Sixteen additional traps were also deployed in two of the primary sampling areas (n=4 per stratum per site) to study trap fouling and degradation over the course of the experiment. These traps were not monitored as part of the routine weekly monitoring, but were used as a reference to document the progression and extent of fouling and to compare overall fouling of traps that had been sampled to those that were not sampled, but subjected to the same fouling as all traps in the study. Reference traps were not baited and the funnels were closed so no organisms could enter the traps. These traps were retrieved at the end of the study, and the fouling condition was compared to fouling accumulated on the experimental traps that were sampled routinely throughout the study.

Sampling of experimental traps was conducted weekly during fall (October-December), winter (January-March), spring (April through June), and summer (July through September). During each sampling event, all traps within a primary site location were monitored. Because actual derelict traps are not routinely retrieved and redeployed, a concerted effort was made to keep handling of experimental traps and organisms to a minimum during sampling events. This would reduce possible stress on captured fish and crabs and alleviate the loss of fouling organisms due to extended stays on the vessel deck or other incidental removal during retrieval and redeployment. During sampling, all species were identified, counted, and their location was documented (upper or lower chamber). The size of individuals other than blue crabs was estimated using a ruler placed as close as possible to the organism in the trap. The condition (dead, alive, or injured) of all species was also documented.

For blue crabs, the location of each individual was documented and the crab was removed from the trap and measured from spike to spike (carapace width) to the nearest millimeter, the gender was identified, and the stage of maturity was determined for females. To determine individual crab mortality, monitor condition over time, and estimate trap escapement, all crabs collected in traps were also tagged with across the back carapace tags. Tags consisted of 25 X 50 mm pink laminated vinyl disk Floy Tags. Each tag was inscribed with a unique identification number and contact information for the NOAA Chesapeake Bay Office. The tags were attached to the dorsal surface of the carapace with 0.6 mm annealed stainless steel wire (Figure 4-3). This type of tagging procedure has been used in other blue crab tagging studies where they exhibited little to no loss rate (Hines et al. 2008, Rob Aguilar, personal communication). During each weekly sampling event, the total number of crabs not tagged (new recruits), the total number of previously tagged crabs, and the total number of dead crabs with and without tags was documented. Once a crab was tagged the tag number was recorded, the crab was placed back into the chamber from which it was retrieved and the trap was re-deployed in the same location it was retrieved. Other data that were recorded during weekly sampling included depth (ft) of traps, time, fishing activity in the area, fouling condition of the trap, bait condition, and water quality. Fishing activity, fouling condition, and bait condition were categorical, qualitative assessments. The number of active traps fishing around the experimental traps was recorded as none, few traps, medium, or heavy fishing activity. Fouling condition or percent of the trap covered by fouling organism was recorded as clean, light (<25%), medium (26-50%), heavy (51-75%), or extreme (>76%). The bait condition in the traps were recorded as intact-good, intact-degraded, not intact degraded, total degraded, or no bait. Water quality variables were recorded once for each stratum within a site during each sampling event. A Yellow Springs Instruments, Inc. (YSI) 650 MDS (Multiparameter Display System) and YSI 6600 Multi-Parameter Water Quality Monitor sonde were used to collect water temperature (°C), conductivity (µS), dissolved oxygen (mg/L), chlorophyll a (µg/L), salinity (ppt), pH, and turbidity (NTU).

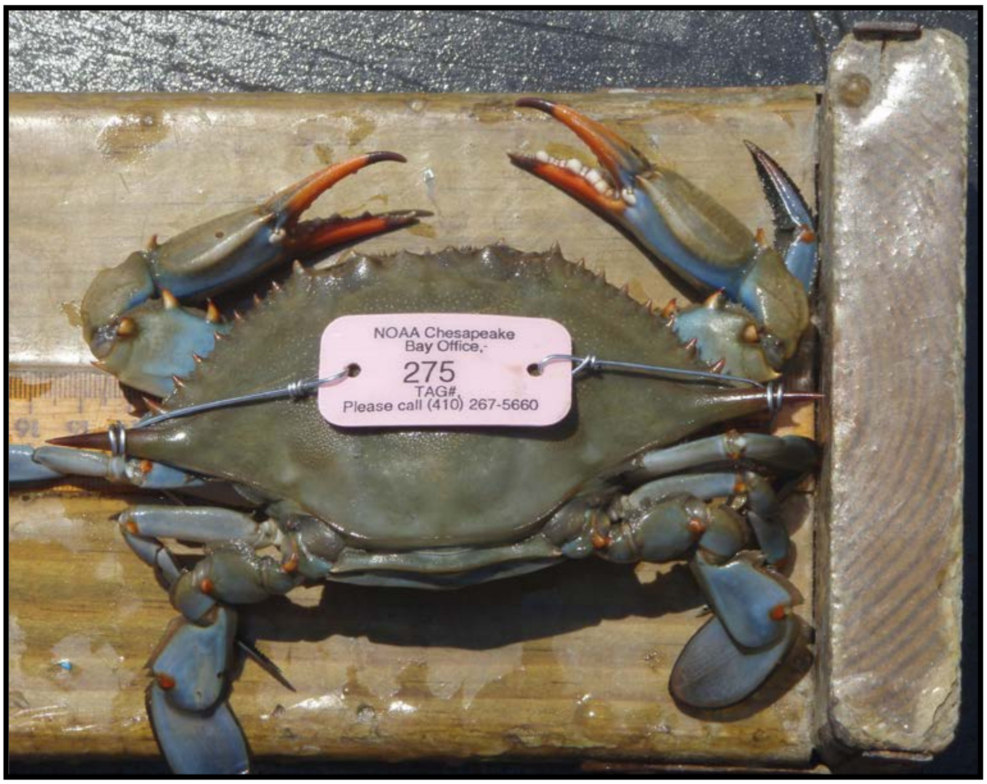



Figure 4-3. Picture of a female blue crab tagged with across the back tag used to monitor individual crabs in the derelict trap experiment.

### 4.2.2 Statistical Analysis

Daily CPUE (catch per unit effort) for blue crabs was calculated by dividing catch abundance by the number of days sampled in a given trap since the previous sampling event. Catch data were $\log_{10}$ (x+1) transformed prior to analyses and statistical significance was concluded for $p \leq 0.05$. Unless otherwise indicated, means ± 1 standard error based on raw data are reported throughout the Results section.

Preliminary evaluation of the data indicated that initial baiting influenced CPUE for approximately the first 14 days of the experiment or until the first sampling event after deployment (Figure 4-4). Derelict traps would naturally experience this effect in the field. Because we were interested in approximating patterns of derelict traps that are actually lost from the fishery, all individuals caught during the deployment period, including those caught during the period of the baiting effect, were included in the analyses.

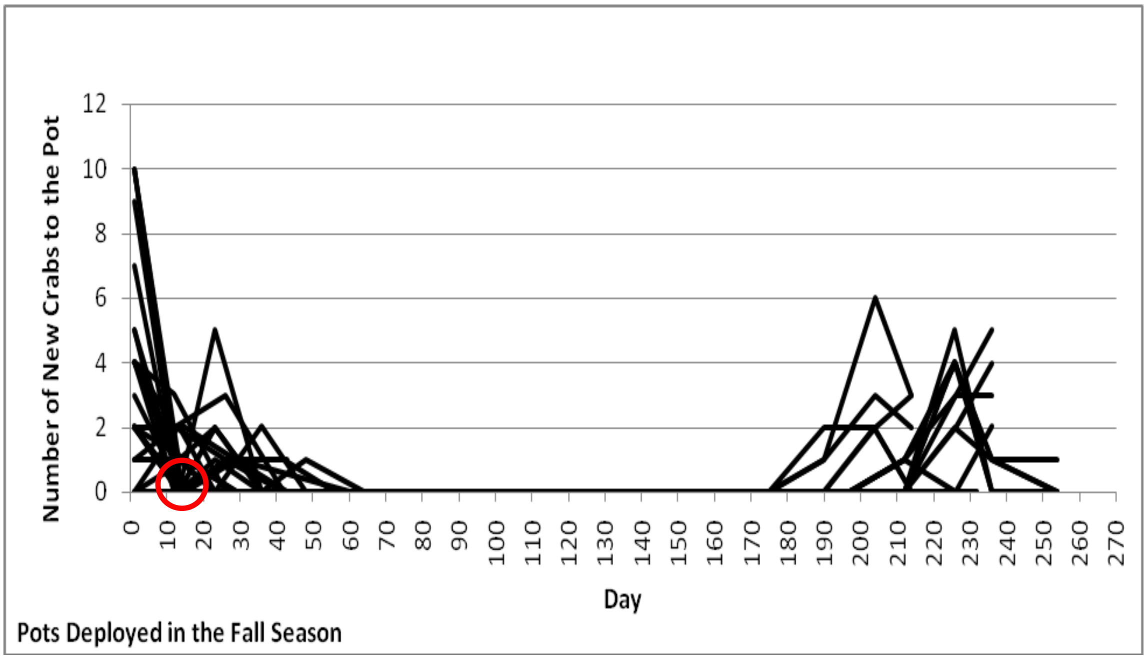



Figure 4-4. CPUE of recruited crabs including initial baiting for experimental traps deployed in the fall. Day refers to the number of days since deployment. Red circle indicates where initial baiting ceased to influence CPUE.

Daily CPUE was calculated in the same way for the most abundant bycatch fish species as it was for crabs except for white perch which was the most abundant bycatch fish in the study. It was not possible to identify individual white perch during the course of the experiment. Therefore, for each sampling date, the number of real recruits is not known; rather only the number of live and dead white perch is known. The number of dead individuals per sampling date was therefore used as a proxy for the number of white perch entering the trap. For this analysis we assumed that white perch were not able to escape from the trap and that all white perch that entered the trap died in the trap. We excluded from the analysis all white perch caught by traps that were subsequently lost during the study because the fate of these fish was unknown. This approach could potentially underestimate the catch of white perch if 1) white perch decompose or are eaten quickly and so are not counted by our weekly sampling interval, 2) white perch are able to escape, 3) those individuals caught in traps that were then lost during the study experienced mortality. This approach could potentially overestimate the catch of white perch if a dead white perch were accidently counted more than once.

For each sampling season, regression analysis was used to explore relationships between blue crab CPUE and bottom dissolved oxygen, temperature, and salinity (Proc Reg, SAS Institute 2009). Sampling seasons were fall (October-December), winter (January through March), spring (April through June), and summer (July through September). Also for each season, individual one-way analyses (ANOVAs) of variance were used to examine the effect of site, depth stratum, trap fouling, and fishing activity on blue crab CPUE, blue crab mortality, blue crab escapement, and bycatch CPUE (Proc GLM, SAS Institute 2009). A Duncan multiple range test was used to make comparisons among sites, depth strata, trap fouling conditions, and fishing activity levels when there was a significant p-value. For analyses that investigated the effects of dissolved oxygen, the continuous measure of dissolved oxygen was categorized into one of three classes: good (> 5 mg/L), fair (2-5 mg/L), and poor (< 2 mg/L). These categories are based upon those described previously by the Chesapeake Bay Foundation to classify dissolved oxygen levels (http://www.cbf.org/site/PageServer?pagename=resources_facts_deadzone). At least 5 mg/L are thought to be required to sustain healthy aquatic life. Areas in the intermediate class (2-5 mg/L) are expected to be hypoxic or stressful for aquatic organisms while those below 2 mg/L are expected to be harmful or lethal. To evaluate whether cull rings influenced catch, a one-way ANOVA was conducted for each season with cull ring status as the main effect. The effect of cull ring status on the size of crabs caught in all seasons was also examined with a one-way ANOVA.

Three-way analysis of variance was used to examine the effects of the number of days the trap was in the water, site, and deployment season on the independent variable of fouling. A second three-way ANOVA examined the effects of number of days the trap was in the water, depth stratum, and deployment season on fouling. Deployment season is defined as the season an experimental trap was deployed. This varies for the traps since some traps were lost and others added during the study time frame. Traps were only deployed during the active fishery, so fall, spring and summer were considered as deployment seasons for this analysis. A variance components analysis was carried out (Proc Varcomp, SAS Institute 2009) to estimate the percentage of variance explained by each independent variable including depth, dissolved oxygen, season, site and deployment season. This procedure determines the proportion of total variance that can be attributed to each of the factors in the analysis. A separate variance components analysis was carried out for each of 7 dependent variables: blue crab CPUE, white perch CPUE, oyster toadfish CPUE, spot CPUE, "other" fish CPUE, blue crab mortality, and blue crab escapement.

## 4.3 RESULTS

### 4.3.1 Water Quality

For each of the three sampling locations, water temperature varied predictably with season; the minimum temperature was recorded in winter and the maximum temperature was recorded in summer (Table 2, Appendix A). Conductivity and salinity also varied seasonally, peaking during fall and winter while reaching minima during the spring and summer. Dissolved oxygen was lower in the summer and higher in the winter at all sampling locations. Dissolved oxygen levels were also similar between the surface and the bottom during the winter, but bottom dissolved oxygen levels were consistently lower and more variable during the summer. There was a low dissolved oxygen (DO) event at Herring Bay on 8/16/2007, where bottom DO was 0.41 mg/L in the shallow strata and 1.3 mg/L in the deep strata. Turbidity levels were consistently less than 20 NTU, with the occasional spike to no more than 40 NTU, and pH in general remained constant between 7 and 9. Chlorophyll a remained near or below 20 μg/L throughout the majority of the study.

There were significant seasonal differences for bottom dissolved oxygen, bottom salinity, and bottom water temperature (Table 4-2). Bottom temperature was the lowest in winter and highest during the summer. Bottom salinity was highest in the fall and summer seasons, and lowest in the spring. Bottom dissolved oxygen was highest in the winter season and lowest in the summer season. There were no significant differences in bottom water quality among sites (Herring Bay, RWS, and Thomas Point) and seasonal patterns were similar among sites. Shallow depth strata had significantly higher dissolved oxygen levels than deep depth strata, but there was no significant difference for bottom salinity or temperature among depth strata. Seasonal patterns in bottom salinity and temperature were similar among depth strata.

### 4.3.2 Overall Derelict Trap Catch

Over the course of this study, a total of 1,096 individuals belonging to10 different species were captured in experimental traps (Table 4-3, Figures 4-5 and 4-6). Blue crab made up the majority of the catch (64%), followed by white perch (*Morone americana*) (19%), oyster toadfish (*Opsanus tau*) (9%), and spot (*Leiostomus xanthurus*) (4%) (Figure 4-7). Together, the remaining species, pumpkinseed (*Lepomis gibbosus*), Atlantic menhaden (*Brevoortia tyrannus*), Atlantic croaker (*Micropogonias undulates*), American eel (*Anguilla rostrata*), sheepshead (*Archosargus probatocephalus*), and black sea bass (*Centropristis striatus*), contributed 4% of total catch and were grouped together as “other species” based on proportionally lower catch abundance. A total of 705 blue crabs recruited to the traps over the course of the experiment. Of these, 660 crabs either died or escaped or, 1 remained in the trap alive until the end of the study, and 44 were lost due to boater or fisher interference with the individual traps they were in.

Table 4-2. Average, minimum, and maximum water quality results at the surface and bottom for all sites and strata combined.

| | Season | Surface | | | Bottom | | |
|---|---|---|---|---|---|---|---|
| | | Mean | Min | Max | Mean | Min | Max |
| Water Temperature (°C) | Fall | 11.99 | 5.60 | 23.66 | 12.18 | 5.60 | 23.31 |
| | Winter | 4.78 | 1.87 | 7.65 | 4.73 | 1.56 | 7.40 |
| | Spring | 19.16 | 8.52 | 25.60 | 16.94 | 8.34 | 24.00 |
| | Summer | 25.83 | 22.81 | 27.85 | 25.29 | 22.20 | 27.20 |
| Dissolved Oxygen (mg/L) | Fall | 9.19 | 6.10 | 13.90 | 8.60 | 5.60 | 13.40 |
| | Winter | 10.49 | 2.20 | 14.38 | 10.09 | 2.30 | 13.83 |
| | Spring | 9.74 | 6.17 | 13.00 | 6.57 | 1.42 | 12.51 |
| | Summer | 7.82 | 5.90 | 10.52 | 5.59 | 0.41 | 9.47 |
| Salinity (ppt) | Fall | 13.18 | 7.90 | 18.00 | 14.23 | 9.10 | 18.00 |
| | Winter | 10.74 | 7.54 | 12.77 | 11.23 | 8.73 | 13.77 |
| | Spring | 8.62 | 4.36 | 10.48 | 9.86 | 6.74 | 11.77 |
| | Summer | 13.77 | 11.20 | 16.00 | 14.03 | 10.90 | 17.20 |
| pH | Fall | 8.23 | 7.89 | 8.97 | 8.02 | 7.00 | 8.45 |
| | Winter | 7.40 | 5.66 | 8.17 | 7.24 | 5.23 | 8.13 |
| | Spring | 8.04 | 7.45 | 8.76 | 7.63 | 7.20 | 8.52 |
| | Summer | 7.96 | 7.63 | 8.33 | 7.57 | 7.07 | 8.10 |
| Conductivity (µS) | Fall | 21.87 | 12.70 | 29.10 | 23.41 | 15.50 | 29.10 |
| | Winter | 18.33 | 13.17 | 21.54 | 19.16 | 15.10 | 23.05 |
| | Spring | 14.89 | 7.87 | 17.97 | 16.78 | 11.78 | 19.73 |
| | Summer | 22.80 | 18.80 | 26.20 | 22.80 | 12.00 | 28.10 |
| Turbidity (NTU) | Fall | 7.93 | 1.10 | 45.50 | 15.07 | 1.00 | 46.00 |
| | Winter | 3.99 | 1.40 | 5.50 | 4.68 | 1.50 | 7.00 |
| | Spring | 11.04 | 6.40 | 19.70 | 14.73 | 8.70 | 28.00 |
| | Summer | 4.50 | -12.00 | 140.00 | 14.92 | -5.50 | 161.00 |
| Chlorophyll a (µg/L) | Fall | 11.80 | 1.10 | 41.00 | 7.28 | 0.70 | 19.70 |
| | Winter | 5.86 | 1.50 | 12.30 | 11.27 | 0.40 | 39.70 |
| | Spring | 36.48 | 2.06 | 112.90 | 57.54 | 5.00 | 141.00 |
| | Summer | 9.95 | 2.00 | 24.80 | 7.19 | 0.00 | 30.00 |

Table 4-3. The number of individuals per species caught with and without baiting effects collected from all sample crab traps.

| Common Name | Scientific Name | Total # of Individuals |
|---|---|---|
| Black Sea Bass | *Centropristis striata* | 3 |
| Blue Crab | *Callinectes sapidus* | 705 |
| Atlantic Croaker | *Micropogonias undulatus* | 5 |
| American Eel | *Anguilla rostrata* | 5 |
| Atlantic Menhaden | *Brevoortia tyrannus* | 13 |
| Oyster Toadfish | *Opsanus tau* | 96 |
| Pumpkinseed | *Lepomis gibbosus* | 13 |
| Sheepshead | *Archosargus probatocephalus* | 5 |
| Spot | *Leiostomus xanthurus* | 43 |
| White Perch | *Morone americana* | 208 |
| Total | | 1096 |

Figure 4-5. Picture of a tagged male blue crab with smaller newly recruited male crab in the top chamber of a trap at the Herring Bay deep strata in August 2007. The carcass of a spot is in the lower chamber under the crabs.

Figure 4-6. Photo of bycatch in the deep strata of the Rhode-West site May 2007. In this photo is a white perch stuck in the trap mesh, an oyster toad is visible to the right, and a dead blue crab is in the upper chamber in the background.

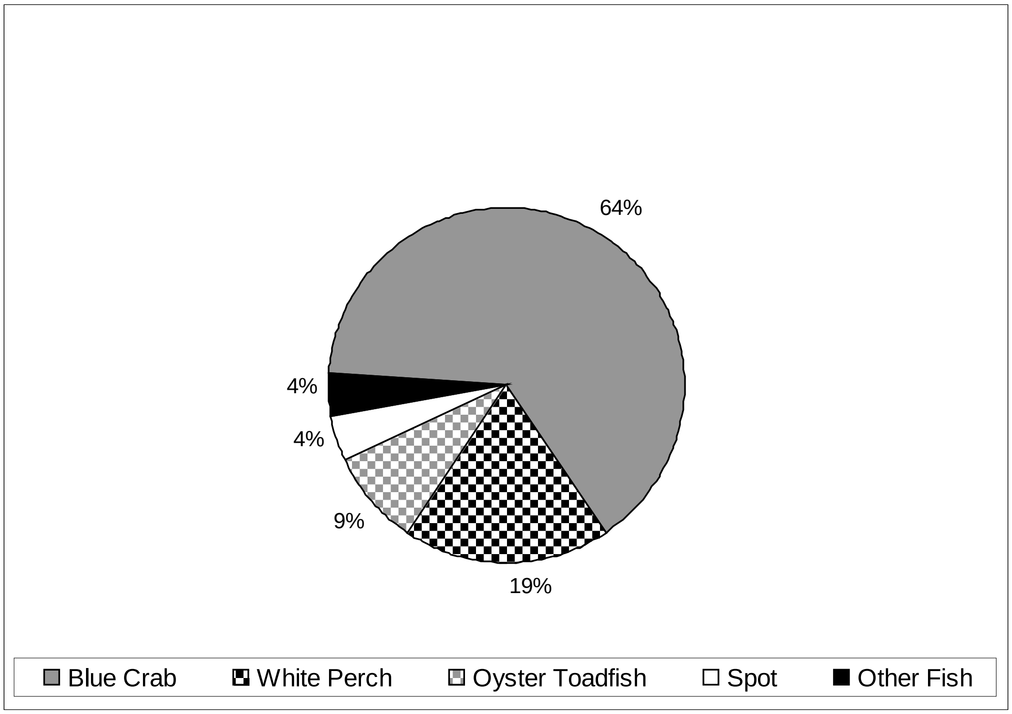



Figure 4-7. Composition of total catch summed across the entire study excluding bait effects. Other fish = pumpkinseed, Atlantic menhaden, Atlantic croaker, American eel, sheepshead, and black sea bass. Total catch = 1,116 individuals; for species specific data, (Table 4-2).

### 4.3.3 Blue Crab

#### 4.3.3.1 Size of Individuals

The size distribution of blue crabs was broad and normally distributed, ranging from 60 to 240 mm (Table 4-4, Figure 4-8). The average size of a blue crab was 143.01 ± 0.84 mm (mean ± standard error). Male blue crabs were the most abundant gender collected (69% of catch), followed by mature females (25%) and immature females (3%) (Figure 4-9). The gender of the remaining 3% could not be determined. The average sizes of male, mature female, and immature female blue crabs was 141.3 ± 0.99 mm, 153.20 ± 1.11 mm, and 104.04 ± 4.98 mm, respectively (Figure 4-10).

#### 4.3.3.2 Recruitment

A total of 705 blue crabs recruited to the experimental traps over the course of the study. Recruitment peaked in late fall of 2006 before tailing off to near zero recruitment throughout the winter and early spring of 2007 (Figure 4-11). Recruitment increased

Table 4-4. The total number of blue crabs caught in derelict traps and the number of blue crabs that died in the total crabs traps for each 10-mm size class. The total number of crabs with known end status does not include those crabs that lasted until the end of the study (1 crab) or were lost when a trap was lost (44 crabs). NM = not measured.

| Size (mm) | Total # of Crabs | Total # of Crabs with Known End Status | # of Dead Crabs | % of Dead Crabs |
|---|---|---|---|---|
| NM | 11 | 11 | 10 | 90% |
| 60-69 | 5 | 5 | 3 | 60% |
| 70-79 | 7 | 7 | 4 | 57% |
| 80-89 | 7 | 7 | 4 | 57% |
| 90-99 | 9 | 9 | 5 | 56% |
| 100-109 | 11 | 10 | 8 | 80.% |
| 110-119 | 24 | 24 | 20 | 83% |
| 120-129 | 75 | 75 | 59 | 78% |
| 130-139 | 109 | 103 | 88 | 85% |
| 140-149 | 133 | 124 | 113 | 91% |
| 150-159 | 138 | 126 | 115 | 91% |
| 160-169 | 117 | 104 | 101 | 97% |
| 170-179 | 43 | 41 | 38 | 92% |
| 180-189 | 5 | 4 | 4 | 100% |
| 190-199 | 8 | 7 | 7 | 100% |
| 200-209 | 1 | 1 | 1 | 100% |
| 210-219 | 0 | 0 | 0 | |
| 220-229 | 1 | 1 | 1 | 100% |
| 230-239 | 0 | 0 | 0 | |
| 240-249 | 1 | 1 | 1 | 100% |

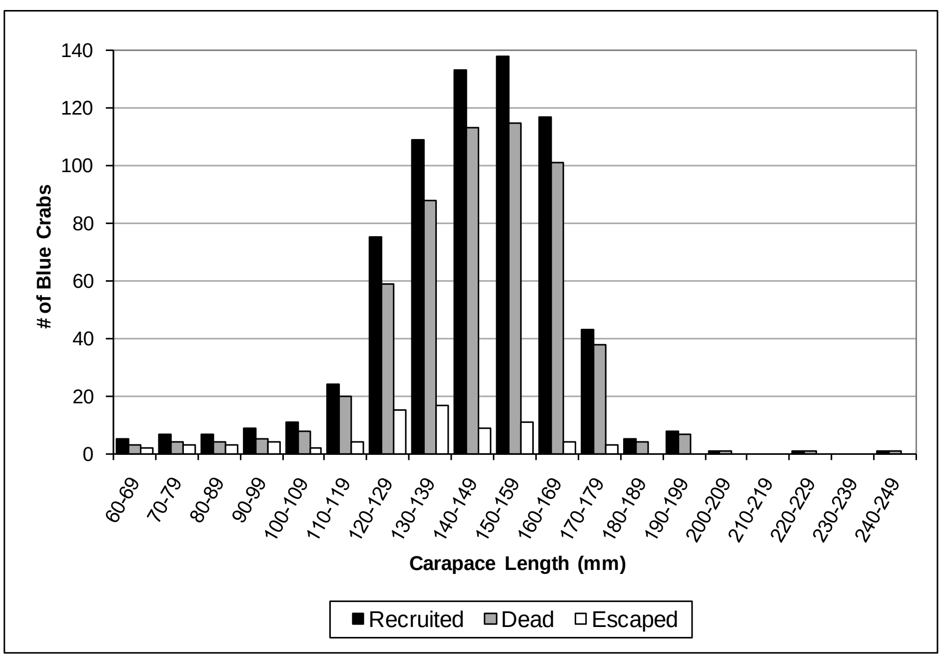



Figure 4-8. Size distribution (10-mm size classes) of blue crabs that recruited to, died in, or escaped from experimental traps.

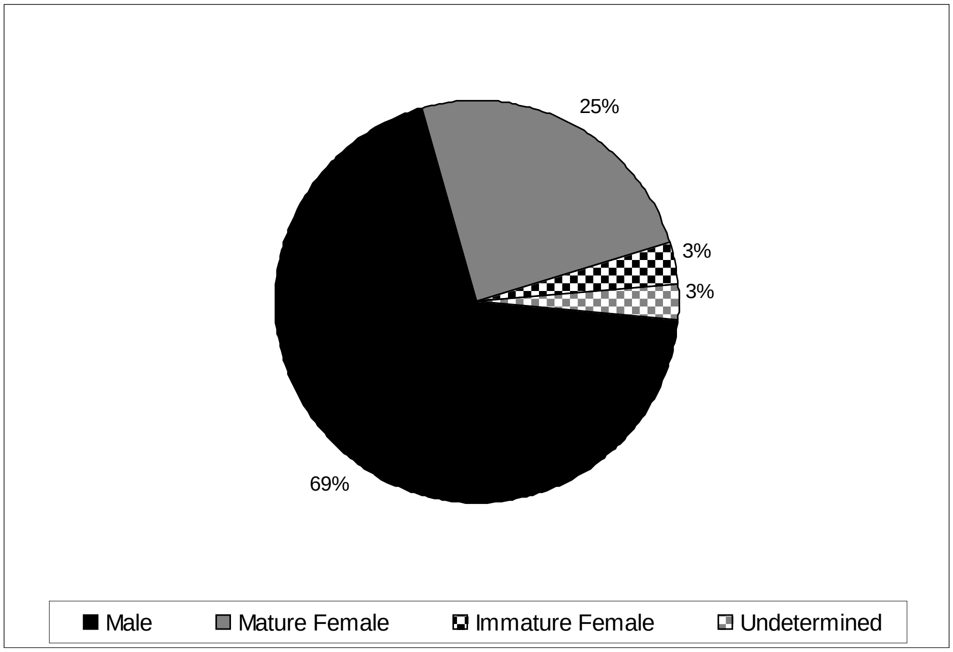



Figure 4-9. Breakdown of blue crab catch by gender and maturity stage (for females). Total number of crabs = 705.

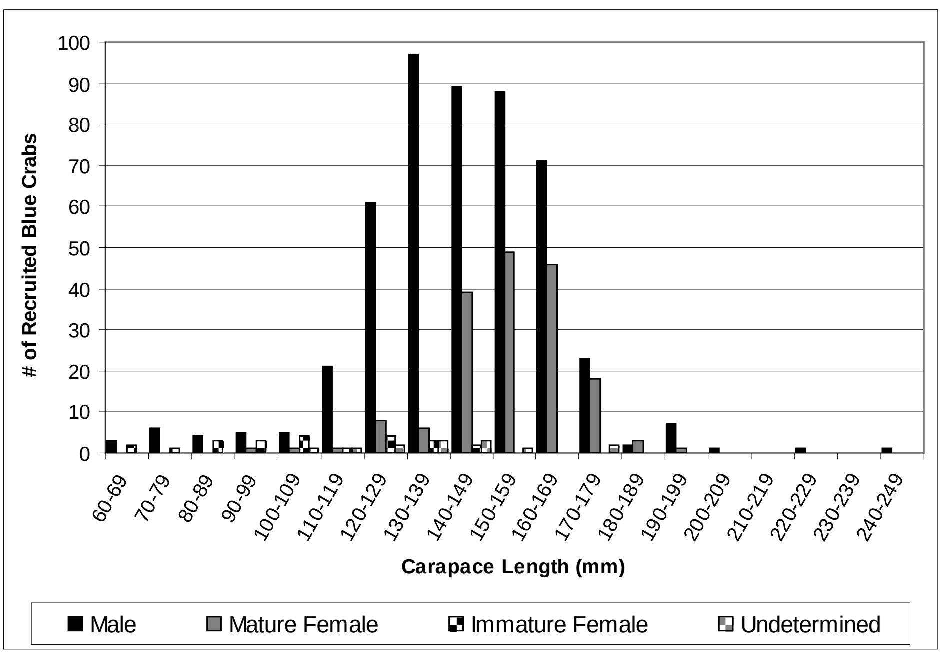
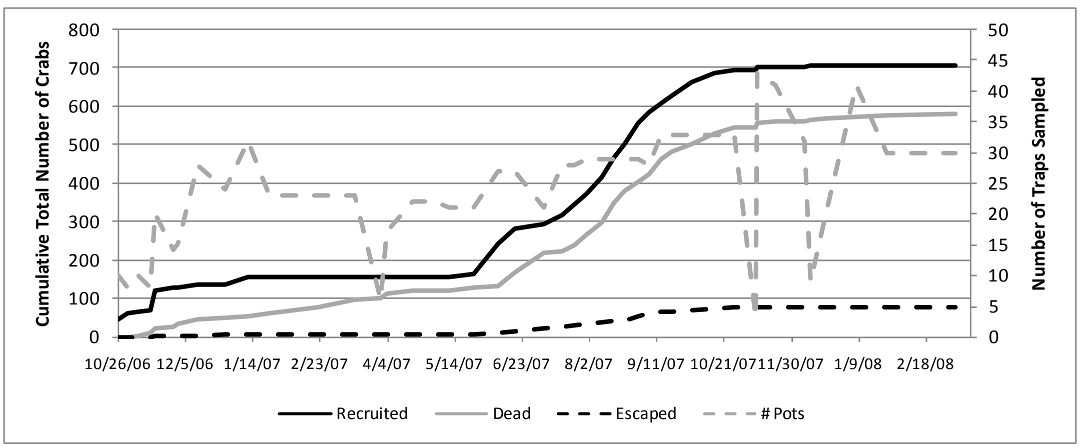



Figure 4-10. Distribution of 10-mm size classes for blue crabs by gender and maturity stage (for females).

sharply in early summer and early fall of 2007 before falling off again to near zero recruitment in the winter of 2007 and 2008. On average, the greatest blue crab catch per trap occurred between May and September of 2007 (Figure 4-11). The mean daily catch rate of blue crabs was 0.058 ± 0.004 (mean daily catch rate ± the standard error), which is an annual catch rate of 21 crabs per trap. Blue crab catch varied significantly among seasons (Figure 4-12). Summer had the highest daily catch rate of 0.138 ± 0.009, followed by spring (0.053 ± 0.008) and then fall (0.025 ± 0.003). There was no recruitment of crabs to experimental traps during winter. Catch rates were also significantly different among sites, but only in the summer season. Herring Bay (0.153 ± 0.012) and Rhode-West (0.11 ± 0.014) were statistically different from Thomas Point (0.057 ± 0.023) during summer according to the Duncan multiple range test. Catch during the first 14 days of the study (the period when traps contained initial bait with which they were deployed) were high relative to the average daily catch rate over the entire course of the study, averaging 0.26 crabs/trap/day in fall, 0.36 in spring, and 0.12 in summer.

(A)




(B)

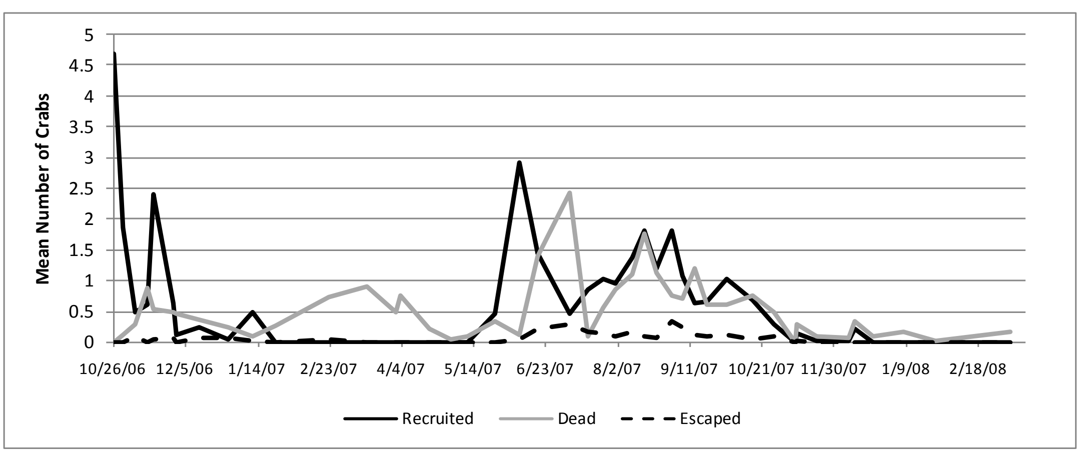



Figure 4-11. Cummulative total (A) and average (B) number of blue crab recruitment, death, and escapement over the course of the study.

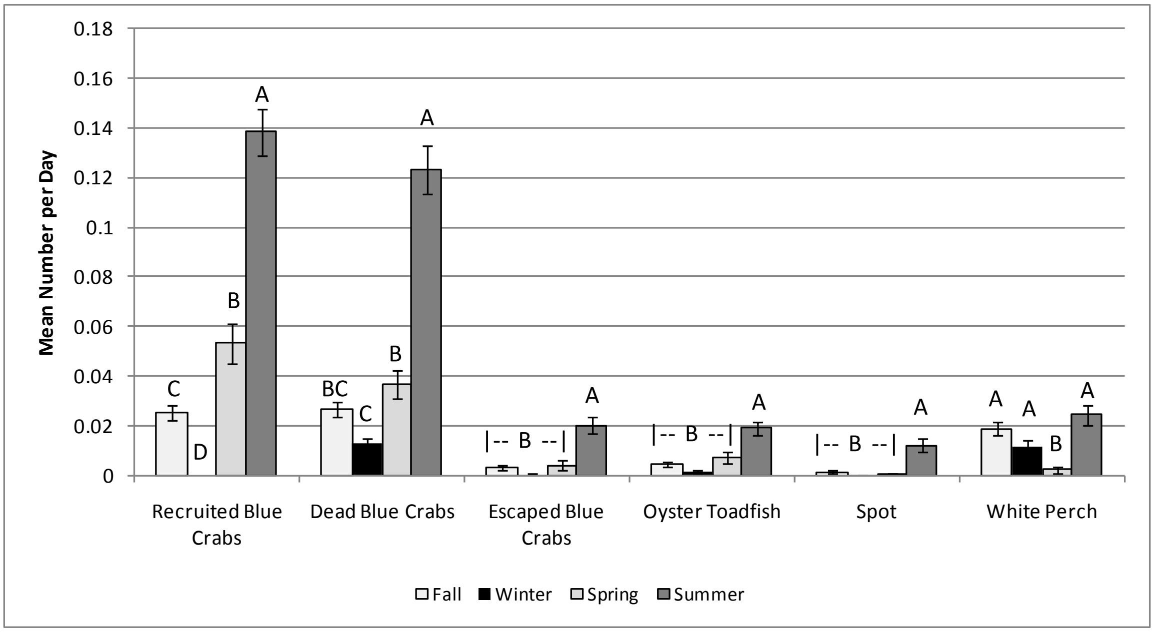



Figure 4-12. CPUE, mortality, and escapement of blue crabs and CPUE of fish for the seasons sampled. Error bars = ± standard error. The Duncan Multiple Range test was used to determine groupings (A, B, C, and D) of seasons within each dependent variable.

Higher catch was associated with lower dissolved oxygen levels during all seasons. Higher catch also generally occurred in areas of higher salinity. One exception was during fall when there was no effect of salinity. Higher catch was also associated with higher temperatures except during summer when there was no difference in catch along a temperature gradient. Differences in catch rates between depth strata were significant only during summer. Deeper strata had a higher mean daily catch rate (0.205 ± 0.019) than shallow strata (0.106 ± 0.01) during summer (Figure 4-13). Separated out by gender, catch of males was greater in deep strata (0.173 ± 0.017) compared to shallow (0.07 ± 0.007) in the summer. There was no difference in female catch between strata during any season.

There was no difference in catch with regard to cull ring status during any season. However, traps with open cull rings caught more large crabs compared to traps with closed cull rings (Figure 4-14). There was a significant negative relationship between catch and fishing activity during summer and fall. Higher catch rates were associated with intermediate levels of fishing during fall but with high levels of fishing activity during the summer.

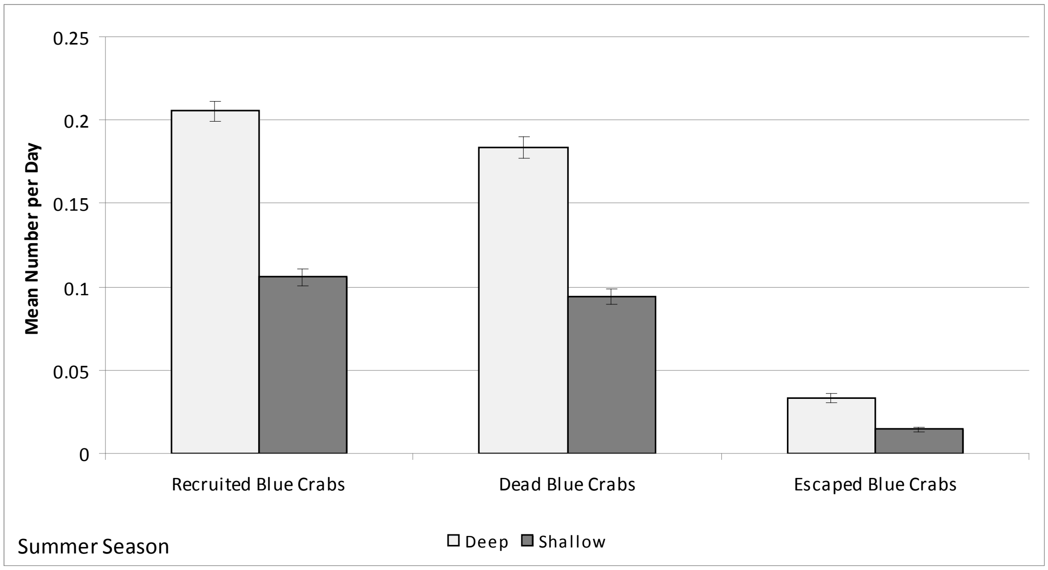



Figure 4-13. CPUE, mortality, and escapement of blue crabs for the two depths sampled. Error bars = ± standard error. For each dependent variable there were significant differences between strata and the Duncan Multiple Range test grouped deep and shallow strata separately.

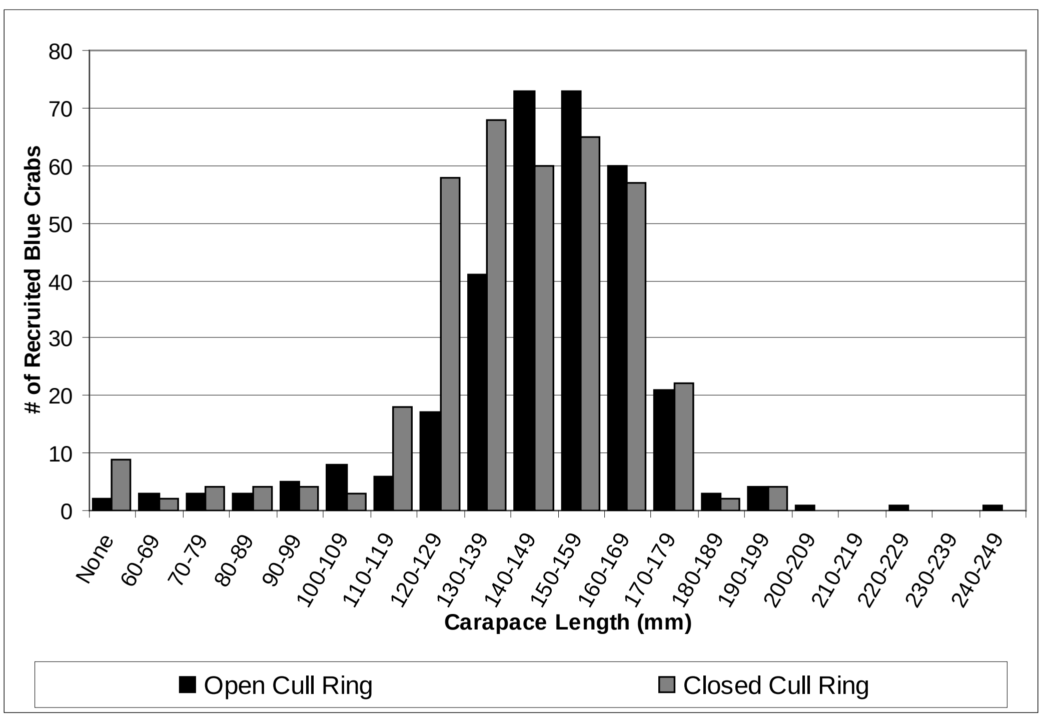



Figure 4-14. Size distribution (10-mm size classes) of blue crabs that recruited to experimental traps with open vs. closed cull rings.

Variance components analysis determined that sampling season was responsible for 22% of the variance in blue crab catch. Dissolved oxygen explained 7% of the variance followed by depth stratum which explained 3%. Site, fishing activity, cull ring status and fouling condition contributed no explanatory power. The rest of the variance in catch was due to natural environmental noise or other factors not examined.

#### 4.3.3.3 Mortality

Seasonal fluctuations in mortality were similar to those for recruitment (Figure 4-11). Mortality was particularly high from mid-summer through late fall of 2007. Over the course of the study, the average residence time of a blue crab in an experimental trap before death was 42.47 ± 1.93 days. Of the 705 crabs that recruited into the traps, 582 individuals died (83% of catch). The mean daily mortality rate of blue crabs in all traps was 0.054 ± 0.003 (± 1 standard error), which corresponds to an annual mortality rate of 20 crabs per trap. Among seasons, summer had the highest daily mortality rate (0.123 ± 0.01), followed by spring (0.037 ± 0.006), fall (0.027 ± 0.003), and winter (0.013 ± 0.002) (Figure 4-12). The average size of dead crabs documented in the traps was 144.39 ± 0.88 SE mm. Mortality was greater for larger crabs (Table 4-4, Figure 4-8).

Blue crab mortality rates were significantly different among sites during the summer season with the highest mortality rate (0.139 ± 0.012) at Herring Bay, compared to either RWS (0.098 ± 0.015) or Thomas Point, which had no mortality. Mortality was greatest during summer (0.0123 ± 0.01) compared to other seasons. During about half of the study mortality was greater in the deep strata. During summer months, the deep depth strata had significantly higher mortality rates (0.184 ± 0.02) when compared to shallow depth strata (0.094 ± 0.01) (Figure 4-13). A similar pattern was observed during fall; the deep strata had higher mortality rates (0.036 ± 0.006) than shallow depth strata (0.021 ± 0.003). Separated by gender, males experienced greater mortality in deep strata (0.15 ± 0.018) than shallow (0.063 ± 0.008) during summer whereas females experienced greater mortality in deep strata during spring and winter.

Blue crab mortality also varied with water quality parameters. Higher mortality rates were associated with low dissolved oxygen levels except during summer when there was no difference in mortality among dissolved oxygen classes. Higher mortality was also generally associated with higher salinities except during winter when there was no difference in mortality across the salinity gradient. Temperature was generally not important for blue crab mortality except during fall when greater mortality occurred at higher temperatures.

Variance components analysis determined that 17% of the variance in mortality was explained by sampling season whereas 15% was attributable to dissolved oxygen levels. Smaller amounts of variation were contributed by depth stratum (3%) and fishing activity (2%). Site, fouling condition, and cull ring status each had no explanatory power.

The remaining variance in mortality was due to natural, environmental noise or from other factors not examined.

### 4.3.3.4 Escapement

Over the course of this study, 78 blue crabs (9% of crab catch) were able to escape from the experimental traps. Escapement rate was significantly different among seasons and was highest in the summer (Figures 4-11, 4-12). The summer escapement peak followed the recruitment peak in 2007, and no escapement occurred during the winter. Escaped crabs had an average residence time in experimental traps of 23.21 days ± 1.61 days. Escapement was normally distributed among 10-mm size classes but no escapement occurred in size classes larger than the 180-189 mm size class (Figure 4-8). The average size of escaped blue crabs was 127.73 ± 2.96 mm. There was no significant effect of cull ring status on the size of escaped crabs (Figure 4-15), and similar numbers of crabs escaped from traps with open cull rings as escaped from traps with closed cull rings except during fall when more crabs escaped from traps with closed cull rings (0.006 ± 0.002) than open cull rings (0.001 ± 0.001). Separated by gender, more male crabs escaped from traps with closed cull rings (0.004 ± 0.002) than open (0.001 ± 0.001) whereas no significant difference was evident for females. While there was no difference in escapement among sites, escapement did vary between depth strata during summer such that deep strata (0.033 ± 0.008) had greater escapement than shallow strata (0.014 ± 0.003) (Figure 4-13). This difference was mainly due to male escapement; more males escaped from traps during summer in deep strata (0.027 ± 0.007) than shallow strata (0.009 ± 0.002).

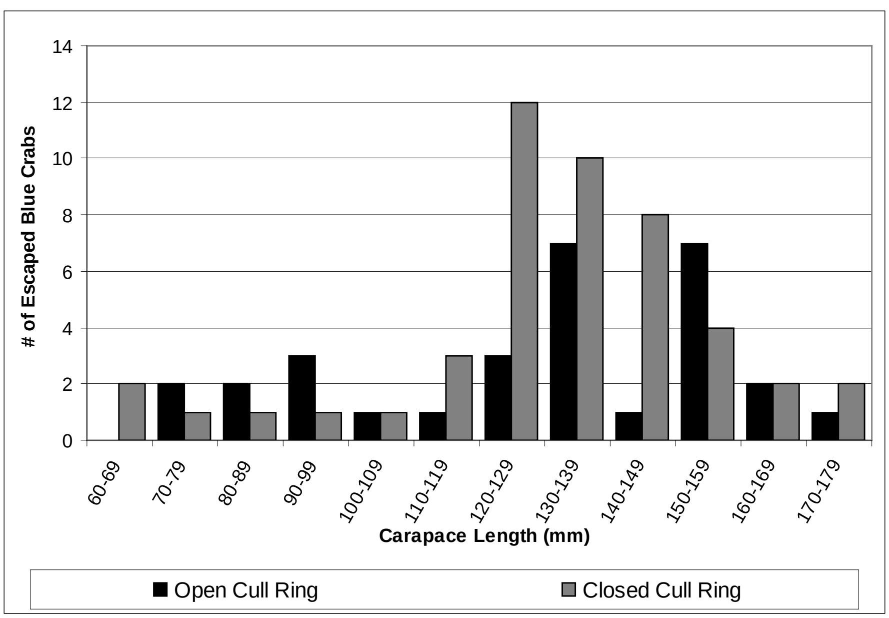



Figure 4-15. Size distribution (10-mm size classes) of blue crabs that escaped from experimental traps with open and closed cull rings.

More crabs escaped at low dissolved oxygen levels and high salinities during spring and high temperatures during fall.

Variance components analysis showed that only a small proportion of the variation in blue crab escapement was explained by factors examined in this study. Season explained 5% of the variance and dissolved oxygen level explained 1%. Fouling condition and cull ring status each explained less than 1% of the variance. Site and fishing activity had no explanatory power. The remaining variance in escapement was due to natural, environmental noise or due to other factors not examined. A summary of all rates by season and year for blue crabs captured in traps is presented in Table 4-5.

Table 4-5. Measured rates by season and year for all blue crabs captured in traps during the simulation study.

| | | Daily Rate | | # of Crabs per Trap per Year | |
|---|---|---|---|---|---|
| | | **Mean** | **SE** | **Mean** | **SE** |
| Catch | All Seasons | 0.0580 | 0.0036 | 21 | 1.32 |
| | Spring | 0.0532 | 0.0081 | 19 | 2.95 |
| | Summer | 0.1383 | 0.0093 | 50 | 3.41 |
| | Fall | 0.0254 | 0.0032 | 9 | 1.15 |
| | Winter | 0.0000 | 0.0000 | 0 | 0.00 |
| Mortality | All Seasons | 0.0542 | 0.0035 | 20 | 1.26 |
| | Spring | 0.0368 | 0.0059 | 13 | 2.17 |
| | Summer | 0.1231 | 0.0095 | 45 | 3.48 |
| | Fall | 0.0269 | 0.0029 | 10 | 1.06 |
| | Winter | 0.0132 | 0.0021 | 5 | 0.77 |
| Escapement | All Seasons | 0.0080 | 0.0011 | 3 | 0.41 |
| | Spring | 0.0043 | 0.0018 | 2 | 0.67 |
| | Summer | 0.0204 | 0.0033 | 7 | 1.22 |
| | Fall | 0.0036 | 0.0010 | 1 | 0.35 |
| | Winter | 0.0004 | 0.0004 | 0 | 0.13 |

### 4.3.4 Bycatch

#### 4.3.4.1 White Perch

White perch were the most abundant fish collected (53%) as bycatch during the experiment (Figure 4-16). The average size of white perch caught in traps was 198.29 ± 1.63 mm and ranged from 110 mm to 260 mm (Figure 4-17). The number of dead white perch was used as a proxy for the number of white perch entering the trap (Section 2.2 for rationale). Recruitment of white perch to experimental traps had a peak centered on September and October of 2007, before experiencing a second peak from November of 2007 through the end of the study (Figures 4-18 and 4-19).

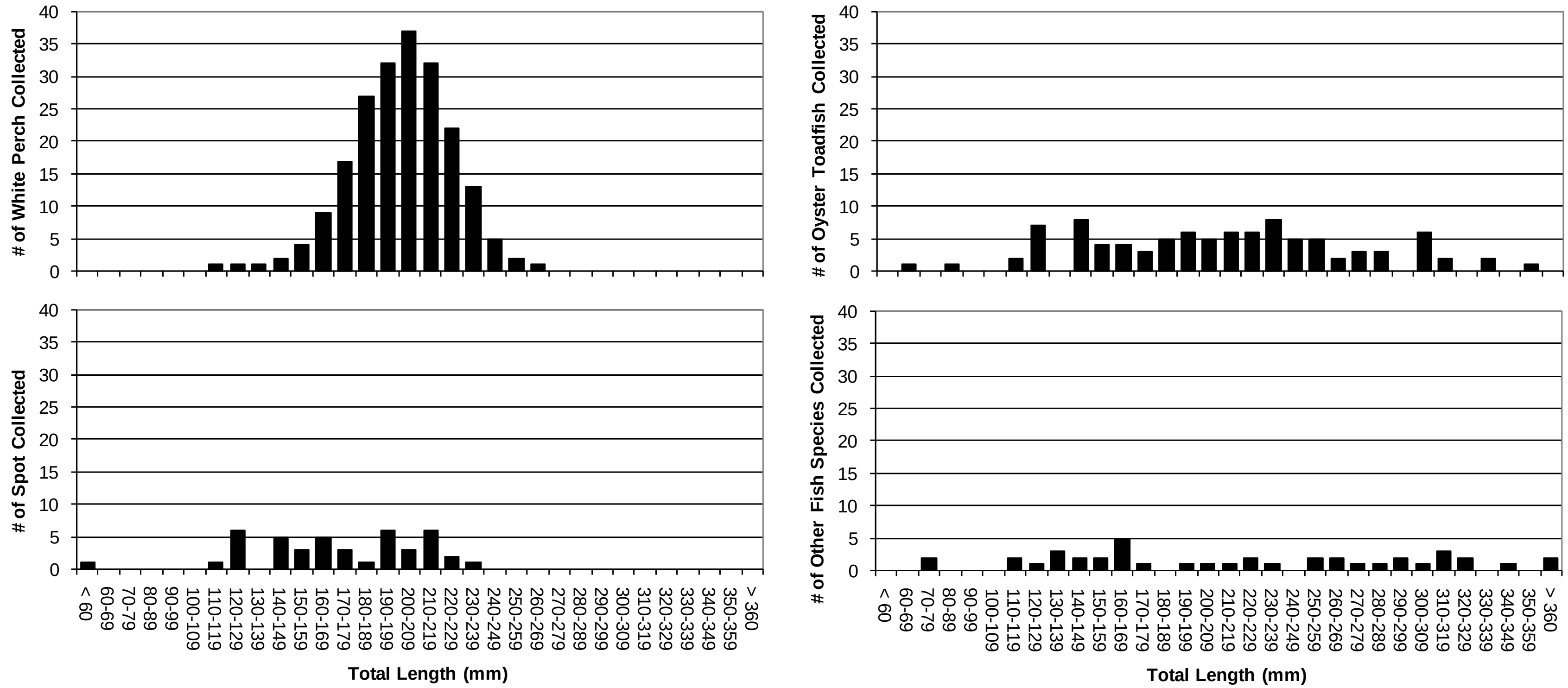



Figure 4-16.  Size distribution of fish species caught during this study.

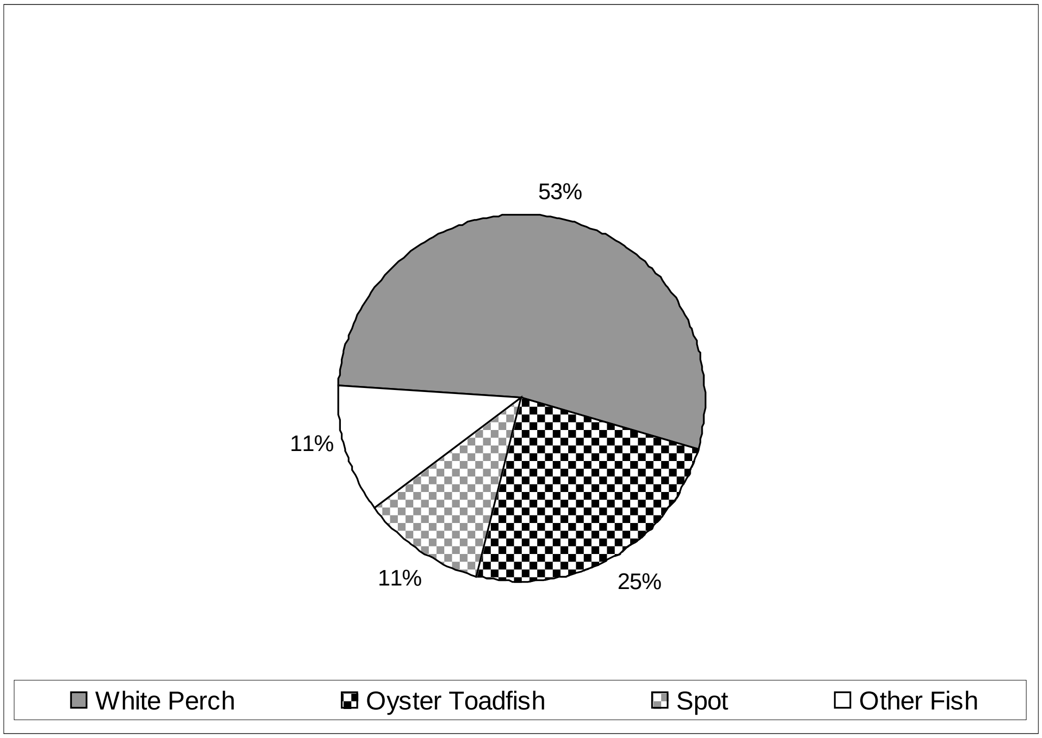



Figure 4-17. Composition of total fish collected in this study. Other fish = pumpkinseed, Atlantic menhaden, Atlantic croaker, American eel, and sheepshead. Total number of fish = 391; for species specific data (Table 3).

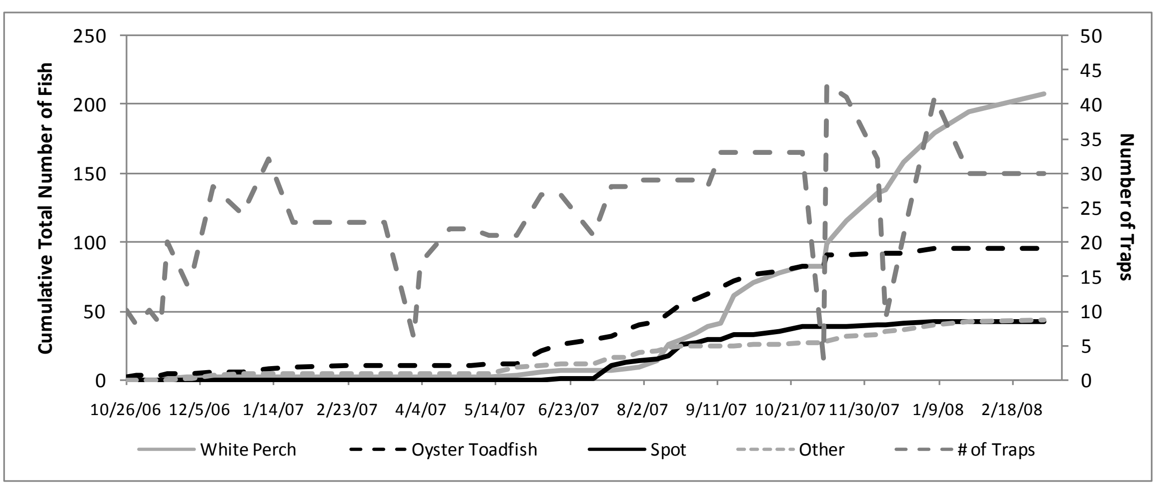



Figure 4-18. Cumulative mean number of white perch, oyster toadfish, spot and other fish per trap over the course of this study.

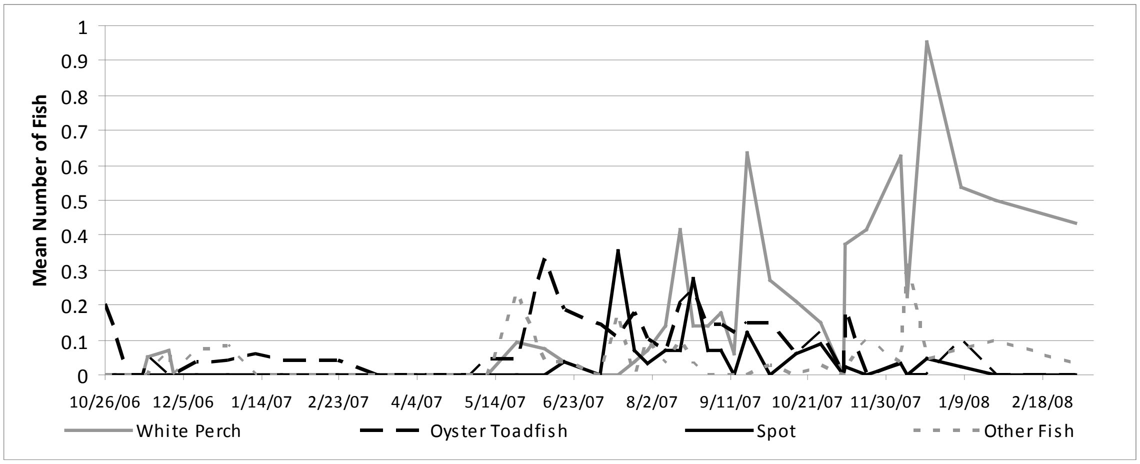



Figure 4-19. Mean number per trap of white perch, oyster toadfish, spot and other fish species.

Catch of white perch was similar in both deep and shallow areas. Among seasons, catch was greatest in summer (0.025 ± 0.004), followed by fall (0.019 ± 0.003), winter (0.012 ± 0.003) and spring (0.002 ± 0.001) (Figure 4-12). Catch was particularly high in Herring Bay during summer (0.033 ± 0.005) and fall (0.027 ± 0.004) (Figure 4-20). Catch varied with cull ring status only during fall when more white perch were caught in traps with closed (0.026 ± 0.005) compared to open (0.012 ± 0.003) cull rings. Water quality parameters were correlated with white perch catch. Catch was also greater in areas with higher salinities during fall and summer and with higher dissolved oxygen during the fall. Catch rate was not correlated with bottom temperature. Evaluation with variance components analysis showed that fouling condition explained 10% of the variation in white perch catch (Section 3.5 for details) whereas all other parameters examined explained ≤3% of the variation.

#### 4.3.4.2 Oyster Toadfish

Oyster toadfish was the second most prevalent bycatch species (25%) (Figure 4-16). Oyster toadfish had the broadest size range (60 mm to 350 mm) of individuals with a mean and standard error of 206.46 ± 6.30 mm (Figure 4-17). Recruitment occurred throughout the study with highest rates occurring during summer (0.019 ± 0.003) and spring (0.008 ± 0.002) (Figure 4-12). Greatest catch was observed at Rhode and West River site during spring (0.016 ± 0.007). Greater oyster toadfish catch was also associated with closed cull rings (0.028 ± 0.005) compared to open rings (0.011 ± 0.003). The water quality parameters of temperature, dissolved oxygen and salinity were not related to catch in any season. Evaluation with variance components analysis showed that fouling condition explained 15% of the variation in oyster toadfish catches whereas all other parameters examined explained ≤2% of the variation.

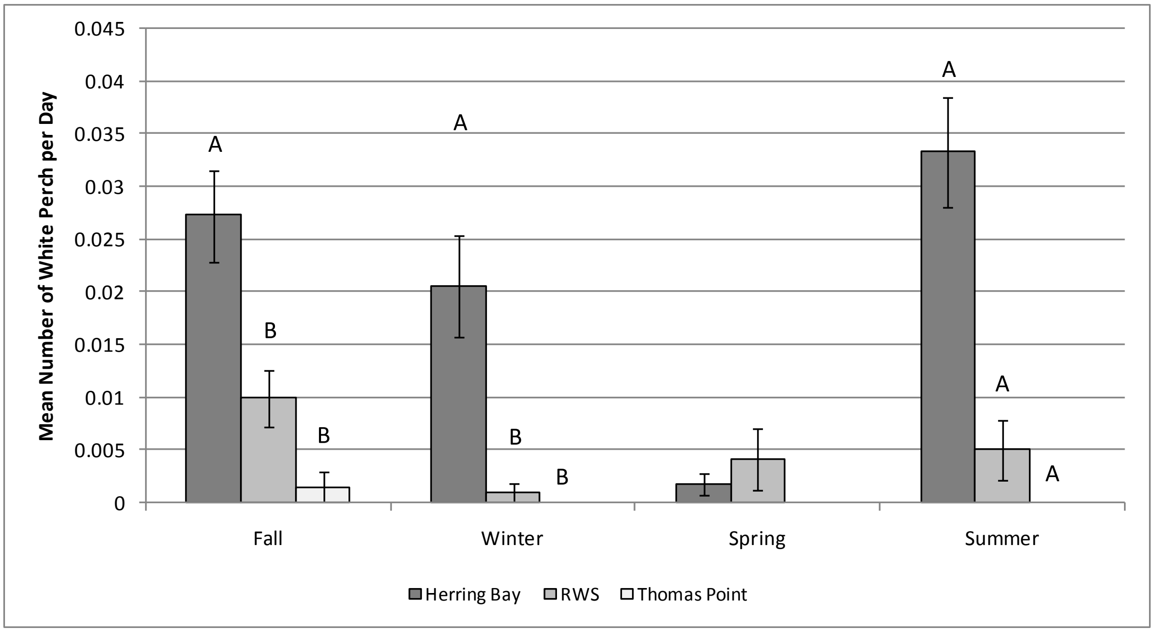



Figure 4-20. Mean catch rates of white perch per day for each season at each site. Error bars = ± standard error. Every season was significantly different between sites except spring, and Duncan Multiple Range test groupings are denoted by A and B.

#### 4.3.4.3 Spot

Approximately 11% of bycatch was contributed by spot, making it the third most abundant bycatch species (Figure 4-16). The average size of spot caught in traps was 167.81 ± 5.85 mm, ranging from 50 mm to 230 mm (Figure 4-17). Greatest catches of spot occurred during summer (0.012 ± 0.003) compared to other months (Figure 4-12), particularly at Herring Bay (0.018 ± 0.004). More spot were caught in deep strata during both fall (0.004 ± 0.002) and summer (0.023 ± 0.006) compared to shallow (fall, 0; summer, 0.007 ± 0.003). Closed cull rings were also associated with greater catches (0.019 ± 0.005) compared to open rings (0.006 ± 0.002). Catch was generally uncorrelated with water quality parameters with the exception of bottom salinity in the fall. Evaluation with variance components analysis showed that season explained 4% of the variation in spot catch whereas all other parameters examined explained ≤3% of the variation.

#### 4.3.4.4 Other Finfish Species

Other fish species found in the traps included pumpkinseed, Atlantic menhaden, Atlantic croaker, American eel, sheepshead, and black sea bass. Average sizes for these species were: pumpkinseed 152 ± 5 mm, Atlantic menhaden 289 ± 9 mm, Atlantic croaker 258 ± 34 mm, American eel 450 ± 131 mm, sheepshead 99 ± 11 mm, and black sea bass, 220 ± 6 mm (Figure 4-17).

Other finfish species were caught throughout the study. Catch was generally similar among sites and between depth strata except for spring when catches were greater in deeper areas. Traps with closed cull rings tended to catch more fish in this category, especially during summer and winter. Water quality was generally unrelated to these species with the exception of dissolved oxygen during summer which was positively correlated with catch. Evaluation with variance components analysis showed none of the parameters examined explained more than 2% of the variation.

### 4.3.5 Fouling

A total of 4 of the sixteen reference traps were left for inspection at the end of the survey. No differences were determined between the reference traps and traps that were sampled during the study and therefore test were conducted to determine the influence of fouling on specific measured values. Deployment duration, or the number of days that a trap was in the water, had a significant and positive relationship with fouling (Tables 4-6 and 4-7, Figures 4-21 and 4-22). The significant statistical interaction between site and deployment duration was primarily due to the effect of deployment duration (Figure 4-23). The main effects of site, deployment season, and depth stratum had no significant effects on fouling (Figure 4-23).

Fouling had significant effects on recruitment and mortality and these effects varied with season. Blue crab recruitment was highest in traps that had medium levels of fouling during spring (Figure 4-24). Mortality of blue crabs was greater in extremely fouled traps during the fall (Figure 4-25). In general, catch of white perch, oyster toadfish, spot and other fish species tended to be higher in more heavily fouled traps (Figure 4-26).

## 4.4 DISCUSSION

Derelict fishing gear could potentially have a significant effect on natural populations. We examined how three important rates, recruitment (catch), mortality, and escapement varied during the course of simulated derelict trap deployment. Each of these rates plays an important role in determining the overall effect of derelict traps on blue crab and bycatch population dynamics at the Bay-wide scale.

Recruitment of blue crabs into experimental traps varied over space and time. An individual trap was found to have an annual catch rate of about 21 blue crabs. High catch rates between May and September, particularly in deeper waters (5-10 m), are consistent

Table 4-6. Three- way ANOVA to examine the effects of deployment season (fall, spring, and summer), deployment duration (number of days), and site (Herring Bay, RWS, and Thomas Point) on fouling condition.

| Source | DF | Type III SS | Mean Square | F Value | Pr>F |
|---|---|---|---|---|---|
| Season Deployed | 2 | 1.483 | 0.741 | 2.56 | 0.0799 |
| Deployment Duration | 1 | 14.055 | 14.055 | 48.51 | <.0001 |
| Site | 2 | 0.063 | 0.031 | 0.11 | 0.8973 |
| Deployment Duration * Site | 2 | 2.102 | 1.051 | 3.63 | 0.0283 |
| Season Deployed * Site | 2 | 0.404 | 0.202 | 0.7 | 0.499 |
| Deployment Duration * Season Deployed | 2 | 1.596 | 0.798 | 2.75 | 0.0661 |
| 3-way Interaction | 2 | 0.946 | 0.473 | 1.63 | 0.198 |
| Error | 204 | 59.113 | 0.290 | | |

Table 4-7. Three- way ANOVA to examine the effects of deployment season (fall, spring, and summer), deployment duration (number of days), and depth stratum (deep and shallow) on fouling condition given the number of days in the water.

| Source | DF | Type III SS | Mean Square | F Value | Pr>F |
|---|---|---|---|---|---|
| Season Deployed | 2 | 0.520 | 0.260 | 0.83 | 0.4362 |
| Deployment Duration | 1 | 1.646 | 1.646 | 5.28 | 0.0226 |
| Depth Stratum | 1 | 0.266 | 0.266 | 0.85 | 0.3564 |
| Deployment Duration * Depth Stratum | 1 | 0.102 | 0.102 | 0.33 | 0.5678 |
| Season Deployed * Depth Stratum | 2 | 0.361 | 0.181 | 0.58 | 0.5613 |
| Deployment Duration * Season Deployed | 2 | 1.790 | 0.895 | 2.87 | 0.059 |
| 3-way Interaction | 2 | 0.204 | 0.102 | 0.33 | 0.7209 |
| Error | 206 | 64.244 | 0.312 | | |

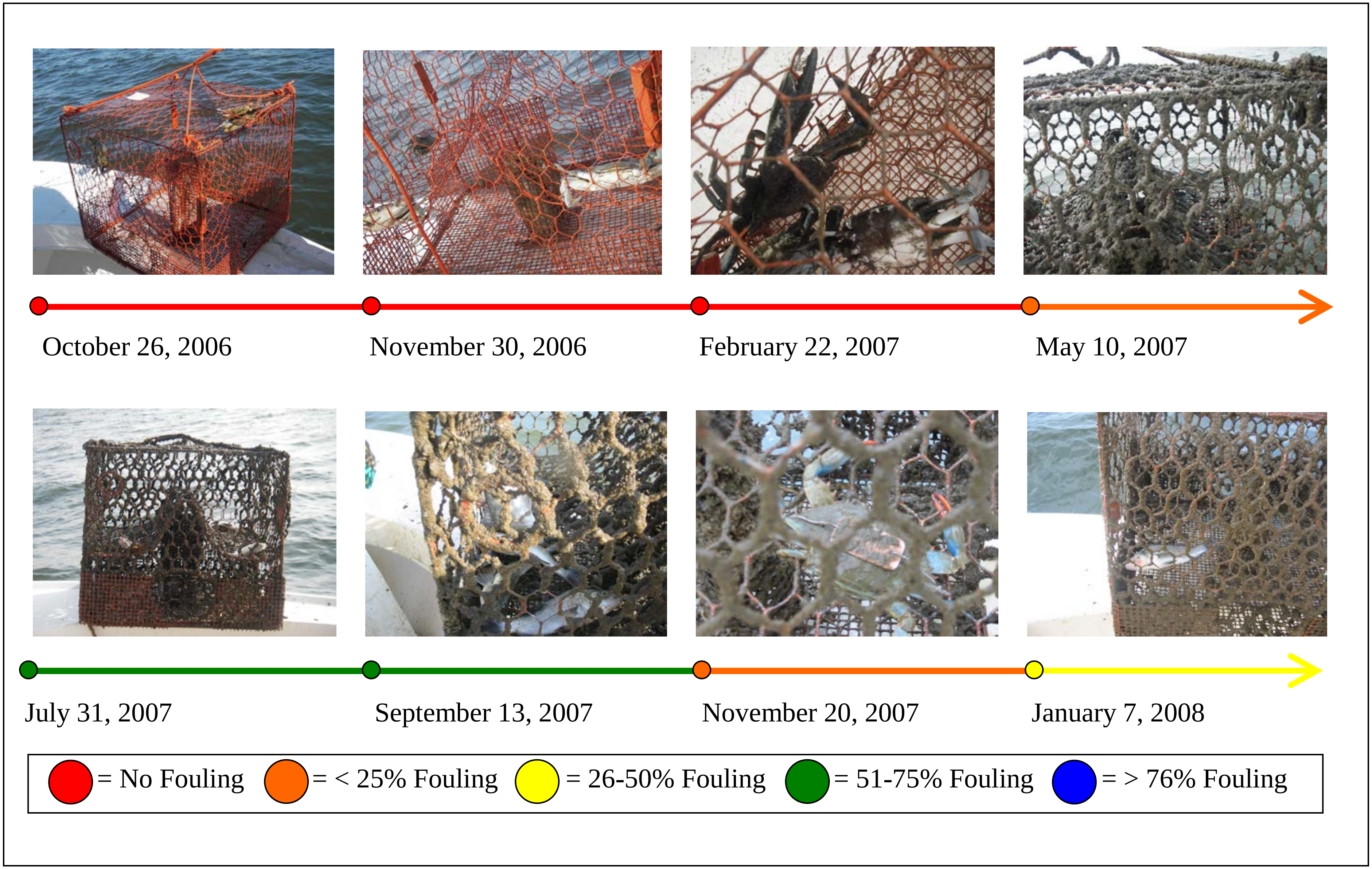



Figure 4-21. Timeline of fouling growth on an original trap throughout the study. This trap was in the shallow strata of Herring Bay.

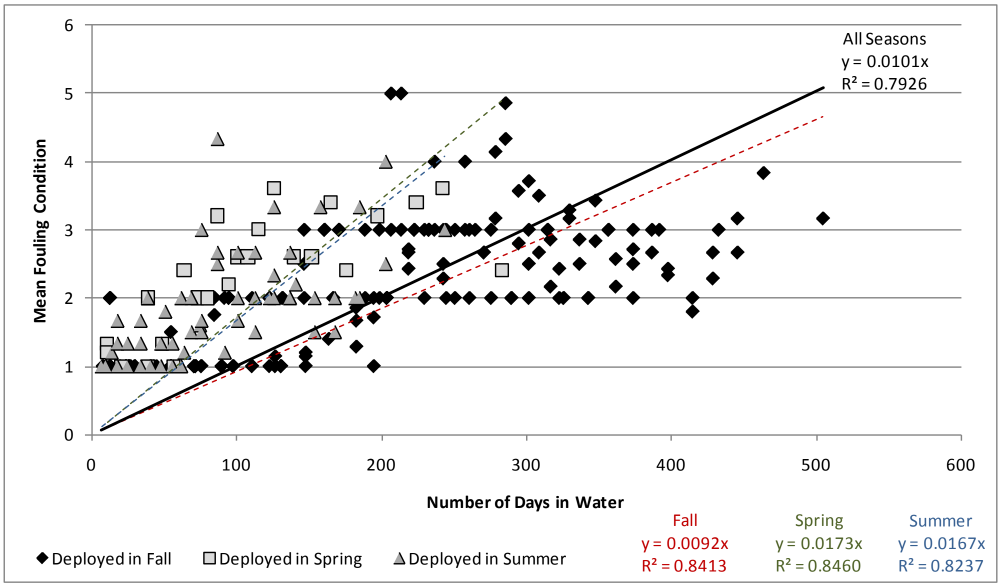
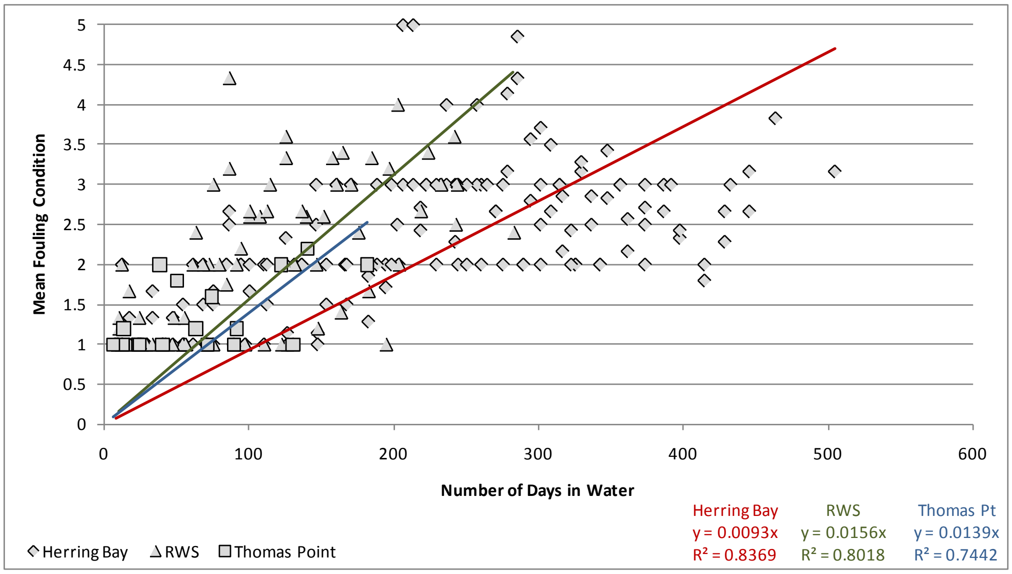



Figure 4-22. Regression results for fouling condition given the number of days in water of experimental traps between deployment season. Dotted lines represent regression lines for individual seasons; red=fall, green=spring, blue=summer. The solid line represents the regression line for all seasons combined.

(A)




(B)

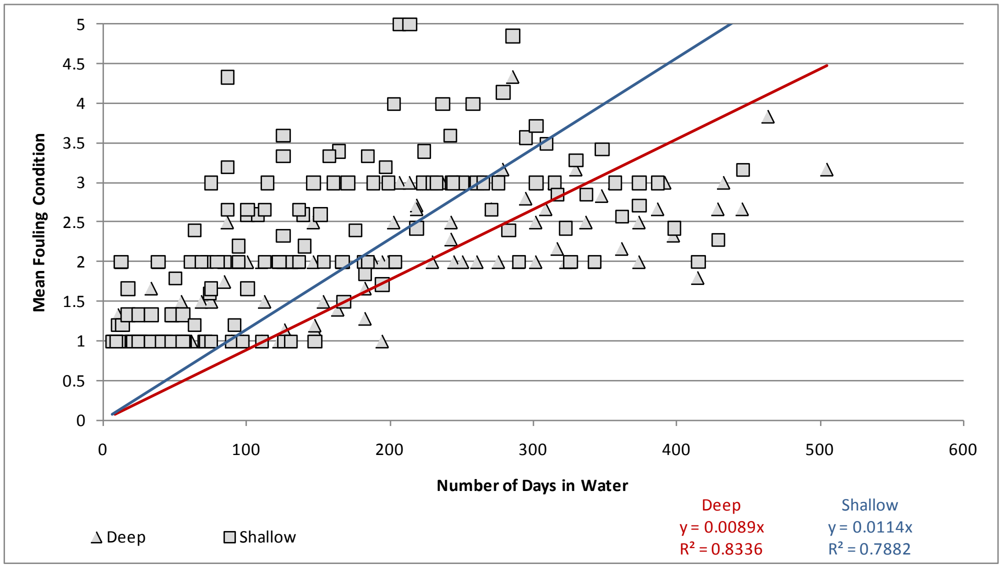



Figure 4-23. Regression results for fouling condition given the number of days in water of experimental traps for the three sites (A) and for each depth stratum (B). In panel A, individual regression lines are given for each site; red=Herring Bay, green=RWS, and blue=Thomas Point. In Panel B, individual regression lines are given for each depth stratum; red=deep, blue=shallow.

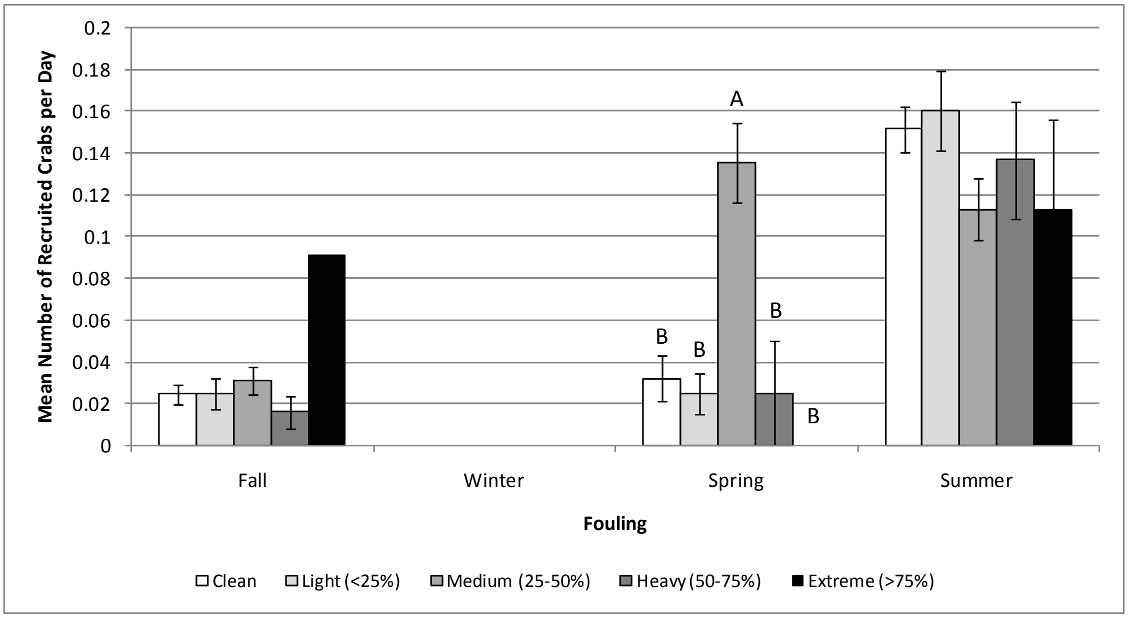



Figure 4-24. CPUE of blue crabs by traps of different fouling condition throughout the year. Error bars = ± standard error. Spring and summer seasons had significant differences of catch rates between fouling condition classes, and Duncan Multiple Range test groupings are denoted by A and B.

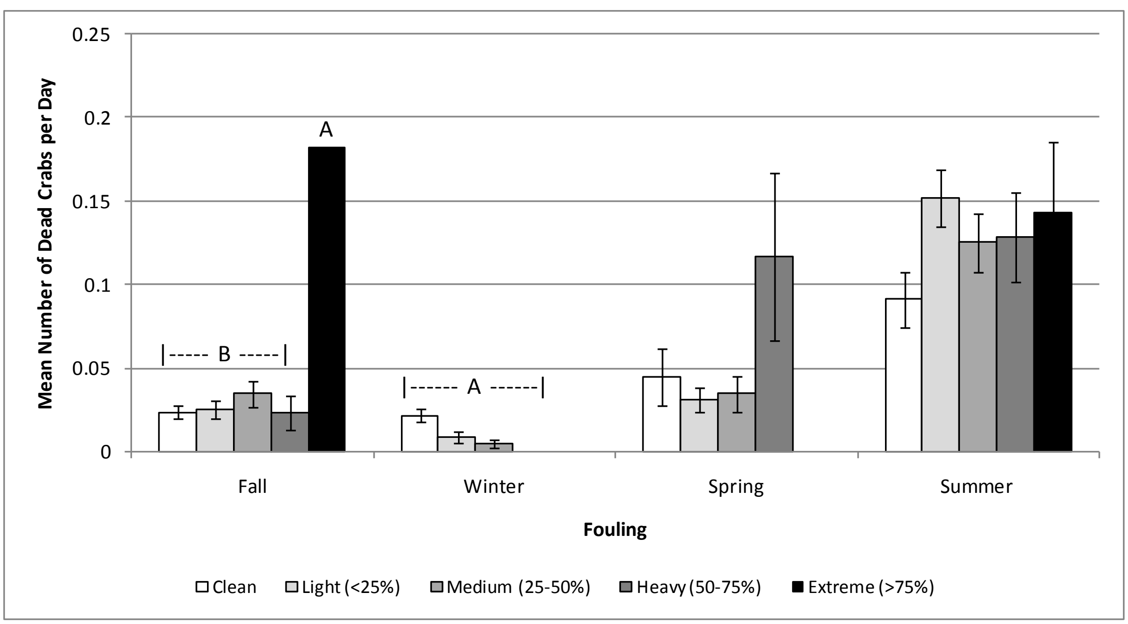



Figure 4-25. Mean daily mortality rate of blue crabs in different fouling conditions throughout the year. Error bars = ± standard error. The fall season had significant differences of mortality rates between fouling condition classes, and Duncan Multiple Range test groupings are denoted by A and B.

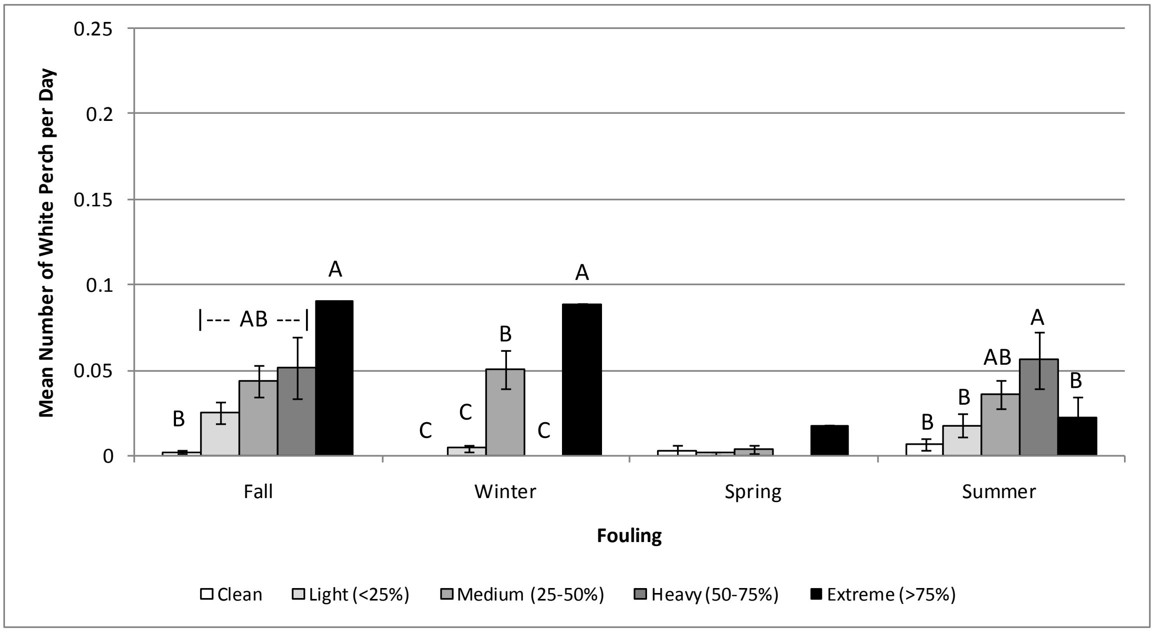



Figure 4-26. Mean daily white perch catch rates in different fouling conditions throughout the year. Error bars = ± standard error. All seasons except spring had significant differences of fish catch rates between fouling condition classes, and Duncan Multiple Range test groupings are denoted by A, B, and C.

with the seasonal population dynamics for this species. Recruitment into traps at Herring Bay was greater than the other two sites. Although cull ring status (open versus closed) appeared to have no effect on catch rates in general, more sublegal crabs were present in traps that had closed cull rings. This indicates that cull rings are effective at allowing sublegal crabs to escape from derelict traps. Low dissolved oxygen appeared to enhance catch rates. This may be because crabs are more mobile during periods of hypoxia and enter the traps while seeking more suitable habitat. Higher temperatures and higher salinities were also associated with higher catch.

Mortality also varied both spatially and temporally. Mortality was particularly high in the summer, in deeper depths, at low dissolved oxygen levels, and in high salinity areas. Males were more vulnerable to mortality in deep areas during summer months whereas females were more vulnerable to mortality during the winter. This probably reflects the seasonal patterns of movement for male and female blue crabs in the Bay (Hines et al. 2008). Among sites, mortality was greater at Herring Bay due to higher numbers of crabs recruiting to traps at this site. Although specific causes of mortality were not examined, death could have been caused by numerous factors inside the traps including starvation, over-crowding stress, injury, predation, cannibalism, and poor environmental conditions (Guillory 1993, Guillory 2001, Breen 1990).

Like recruitment and mortality, escapement was greatest in summer months particularly in deeper areas. More male crabs were able to escape than females but any crabs larger than 180 mm were not able to escape from the traps at all. In addition, the abundance of larger individuals with open cull rings indicates that open cull rings may allow small individuals to escape while selectively trapping larger individuals and removing them from the population. Low dissolved oxygen and high salinity in the spring and high temperatures in the fall were also correlated with escapement.

In addition to impacts on blue crabs, resource managers are also concerned about the potential effects of derelict crabs on bycatch species population biology. A variety of species have been observed in derelict blue crab traps (Davis 1942, Whitaker 1979, Guillory 1993, Havens 2008). Bycatch species may be attracted to derelict traps for shelter, potential forage, or by conspecifics inhabiting the trap. In the study presented here, white perch was by far the most abundant bycatch species. Catch of white perch was greater in summer and fall, especially in more saline areas and in Herring Bay. Similar to what was observed for white perch, bycatch of oyster toadfish, spot, and other fish species was also greatest during summer and in traps with closed cull rings. While catch of spot was greatest in Herring Bay, more oyster toadfish were caught in the Rhode-West site. Water quality did not appear to be particularly important for bycatch species abundance inside traps.

Left on the bottom for long periods, derelict traps can provide a substrate for a benthic fouling community. The degree of fouling on a trap could potentially influence the ability of a trap to capture organisms. High levels of fouling or the presence of particular fouling species may act as an attractant for crabs or other species by providing food resources or spatial refugia from predators (Diaz et al. 2003, Enderlein et al. 2003, Laegdsgaard and Johnson. 2001). Fouling may also facilitate ghost fishing and mortality by blocking escape routes, thereby causing longer-term entrapment and higher densities of entrapped organisms. We found that deployment duration, more so than other variables, was important for the amount of fouling on traps. For blue crabs, intermediate levels of fouling were associated with higher catch. Mortality for blue crabs as well as for all bycatch fish species were greater in more heavily fouled traps.

Fouling of derelict traps has previously been investigated by Havens et al. (2008). They measured fouling by weighing traps during sampling and found that trap weight generally increased over time. This was consistent with the pattern observed during the study presented here. However, they also found evidence for a die-back of growth in tunicates on traps in the lower York River main stem during late spring-early summer which caused low trap weights at this time. Both studies indicated a general growth and die-off pattern whereby fouling was highest in the summer and lowest in fall into winter.

Previous studies have examined the effects of derelict crab traps on invertebrate and fish populations (blue crabs in Gulf of Mexico: Guillory 1993, blue crabs in southern Chesapeake Bay: Havens 2008; Dungeness crabs in British Columba: Breen 1987; Tanner crabs in Alaska: Stevens et al. 2000; American lobster in New England: Sheldon and Dow 1974; fish and invertebrate communities in England: Bullimore et al. 2001; see Guillory et al. 2001 for review). Guillory (1993) examined the effects of derelict traps on blue crabs in the Gulf of Mexico. Deployed for approximately 1 year, traps were sampled weekly from October to January and then bi-weekly thereafter. Similar to our findings, Guillory (1993) found that patterns varied with season and that larger individuals (>140 mm) tended to remain trapped in cages longer than smaller crabs (<120 mm). Over the entire course of their study (including both the baited and unbaited periods), an average of 47.7 blue crabs/trap/year were caught by an individual trap compared to 21 crabs/trap/year in the current study.

We estimated an average annual mortality in derelict traps of 20 crabs/trap/year. This is within the range of 20-60 crabs/trap/year reported by (Whitaker 1979) for blue crabs in South Carolina and similar to Guillory's (1993) estimated annual mortality rate in coastal Louisiana (25.8 crabs/trap/year). However, our estimate is comparatively lower than reported by either Havens (2008) for lower Chesapeake Bay (50.6 crabs/trap/year) or Poon (2005) as an average across multiple ecosystems (53.8 crab/trap/year).

The presence of cull rings or escape panels is expected to increase escapement and possibly reduce mortality of blue crabs and other species that enter derelict fishing traps. Despite this, we found little effect of cull rings on blue crab recruitment or mortality. This is in contrast to findings by Arcement and Guillory (1993) who found a significant effect of cull rings on mortality (17.3 crabs/trap for 3 months without rings versus 5.3 crabs/trap for three months with cull rings). However, our estimated overall annual rate of mortality is about 20 crabs/trap/year, which is similar to their estimates for traps with no cull ring. This suggests that the cull rings on the traps used in our study did not function as efficiently as those used by Arcement and Guillory (1993). This could also be an artifact of the sampling methods because very small crabs could not be tagged and therefore escapement was not monitored for all size classes which may have occurred in Arcement and Guillory (1993). One possible explanation is that cull ring size or placement may have differed between the two studies. Ruderhausen and Turano (in press) demonstrated that larger cull ring sizes were associated with reduced CPUE of sub-legal males and mature female blue crabs. Previous estimates of mortality of blue crabs in derelict traps for the Coastal Bays of Maryland were also much lower, ranging from 7.5 crabs/trap (from January to March) to 7.7 crabs/trap (from August and September) (Casey and Wesche 1977 and Casey and Wesche 1980); however, these studies only examined a portion of the year (August to September and January to March, respectively).

On average, we estimated the annual escape rate for blue crabs to be 3 crabs/trap/year or 14% of total catch. This is much lower than the rates reported by Arcement and Guillory (1993) who reported an escape rate of 34% and by Guillory (1993) who reported 56%. The rate of escapement may be influenced by a number of factors related to trap construction including the number, size, and placement of cull rings (Havens et al. in press, Ruderhausen and Turano in press), mesh size and shape, presence of escape panels, rate of trap deterioration, and burial by substrate (Guillory 1998, Smolowitz 1978).

Bycatch of finfish and other invertebrates is common for derelict fishing gear. In Lower Chesapeake Bay, Havens et al. (2008) reported similar bycatch species as those found here. The most abundant bycatch in Havens (2008) was Atlantic croaker (6% of catch); white perch (3.6%), oyster toadfish (4.2%) and spot (1.1%) were also important components bycatch. By comparison, white perch was the most abundant bycatch in the current study (19%), followed by oyster toadfish (9%), and spot (4%).

The study design and findings reported here differ from that of the work of Havens et al. (2008) for lower Chesapeake Bay. Havens et al (2008) focused on blue crab capture rates by derelict traps and in the York River, VA. Their design allowed for the deployment of 56 traps which were opened to allow active fishing for a 7-day period each month. Catch was monitored each month by counting the organisms in the trap. Organisms were removed from the trap during sampling and then released after measurements were taken. While this study can address potential catch rates of derelict traps, it did not monitor individual crabs. Therefore, it is not known whether individuals entered and then subsequently escaped or suffered mortality between sampling dates. Instead, Haven's et al. (2008) assumed that all captured crabs were present and alive at the time of sampling. In contrast, the study presented here identified individual crabs using across-the-back tags so that their entry into the derelict trap and the ultimate fate could be determined for individuals. The current study also presented a realistic simulation of how derelict traps would capture organisms by allowing active fishing throughout the study period which has important management implications for the blue crab fishery. The final conclusions and recommendations based on this and the other section is presented in Section 5.0.

# 5.0 FINAL CONCLUSIONS AND RECOMMENDATIONS

A suite of techniques and technologies were used to quantify the distribution and overall effects of derelict crab traps in the Maryland portion of Chesapeake Bay. Traps were successfully quantified and examined using side-scan sonar, ground-truthing surveys, and a diver-based survey. Side-scan sonar is a novel approach for exploring derelict traps on the Bay bottom because of the added efficiency of surveying a large area over a relatively short period of time and because it overcomes the significant water clarity problem which hinders direct visual observations in Chesapeake Bay. A series of ground-truthing surveys improved the accuracy of detecting derelict traps in sonar imagery and provided invaluable information on which to compare information from the simulated ghost fishing derelict trap experiment. The diver-based survey provided a highly efficient, supplemental approach for precisely identifying and sampling derelict traps from a range of target pixel intensities and object configurations. Together, these approaches allowed us to develop the first reported estimate of the number of derelict traps in Maryland Chesapeake Bay and to describe their effects on the living resources in this system.

Derelict crab traps appear to be common throughout areas of the Maryland Bay where the commercial hard crab trap fishery is active. The results of the side scan-sonar survey show that the spatial distribution of derelict traps is non-random. The total number of derelict traps in Maryland Bay is estimated to be 84,567 traps based on a total of 285 transects conducted during the survey. The Upper Bay (code 025) and Mid Bay (code 027) regions had the greatest estimated number of derelict traps. Lower Bay and Tangier Sound region had an intermediate number of traps. The smallest estimated number of derelict traps was located in NOAA code 072 which is the smallest NOAA code by area in this study. These estimates are a function of both the density per transect and the total area of the NOAA code. The greatest densities of derelict traps per transect were found in NOAA codes 025, 027 and 072.

Derelict trap density was also greater in areas of intermediate to high fishing effort which correspond with areas of shallow depth (Slacum et al. 2008). Because greater numbers of traps are deployed in areas of high fishing pressure, there is a greater number of traps that could potentially become derelict. Areas of high fishing effort tend to be locations in front of river mouths where significant boat traffic occur. Because passing vessels can sever buoy lines with their propellers, buoyed traps are subjected to higher losses in these areas of the Bay. This was corroborated during derelict trap retrieval activities, in which the vast majority of retrieved derelict traps were found to have a large portion of their float lines still attached to the trap. This indicated that the line had been unintentionally cut most likely by a passing vessel.

Another piece of evidence linking boating traffic to trap loss is that lower densities of derelict traps are found in areas where overall boating activity is low, but fishing effort is high. For example, almost one third of all commercial crabbing effort in Maryland occurs in Tangier Sound (Slacum et al. 2008), but the mean derelict trap densities in Tangier were the second lowest of all survey strata. Lower densities of derelict traps occurred in this area because it is located far from the high density population centers of the Chesapeake Bay where the majority of boat traffic would occur. In addition, Tangier Sound is a large shallow water body with well defined channels for navigation. Mariners are likely to adhere to navigational channels more readily in an unfamiliar area, keeping them away from the majority of fishing effort which occurs over the expansive shallow areas adjacent to well known channels and thereby reducing the probability that a vessel would encounter the buoys of crab traps. Based on the spatial patterns of derelict crab traps observed in this study, we conclude that the severing of buoy lines by vessel traffic contributes to the abundance of derelict traps in the Maryland Chesapeake Bay.

In the simulation study, both blue crabs and other non-target species were captured and exhibited high amounts of mortality throughout the study time frame. Little to no escapement was documented for all species identified in experimental traps. Of the non-target species, white perch exhibited the highest catch rate and the highest mortality. White perch was also the largest part of the catch in derelict traps retrieved during all ground-truthing surveys. This species is among the most important recreational and commercial fishes in the Chesapeake Bay, especially in Maryland (MDNR 2004). The combined results of the simulation study and ground-truthing surveys indicate that white perch are highly susceptible to being captured and killed by derelict traps in the Maryland portion of Chesapeake Bay. However, the catch of white perch in derelict traps probably only represents a small fraction of the total population of white perch in the Bay.

Blue crabs recruited into experimental traps at a mean rate of 21 crabs/trap/year and were also present inside derelict traps that were collected during ground-truthing surveys. High catch rates between May and September, particularly in deeper waters (5-10 m), are consistent with the seasonal population dynamics for this species in the upper Bay. Mortality was estimated to occur at a rate of 20 crabs/trap/year. Mortality was particularly high in the summer, in deeper depths, at low dissolved oxygen levels, and in high salinity areas. Blue crabs are more abundant and active in summer than any other season of the year (Hines 2007,), and because of this they have a greater probability of encountering and entering a derelict trap. Temperature is higher and dissolved oxygen is lower in summer which is likely the source of most of the mortality of blue crabs captured in derelict traps. Although specific causes of mortality were not examined, death could have also been caused by numerous other factors inside the traps including starvation, cannibalism, over-crowding stress, injury, and predation, (Guillory 1993, Guillory 2001, Breen 1990). High rates of mortality were also observed in spring and fall when male and female crabs entered traps to molt and were devoured by their conspecifics.

Derelict traps can continue to capture target and non-target species long after the initial bait of the trap is gone, in a process known as self-baiting. In the simulation study, the highest catch rates were observed when traps were initially baited, but both catch and species mortality continued to occur after the bait was gone. The carcasses of dead organisms attract other individuals to enter the trap which eventually die, continuing the cycle of self-baiting. Similar patterns have been observed in other trap experiments involving blue crabs in Louisiana (Guillory 1993) and Chesapeake Bay (Havens et al. 2008), and in trap studies of red king crab (Pecci et al. 1978) and Dungeness crabs (Breen 1987). Self baiting was also evident in traps retrieved during ground-truthing surveys when it was observed that the majority of traps containing organisms during retrievals did not contain bait.

The negative effects of an individual derelict trap can last long after it becomes derelict. In the simulation study, we found that all traps from the initial deployment that were not lost or vandalized during the study were still catching blue crabs and by-catch until the day the study was terminated (14 months). This result is similar to that found in other studies designed to determine the lifespan of derelict traps of differing materials. Shively (1997) found the life expectancy of vinyl-coated traps could be up to 2 years depending on salinity. In addition, several traps left in the lower Chesapeake Bay have remained intact for several years (Kirk Havens, personal communication). Undoubtedly, the negative effects of derelict traps can last for years after a trap is lost from the fishery.

We estimate that nearly 85,000 derelict traps could be ghost fishing in the Maryland portion of Chesapeake Bay and that on average 20 blue crabs could be killed each year in a single trap. Taken together this suggests that just over 1.6 million crabs are killed annually by derelict crab traps in the Maryland portion of Chesapeake Bay. This represents less than 1% of the total blue crab population estimated in 2007. However, Chesapeake Bay blue crab population estimates include many size classes that are not susceptible to the effects of derelict traps. By design, derelict blue crab traps capture and kill larger crabs of harvestable size and juveniles to a lesser extent. Approximately 79% (15 crabs/trap/year) of all crabs killed in the simulation study were of harvestable size (>133 mm/5.25 in). Crab weight (grams and lbs.) was calculated from a weight-length model (Newcomb et al. 1949) using known lengths in order to compare crab loss due to derelict traps with that due to the fishery in 2007. Harvestable crabs were grouped into 10 mm length classes and the total weight of all crabs within a group was calculated and summed up for all harvestable crabs killed in the simulation study. Based on this, a total of 285,000 kg or nearly 628,000 lbs of harvestable blue crabs are killed in derelict traps each year in the Maryland portion of Chesapeake Bay. This represents 4% of the entire catch of blue crabs in the Maryland trap fishery in 2007 (Slacum et al. 2008) which may equate to a large amount of lost revenue for the crabbing industry.

The results of this study indicate that ghost fishing by derelict traps is widespread and a measurable source of unaccounted fishing mortality for the blue crab. The blue crab trap fishery is one of the largest and most wide spread fisheries in Chesapeake Bay and based on the spatial distribution and densities of derelict traps documented in this study it is clear that trap losses are an unavoidable consequence of the fishery. This could have serious implications because the fishery occurs within a wide range of habitats in the Bay. The fact that the highest densities of derelict traps occur adjacent to river mouths and in shallow depths is also cause for concern because of the proximity of these areas to adjacent importance habitats of the blue crab. In Chesapeake Bay, newly recruited juveniles use a variety of micro-habitats such as sea grass beds, salt-marsh fringes, and coarse woody debris structure to forage, avoid predation, and to grow to maturity (Hines 2007). Many of these habitat types occur in and around the rivers of the upper Chesapeake Bay. Posey et al. (2005) found that lower salinity areas, such as rivers, are important habitats for juvenile blue crab in river dominated estuaries of the southeast United States. These areas are important nursery areas and are used by blue crabs to avoid predation and increase growth (Posey et al. 2005). Once juvenile blue crabs mature to adults they move out of the nursery areas and into other habitats of an estuary to forage and mate. Blue crabs moving out of rivers are restricted to using the river mouths as corridors to other habitats. Because the highest densities of derelict traps tend to occur close to some river mouths it is likely that crabs moving out of rivers will encounter high densities of derelict traps.

Female blue crabs could also be more susceptible to derelict traps for similar reasons. Mature female blue crabs begin to migrate to the lower Chesapeake Bay between September and November (Hines et al 2008, Aguilar et al 2005). While female are distributed throughout the Bay when the migration begins, a good portion of the population will be moving out of the rivers and through the river mouths to begin their migration. They would also encounter high densities of derelict traps while moving through the river mouths. River mouths represent an important migratory corridor for adult male and female blue crabs and it's possible that the effects of derelict traps are worse in these areas because of the large numbers of crabs encountering derelict traps as the move through this corridor. There could be population level effects if the majority of the blue crabs captured in these areas are mature females or newly mature adults moving out into the estuary. However, this would need to be investigated directly.

These results also have implications for research and monitoring of derelict traps. In a similar study, Havens et al. (2008) surveyed the York and found derelict traps occurred in high densities in several areas. That survey demonstrated the value of using side-scan sonar to detect derelict crab traps and exposed the potential for certain areas of the Bay to contain high densities of derelict traps; however that survey was conducted in only one area of the Bay which limits the inferences of those data Bay wide. To manage derelict traps effectively throughout the Bay, it is necessary to have an understanding of the spatial patterns and densities of derelict crab traps. Our survey was stratified based on known fishing effort and our results indicate that derelict traps are somewhat related to the amount of fishing effort that occurs in an area. This has implications for both monitoring and the management of derelict crab traps in the Bay. These data represent baseline conditions that can be used as benchmark for future assessments or to track the effectiveness of any management measures or changes in fishing practices designed to reduce the number traps from becoming derelict in the Bay. These data can also be used to design surveys for further monitoring of derelict traps in specific environments or for other mitigation techniques such as trap retrieval efforts.

There are currently no management regulations in place to reduce ghost fishing by derelict traps in the Maryland portion of Chesapeake Bay. Because of the spatial extent of the fishery and the number of variables responsible for the densities of derelict traps, it is unlikely that any management option will completely prevent crab traps from becoming derelict in the Bay on an annual basis. However, there are options to reduce the effects and potentially reduce the numbers of derelict traps in the Bay. These include modifications to the traps to aid in escapement of organisms, developing management strategies to reduce crab trap losses, and retrieving traps once they become derelict.

The use of cull rings and biodegradable escape vents is one way to lessen the effects of ghost fishing by derelict traps. Cull rings are only effective at allowing small crabs and fish to escape a derelict trap and so would not completely alleviate the effects of derelict traps. In

Maryland cull rings are merely required to be present on crab traps but they do not have to be functional. If a trap with non-functioning cull rings becomes derelict, then any organism that cannot escape through the trap mesh has the potential to be killed. In the simulation study, we found that traps with open cull rings had fewer sub-legal crabs on average indicating that smaller crabs had the ability to escape the traps. Even though it is more important to conserve larger, more reproductively viable adults of any species, requiring functioning cull rings on all traps would at least allow some crabs and fish to escape.

The use of biodegradable material or panels to create escape routes for trapped organisms in derelict traps is not a novel concept. Escape panels are a requirement on traps in many lobster fisheries. In Florida, the spiny lobster fishery has had a requirement for degradable escape panels since 1982 (Matthews and Donahue 1996). Requiring escape panels on all blue crab traps would reduce the mortality of blue crabs and other non-target species when the panel degrades and opens. However, because of the spatial and temporal nature of the fishery it is unlikely that one type of biodegradable material will work on all traps. Research should be conducted in collaboration with the commercial industry to identify and develop an escape panel that will be acceptable and used in the fishery.

Another way to reduce the effects of ghost fishing by derelict traps is to reduce the number of derelict traps in the environment. This could be done by developing management strategies designed to curb trap loss and or by developing programs to retrieve derelict traps from the Bay bottom. Changes in fishing practices or regulations to reduce derelict traps are viewed as long-term options, but management strategies should also include shorter-term goals such as educating user groups on the effects of derelict traps. Although the current study did not measure the numbers of traps lost from the fishery each year, several researchers have suggested that losses could be as high as 30% per fisher per year (Casey 1994, Guillory et al. 2001, Havens 2008). In Maryland, this could mean that in total close to 100,000 new traps become derelict each year. One of the main sources of derelict traps is severed buoy lines by vessel propellers. Because areas of high density vessel traffic correspond closely with productive fishing grounds (Slacum et al. 2008), it is unlikely that the numbers of derelict traps in the environment will be reduced without a significant change in behavior by all users of the Bay. Education of and outreach to commercial fishers and the recreational boating community on the effects of derelict traps should be a high priority for any management strategy.

There are several examples of state sponsored volunteer derelict trap retrieval programs that operate during the off-season or during a special closed season. These programs are designed to remove abandoned traps that are easily retrieved or still have buoys attached. Most of the programs rely heavily on support from the general public and participants in the fishery. Volunteers are recruited through public awareness campaigns that educate the public on the effects of derelict traps. This proactive approach has been successful at removing thousand s of traps in the states of Texas, Mississippi, North Carolina, South Carolina, Louisiana, and Georgia (Guillory et al. 2001). Programs such as these could be used as models to promote awareness of the effects of derelict traps in the Maryland Bay.

Longer term management options include changing fishing practices and implementing new regulations to reduce crab trap losses in the fishery. Derelict traps are an unavoidable consequence of the fishery with the highest densities occurring in areas of heavy boat traffic. One solution to reduce trap loss in these areas would be to separate the fishery from boating activity. In some ways this is already in place with designated float-free channels where crab trap buoys are prohibited and vessels are supposed to navigate within the channel. This regulation certainly reduces the amount of derelict traps in the channels, because the commercial industry complies with the regulation. However, in many areas the channels are not used by all vessels (H. Ward Slacum personal observation) because it is not convenient to do so. Because the float-free channels are also located in preferred fishing areas, the densities of actively fishing traps adjacent to the channels can be extremely high. This makes navigation in those areas difficult and avoiding crab trap buoys nearly impossible. Because of this the numbers of derelict traps are much higher in these areas.

Another solution would be to restrict the fishery from these areas altogether. However, this is not practical because most of these areas have been proven to be productive fishing grounds. A more practical solution would be to work with the industry to identify areas where trap losses are the greatest and then develop strategies to reduce losses through modified fishing practices. One potential modification currently being used in Maryland is fishing multiple traps on a submerged line that only has two buoy ends. This gear is not widely used throughout the fishery and currently represents around 3% of the total fishing effort (Slacum et al. 2008). This gear has several advantages over single-buoyed traps when it comes to reducing derelict traps. First, there is a reduction in the number of buoys present in the system when this gear is deployed in certain areas. Fishers can deploy up to 35 traps on a line and the length of the lines can be up to 1,200 m (Slacum et al. 2008). The reduction in buoys opens up more area for vessel navigation. Secondly, fishers are required to distinguish this gear from single-buoyed traps by marking the ends with flags. This generally requires a piece of PVC through a buoy with a flag attached which greatly enhances the visibility and size of the buoys and would discourage boaters from nearing the buoy. One disadvantage of this gear is that multiple traps could become derelict as a result of the severing of a single submerged line.

Education and management regulations are viewed as long term strategies to reduce the numbers of derelict traps in the environment. One effective short-term management option is the development of a targeted derelict trap retrieval program. Our results show that high densities of derelict traps occur in areas near river mouths and in the shallow areas where the fishery is dominant. This information could be used to develop and guide an efficient derelict trap retrieval program. In addition, results from ground-truthing proved that grapples and other similar devices can be used effectively to retrieve traps in an efficient manner from small research vessels. A targeted derelict trap retrieval program would have the advantage of observable short term results that could be evaluated immediately. Retrieval efforts can also be used as a means of integrating users from the fishery into a management strategy which is not only ecologically beneficial, but also serves as an educational bridge between industry and management. Fishers are ideally suited for such a project because they possess intimate knowledge of both the Bay and the crab fishery and they also have ready access to necessary fishing gears for retrieval. Retrieval efforts should only be conducted in a targeted manner in coordination with researchers and management so that any potential negative effects on the environment from retrieval activities could be avoided (See Slacum and Giordano 2008).

In summary, we used a combination of methods and techniques to quantify the overall effects of derelict crab traps in the Maryland portion of Chesapeake Bay. The management options and mitigation measures based on our findings represent just a few approaches to reduce the effects of derelict crab in the Maryland portion of Chesapeake Bay. We recommend that scientists and managers work with industry to determine the best combination of approaches to reduce the loss of crab traps in the Maryland portion of Chesapeake Bay. Based on three years of research we conclude that:

- There are an estimated 84,567 ± 6,801SE derelict crab traps where the commercial hard crab trap fishery occurs in the Maryland portion of Chesapeake Bay.
- Blue crab mortality in derelict traps is 20 crabs/trap/year.
- Given the number of traps and the rate of mortality, blue crab loss in derelict traps equates to 4% of the annual catch in Maryland.
- Vessel traffic is a major contributor to the abundance of derelict traps.
- Areas of high fishing effort contain high densities of derelict traps.
- White perch are highly susceptible to being captured and killed by derelict traps in the Maryland portion of Chesapeake Bay.
- Derelict traps are self baiting and can continue to capture and kill blue crabs and other by-catch for at least 14 months.
- Poor environmental conditions (i.e., low dissolved $O_2$) and predation contributes to the mortality of entrapped crabs.
- Fouling of derelict traps is seasonal and does not affect catch rates or species composition of catch.
- Functional cull rings allow crabs, particularly smaller individuals, to escape.

Based on these conclusions, the following educational outreach, research and management recommendations are given to reduce the effects of derelict traps on blue crab and other by-catch in the Maryland portion of Chesapeake Bay:

Education & Outreach

- Educate the general public, commercial fishers and recreational boaters on the negative impacts that derelict traps have on crabs and other species.
- Convey to the boating community how vessel activity contributes to the loss of crab traps and ultimately crab mortality.
- Educate fishers on the differences between derelict traps with functional and non-functional cull rings to entice fishers to voluntarily use functional cull rings.

Management

- Enforce navigational rules that curb vessel traffic outside of float-free channels.
- Require functional cull rings on all traps.
- Promote submerged line gear as an alternative to single-buoyed gear.
- Reduce the number of derelict traps in the Maryland portion of Chesapeake Bay.

Cooperative Research

- Identify locations of high gear loss in cooperation with the crabbing industry and determine the causes of loss.
- Investigate practical approaches to reduce trap loss that can be implemented by crabbers.
- Develop an effective biodegradable escape panel in Chesapeake Bay crab traps.
- Conduct limited derelict trap retrieval surveys in areas of high derelict trap densities.

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# APPENDIX A

## DERELICT TRAP DETECTION

## ACCURACY ASSESSMENT METHODOLOGY

## Accuracy Assessment Rationale

Information on the signatures of other types of debris is lacking in the Chesapeake. The purpose of this assessment was to evaluate our accuracy at identifying traps in order to maximize this accuracy and prevent confusion with other debris. We expected reviewers to commit the two most common types of classification error: (1) identifying something as a trap when it was not a trap (commission), and (2) failing to identify a trap when a trap is present (omission). An understanding of the amount of commission and omission error exhibited by each reviewer is essential to estimating the number of derelict traps in the Bay using side-scan sonar transect imagery.

The most straightforward approach to quantify classification error is to conduct an accuracy assessment. Assessments require: (1) unbiased and consistent sampling procedures, and (2) rigorous analysis of the sample data (Congalton and Green 1999). One method of accuracy assessment involves creating an error matrix in which reviewer classifications are compared to known information. In our case, this would have been done by instructing reviewers to analyze a test data set containing both traps and other debris and having them make judgment calls on all signatures in the imagery, i.e. trap or non-trap. However, this was not feasible for our survey because of the logistical limitations associated with deploying and retrieving multiple types of debris in the environment. Collecting unbiased and accurate representations of that debris with side-scan sonar imagery would have presented an additional challenge. Instead, we implemented a more practical approach that incorporated a set of side-scan sonar transect images (i.e., mock transects) with known derelict traps into the final data. These transects served as controls allowing us to compare the accuracy of each reviewer at identifying known derelict traps.

## Mock Transects

The mock transects were created by placing a string of known traps in two areas that differed in bottom depth and then conducting a series of side-scan sonar transects in various directions relative to the trap strings. Each individual transect included the entire string of traps or a subset of the string depending upon the direction of the transect and its orientation to the test string. Sonar data acquisition and processing were conducted following the same methods and settings used in the transect survey. A total of five mock transects from each depth (n=10 transects) was created to serve as controls for the transect survey review and analysis.

The sonar images from the mock transects were placed randomly within the final set of images collected during the side-scan sonar transect survey so that the reviewers assumed the mock transects were part of the survey data. In order to eliminate any bias toward the mock transects, the software settings precluded the reviewers from knowing the geographic location of the transects as they were reviewed. Each reviewer followed the review criteria developed for the overall review and identified derelict traps in the sonar imagery for all transects in the entire data set.

The mock transects included in the final data set served to establish reviewer accuracy at identifying known derelict traps. The ability of each reviewer to identify traps correctly was compared for individual mock transects to quantify how often the reviewers agreed or disagreed on known traps. The analysis of reviewers' accuracy at identifying known traps in the mock transects and the correspondence of identifying derelict traps between reviewers within the entire data set, was used to develop the final estimate of the total number of derelict traps per transect. Based on these analysis, the sum of the two reviewers individual counts ($R_1$+$R_2$) minus the number of traps that they both agreed upon (A) or $R_1$+$R_2$-A (RRA) was used for the final derelict trap count per transect. Assuming that these three non-overlapping numbers did not include non-traps, the RRA is the minimum estimate of the total number of traps in each transect. It is a minimum because, in using criteria that reject all non-traps, both reviewers were bound to reject some legitimate traps as well. The 84,567 derelict traps estimated to occur in the Bay is based on the RRA minimum estimate.

**Sources of Classification Error and Rational for Using RRA**

During the side-scan sonar transect review each reviewer frequently reported derelict traps that the other did not. This is a normal result in human interpretation of complex imagery (Congalton and Green 1999). Quantifying the magnitude of the disagreements is an important step in establishing the likely error in the estimates. The unidentified mock transects serve to establish the reviewer accuracy in identifying known targets and to quantify how often the reviewers agree or disagree. Each reviewer successfully identified about three of four known traps in the mock transect imagery (accuracies of 0.75 and 0.725 correct) FIGUR FROM LISA. However, their identifications were highly correlated, so that when taken together (i.e. using the RRA sum defined above), they only identified 80% of the known traps. Thus, if the mock transect data exactly mirrored the actual mock transect conditions, the estimate of 84,567 derelict traps (See Section 3.3. of the report) would be an underestimate by 20%.

Conversely, any non-traps that were included in the reviewers' counts would increase the estimate. Non-traps may be present when there are unusually high disagreements between the reviewers compared to the mock transect data. Disagreements in reviews of mock transects between reviewers (in which one reviewer reported a derelict trap location and the other did not) were only a small fraction (0.16) of the review and they were about equally split between the two reviewers (Possibly FIGURE FROM LISA). While this expected pattern was observed in some of the actual transects, some individual transect reviews were widely different (Table A-1).

Table A-1. Analysis of Reviewer Disagreements

| Transect | RRA* | Disagree-ments | Disagree-ment Rate | Expected Disagree-ments | Excess Disagree-ments (Overcount) | Estimated Uncounted | Net Error |
|---|---|---|---|---|---|---|---|
| **Mock Transect Reviews** | | | | | | | |
| Mock | 32 | 5 | 0.16 | 5 | 0 | -8 | -8 |
| **Highest Disagreement Error in Transect Reviews** | | | | | | | |
| 027-L | 26 | 26 | 1.00 | 4 | 22 | -6 | +16 |
| 029-L | 11 | 11 | 1.00 | 2 | 9 | -3 | +6 |
| 025-H | 10 | 10 | 1.00 | 2 | 8 | -2 | +6 |
| **Moderate Disagreement Error in Transect Reviews** | | | | | | | |
| 025-H | 39 | 25 | 0.64 | 6 | 19 | -10 | +9 |
| 025-L | 51 | 27 | 0.53 | 8 | 19 | -13 | +6 |
| 027-M | 31 | 18 | 0.58 | 5 | 13 | -8 | +5 |
| 027-H | 26 | 14 | 0.53 | 4 | 10 | -6 | +4 |
| 092-H | 23 | 12 | 0.52 | 4 | 8 | -6 | +2 |
| **Nominal Disagreement Error in Transect Reviews** | | | | | | | |
| 027-M | 25 | 10 | 0.40 | 4 | 6 | -6 | 0 |
| 027-M | 30 | 10 | 0.33 | 5 | 5 | -8 | -3 |
| 072-H | 22 | 7 | 0.32 | 3 | 4 | -6 | -2 |
| 027-L | 20 | 6 | 0.30 | 3 | 3 | -5 | -2 |

***** RRA is the minimum estimate of the total number of traps in a transects and is based on the sum of the two reviewers individual counts ($R_1$+$R_2$) minus the number of traps that they both agreed (A) upon or $R_1+R_2-A$.

The first group of three transects in Table A-1 are those that had no agreements between the reviewers, yet relatively large numbers of contact locations (i.e., signatures in the sonar imagery recorded by the reviewers as traps) (between 10 and 26) were reported. According to the mock transect data, when both reviewers looked at a signature generated by a derelict trap, they agreed that it was a trap 67.5% of the time. The probability of 10 or more successive random disagreements about derelict traps is so small (i.e., $(0.325)^{10}$, or about 1 in 100,000 times) that we concluded that for these transects, either the reviewers were not looking at signals from the same locations or they applied distinctly different classification criteria. The data from these transects were regarded as suspect and therefore were not included in the analyses. Upon further analysis, we found that at least one of these transects occurred in a fish haven which are areas where fishers have historically dumped debris to enhance fish productivity.

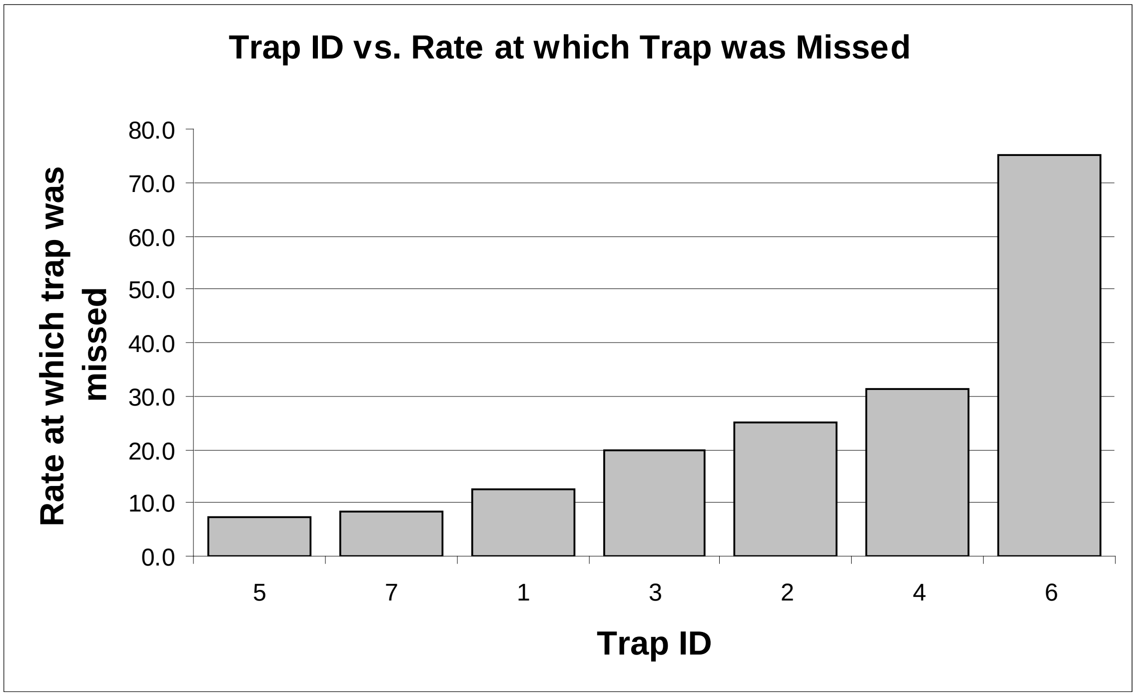


Figure A-1. Figure showing the individual known traps in mock transects and the rate at which the trap was missed by both reviewers combined.

It is likely that different types of errors were reflected in the second set of four transects in Table A-1. With rates of disagreement around 0.5, each reviewer generally agreed with the other on the majority of the contact locations he reported. Although they looked at the same locations and applied similar classification criteria, the total number of disagreements was larger than expected on the basis of the mock transect data. Since each reviewer was contributing to the excess disagreements in these examples (there was no one-sided bias), it is possible that there was a large number of non-trap signals in the images. Even occasional random misidentification of these non-traps as traps would lead to an increase in disagreements for both reviewers, inflating the RRA. For this set of transects, the estimated overcount represented by excess disagreements was greater than the estimated undercount that results from true derelict traps that both reviewers rejected. The net errors indicated that RRA could be 10-20% too high for this class of transects.

The third set of four transects shows examples, in the same range of RRA values, that were reasonably similar to the mock transects. The excess disagreements likely represent normal chance variation in detecting true traps, although any particular contact location among the disagreements might have been due to one of the factors mentioned above. For this class of transects, the net error was slightly negative, indicating that RRA could be about 10% too low.

**Accuracy Assessment Discussion and Final Conclusions**

Based on the mock transect data, both false negative and false positive errors were expected to affect the RRA estimate of the true number of derelict traps. These errors were of the same order of magnitude, and therefore tended to cancel, leading to small net overestimates for some transects and small net underestimates for others. Table A-1 illustrates the worst cases; RRA estimates for over half of the transects were in the range 0-5 traps, and the net errors were more on the order of no more than +/- 1 trap. Therefore, stratum averages of derelict trap densities based on the RRA values for the transects within them are expected to be accurate.

# APPENDIX B

## VIRGINIA DERLICT FISHING GEAR SURVEY DESIGN

## Introduction

During the winter of 2007 the NCBO Derelict Fishing Gear Program (DFGP) conducted a side-scan sonar survey in the Maryland portion of Chesapeake Bay to quantify the number of derelict traps residing on the Bay bottom. The survey was conducted using a transect survey design and the data collected and analyzed from the survey indicated the presence of over 40,000 derelict traps. To determine an overall estimate of trap densities Bay-wide a survey must be conducted in the Virginia portion of Chesapeake Bay. To assist with this effort, Versar has identified the Center for Coastal Resources Management (CCRM) at the Virginia Institute of Marine Science (VIMS) as having the necessary equipment and expertise to conduct the survey. CCRM is located on the York River, which is central to where the overall survey will be performed. CCRM has several research vessels and the side-scan sonar equipment necessary to collect the sonar imagery needed for proper data analysis. CCRM has been a collaborator with the DFGP from the onset of the project and has extensive experience conducting similar surveys using side-scan sonar. Under this scope of work, CCRM will follow a similar transect survey design as the Maryland survey (Slacum et al. 2007), and will work with the DFGP to develop the analysis methodology and finalize deliverables over the course of the contract period (See deliverable section below for specifics). The period of performance under this contract is from March 17$^{th}$, 2008 to December 31, 2008.

## Survey Design

Transect sampling sites will be chosen using a stratified random sampling design. In Maryland, sampling strata were generated from the Maryland Department of Natural Resources (MDDNR) commercial crabbing effort survey data collected from 2002 to 2004. Those data were derived from monthly (April- November) field surveys during which six-minute boat transects were performed at random sites to count crab buoys for fishing effort determination. That survey was conducted at varying depths within known fishing areas throughout the Maryland portion of the Bay. The effort data derived from this survey are reported as fishing effort by NOAA code region within the MD portion of the Bay. Although there is no similar survey data in Virginia, there is monthly effort data reported by fisherman working in Virginia waters during the commercial season. Because fishing effort in Virginia occurs in shallower depths than fishing in Maryland, overall survey strata boundaries were created from depths between 2 and 5 meters rather than between 2 and 10 meters like the Maryland survey strata. The magnitude of trips within a month was used as a proxy for overall effort within a reported area (Table B-1).

Following the survey design used for the Maryland survey , fishing effort by area was selected based on 2006 reporting data from the Virginia Marine Fisheries Commission (Rob O'Reilly personal communication). Based on lessons learned from the Maryland survey, two substrata were partitioned within each reporting area. These are areas of potential high and low derelict gear loss. Areas designated as high loss are areas that corresponded to high boat traffic such as areas near river mouths and near the entrances to marinas. Low areas are designated as all other strata area. The boundaries (contours) of these two density classes were then delineated and individual polygons were created for random site selection. Random samples were then generated within these substrata.

The number of transects to be conducted in this survey will be approximately 300. The number of transects sites allocated to a particular strata was determined using two steps. In the first step, a proportion of transect samples were allocated within each Virginia reporting code based on the percentage of overall effort (as determined by overall seasonal trips, Table B-1) reported in 2006 for that reporting code. In VA, there are a total of 13 reporting codes applicable to this survey (Figure B-1). In the second step, the total number of samples were allocated within each code, into the high and low substratum. This was done in proportion to the size of each substrata located within each code.

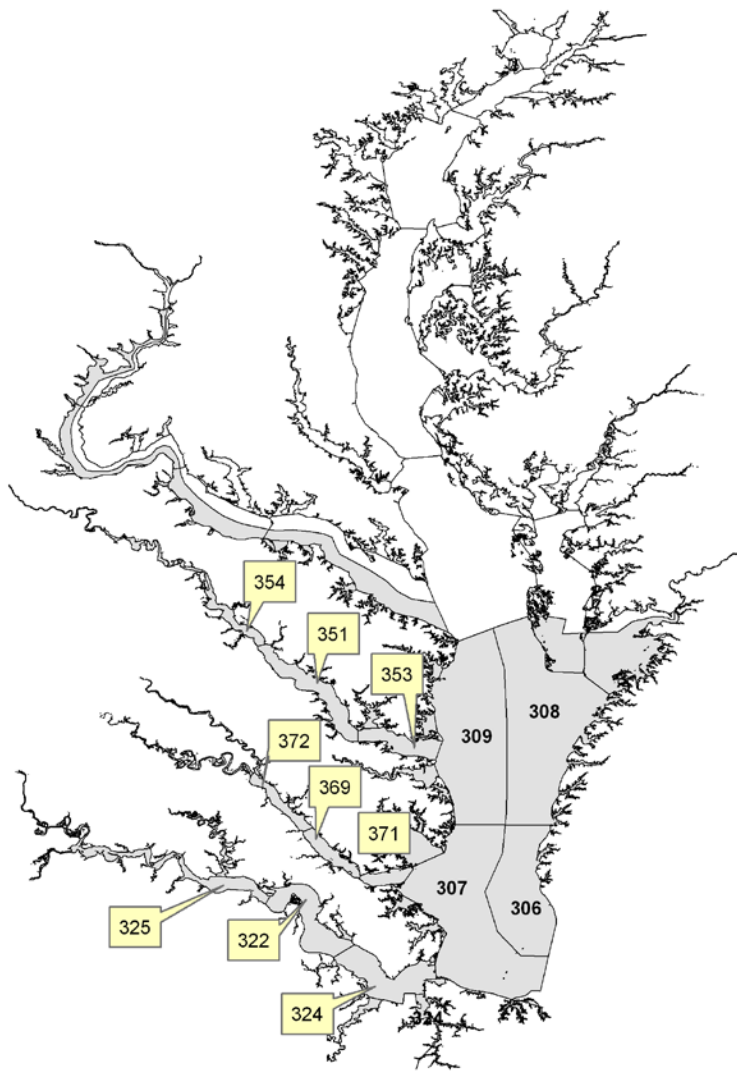


Figure B-1. Map showing Chesapeake Bay with relevant Virginia commercial harvesting reporting codes. Codes include 306, 307, 308, 309, 324, 322, 325, 369, 371, 372, 353, 352, 354.

Table B-1. Average yearly commercial crabbing trips taken in each reporting code during the 2006 season. Data from VMRC.

| Reporting Code | Water Body Name | Average Yearly Trips |
|---|---|---|
| 306 | CHESAPEAKE BAY (LOWER-EAST) | 298 |
| 307 | CHESAPEAKE BAY (LOWER-WEST) | 409 |
| 308 | CHESAPEAKE BAY (UPPER-EAST) | 198 |
| 309 | CHESAPEAKE BAY (UPPER-WEST) | 262 |
| 322 | JAMES RIVER (CENTRAL) | 86 |
| 324 | JAMES RIVER (LOWER) | 270 |
| 325 | JAMES RIVER (UPPER) | 34 |
| 352 | RAPPAHANNOCK RIVER (GENERAL) | 108 |
| 353 | RAPPAHANNOCK RIVER (LOWER) | 166 |
| 354 | RAPPAHANNOCK RIVER (UPPER) | 27 |
| 369 | YORK RIVER (CENTRAL) | 82 |
| 371 | YORK RIVER (LOWER) | 78 |
| 372 | YORK RIVER (UPPER) | 103 |

## Field Survey Methods

Side-scan sonar transects will be carried out using methods nearly identical to the Maryland survey field protocol, summarized here. Transects will be conducted at each randomly generated sample site by navigating to the latitude and longitude of each point. Once the field crew is on station, the heading or direction of each transect will be selected. To avoid bias, headings will be chosen by rolling a 12 sided die or by using the random number generator in Excel, so that each number between 1 and 12 multiplied by 30 represents a direction on the compass. For example, if a two is rolled then the boat will conduct the transect following a heading of 60 degrees. Care should be taken to stay within a sub-strata when a transect is conducted. Therefore if an initial heading is determined to take you immediately out of substrata, then an alternate heading should be chosen until one is acceptable. The overall goal of this survey is to collect good quality sonar data while keeping an unbiased approach. However, there are many factors and field conditions that will dictate where and at what direction a transect will be performed. This process is adaptive and should be as parsimonious as possible, therefore we should use the transect direction and locations as guides to help reduce the bias in this survey and if things need to be changed because of certain conditions or circumstances in the field, then it just needs to be fully documented.

In the case where a sample point cannot be navigated to because of depth or other reasons, a new sampling point can be generated. New sampling points should be moved to an area that can be surveyed within the same substrata and as close to the old point as possible. When this situation occurs, reasons for the movement should be documented in the daily survey log file.

Transects will be conducted for six minutes at approximately 3-5 knots, which will likely correspond average transect lengths of ~ 700 to 1200 m. One change from the Maryland survey is the range setting of the sonar swath. The range will be set to 20 m for the survey, and depending on depth, the sonar towfish height above the seabed should be set to a height so that the best quality imagery can be collected at this range scale, 8-20% of the range. Sonar imagery shall only be acquired from the beginning to the end of a trans ect. All longitude and latitude position data shall also be time-stamped and recorded in the sonar file.

The latitude and longitude of all randomly generated sampling points will be provided by Versar and will be in WGS 84 datum. These data will be in an excel spreadsheet and each sampling point will be identified by a unique sample ID that corresponds to the reporting code and strata where the sample occurs. For example, sampling point number 14 occurring in the low substrata in area 308, will have a sample ID of 308L-14. Each of the sonar data files should be documented by this sample ID.

**Image Analysis**

Side scan sonar transects will be reviewed on a desktop computer to enumerate suspected intact derelict traps in the imagery. The Maryland survey used two independent reviewers to conduct the analysis. To differentiate derelict traps from other debris seen in the imagery a set of criteria was developed. These criteria were derived from ground-truthing efforts and in-situ experiments. The Maryland survey used a series of known traps to create a side scan sonar image catalogue which was then used as a reference for trap identification. Traps in that survey had to meet the following criteria to be considered a derelict trap:

- It looks like an intact crab trap target documented in the image catalog.
- It is square in shape (and may have an acoustic shadow distal to the nadir).
- The side dimensions are on the order of 1m or less.

In order to properly determine an overall estimate for likely intact derelict traps in Virginia waters, the error associated with the transect survey (i.e. standard error of the mean) and the trap detection errors need to be determined. Both types of error shall be evaluated and incorporated into the overall Virginia derelict trap estimate. There are several types of error associated with image analysis. For this survey there are two major types of classification error: (1) identifying other debris as a trap, and (2) identifying traps as other debris and not documenting or counting them. One method to classify error would be to use ground-truthing as a way of verifying trap identification from the imagery. A straight forward and usable method will be designed and accepted prior to image analysis.

**References**

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