Phase II Evaluation of Waste Concrete Road Materials for Use in Oyster Aquaculture-Field Test

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Phase II Evaluation of Waste Concrete Road Materials for Use in Oyster Aquaculture – Field Test

Final report

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16. Abstract

The overall objective of this study was to determine the suitability of recycled concrete aggregate (RCA) from road projects as bottom conditioning material for on-bottom oyster aquaculture in the Chesapeake Bay. During this Phase of the study, the research team placed RCA on test plots in the Chesapeake Bay to evaluate the impact on the benthic community. Miniature oyster reefs were also built to determine potential impacts or disruptions of RCA on the use of traditional harvesting gear. The results of this project showed that 1.) There was no significant difference between substrate type (RCA, oyster shell) on benthic community structure, oyster recruitment, and the abundance and size distribution of key faunal species, demonstrating that RCA, as an alternative material, was generally similar to natural oyster shell with regard to ecosystem services provided, and 2.) RCA makes a suitable substrate for supporting oysters for aquaculture operations but would require a veneer of old shell to be placed on top so as not to introduce additional weight to the catch when using shaft tongs.

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EXECUTIVE SUMMARY

In order to restore oyster populations, it is necessary to condition the bottom with a hard substrate. Oyster shells, which have historically been used for this purpose, have become increasingly scarce, resulting in the need for an alternative substrate. Recycled concrete aggregate (RCA) is created by crushing and milling old concrete pavement/road infrastructure. While concrete has long been used in aquatic systems, the source and size of this use is unique. For RCA to be used within the aquatic setting of the Chesapeake Bay, it is necessary to ensure that it does not have adverse impacts on oysters, or the Bay's aquatic ecosystem and is compatible with the traditional ways of oyster harvesting in the Chesapeake Bay. In Phase I of this project, the research team used laboratory experiments to determine the type and quantity of leachates from RCA and evaluated the impacts of RCA on the growth and survivorship of juvenile oysters.

The primary objective of this Phase II study was to determine the suitability of RCA from road projects as bottom conditioning material for on-bottom oyster aquaculture in the Chesapeake Bay. The testing was designed to:

- Evaluate the potential introduction of organisms attracted to the RCA pile in situ that may be potential predators of oyster spat.
- Determine potential impacts on or disruptions to the use of traditional harvesting gear on aquaculture areas conditioned with RCA.
- Identify regulatory or administrative structures that oversee the use of RCA and challenges within those structures.

Three substrates were tested for their effect on benthic communities: RCA, RCA with a veneer of oyster shells and oyster shells. There was no difference in population or community parameters among the three substrates. The number and type of species were the same among the substrates as were their absolute and relative abundances. Oyster spat settlement was the same among the three substrates as well. Waterman tonging on RCA found it heavier and more difficult to work than tonging on oyster shells. They recommended that RCA be used either with a veneer of oyster shells or in applications where tonging was not anticipated. Overall the findings support the use of RCA in select applications. However, the regulatory structures presently in place do not include a mechanism for the acceptance of a novel material. Moving forward with RCA or any new material requires an application for a reef project. The acceptance of the project is then a de facto acceptance of the material. Adopting a criteria for materials used in reef construction will provide agencies with a basis for supporting choices on materials used and the private sector with a basis to develop products to meet restoration and aquaculture needs.

INTRODUCTION

The SHA commits to maintaining at least 84% of its pavement network in “acceptable” overall pavement condition, and also intends to increase the use of recycled materials in an environmentally responsible manner. As roads and bridges are resurfaced, old concrete is removed and is usually placed on the roadside to serve as unpaved highway shoulders, or discarded. To support environmental initiatives, the SHA seeks to identify novel reuse applications, such as supporting oyster restoration or aquaculture projects in the Chesapeake Bay.

Native oyster populations in the Chesapeake Bay are at less than 1% of historic levels due to the two protozoan diseases (MSX disease caused by *Haplosporidium nelsoni* and Dermo disease caused by *Perkinsus marinus*), overharvesting, and pollution (CRC, 1999). This tremendous decline in the oyster populations has not only changed the Bay ecosystem but the oyster industry as well. Individual oysters filter 4 to 34 liters of water per hour, removing phytoplankton, sediments, pollutants, and microorganisms from the water column (CERP, 2007). Historic oyster populations of the Chesapeake Bay could filter excess nutrients from the estuary's entire water volume every three to four days; today that would take nearly a year with existing populations.

Spat-on-shell culture is the most ecologically friendly and traditional method of oyster restoration. In spat on shell, young oysters called spat are grown on oyster shells that are then planted on a reef. The reef requires the bottom, or floor, of the Bay to be built up and stabilized with a hard material. This process is known as bottom conditioning. Bottom conditioning provides the hard substrate required by the young oysters and prevents them from sinking into any soft muddy bottoms. Historically, old oyster shells were used for this purpose. However, the decline of the Chesapeake Bay's oyster industry has led to the scarcity of available oyster shells, rendering this practice impractical and requiring the investigation of alternative materials.

Recycled Concrete Aggregate (RCA) is created by crushing and milling old concrete from such sources as pavement/road infrastructure. The RCA is a material of convenience in that the source of the concrete is dependent on current demolish activities. The material is processed and sorted for reuse as base, sub-base, fill material for embankments, and in new concrete mix. For RCA to be used in the Chesapeake Bay, it must be assessed to determine whether it has any negative chemical impacts or unintentional consequences. Phase I of this study investigated the direct impact of RCA and found that RCA leachate remained orders of magnitude below regulatory levels and did not raise pH above the threshold for introduction in Maryland waters.

Variation in substrate characteristics such as topographic complexity or material type can result in difference in the value of the habitat. The difference in habitats can impact population parameters, such as growth and survival (e.g., ICES. 2012). Differences in the survival and growth of oysters between concrete and alternate substrates have been noted in a number of studies (Lunz 1958, O’Brien 2000). The Phase I study demonstrated that there is no impact on juvenile oyster growth or survivorship between RCA and oyster shell, Fig 1. Habitat characteristics can also affect species assemblage or community structure. For example, Davis et al. found that when compared to oyster shells, granite attracted different numbers and sizes of individuals, resulting in distinctly different communities. This study tested if there are significant differences in community assemblage between RCA and oyster shells.

In environmental management it is necessary to recognize the full array of interactions within an ecosystem, including humans. The restoration of oyster populations has social and economic aspects as well as ecological ones. Regionally, the oyster industry has successfully objected to various placements, materials, and methodologies of oyster restoration projects. Thus, this study also investigated the compatibility of RCA with the regional oyster industry.

STUDY OBJECTIVES

The primary objective of this three-phased study is to determine the suitability of RCA from road projects as bottom conditioning material for on-bottom oyster aquaculture in the Chesapeake Bay. In Phase 1 of this project, the type and quantity of compounds leached from RCA and the impacts of RCA on oyster survivability and growth were evaluated. This second phase placed RCA on test plots in the Chesapeake Bay to: 1) evaluate the potential introduction of organisms attracted to the RCA pile in situ that may be potential predators of oyster spat;2) determine potential impacts on or disruptions to the use of traditional harvesting gear on aquaculture areas conditioned with RCA; and 3) identify regulatory or administrative structures that oversee the use of RCA and challenges within those structures. If this phase continues to demonstrate no ecological or cultural problems with the use of RCA as a base for oyster aquaculture, the third phase of the project will be the use of RCA on a production scale plot on leased bottom.

LITERATURE REVIEW

Management

At the state and national levels there are guidelines for material used in in the construction of artificial reefs, however there are no criteria for the material to be used. The National Marine Fisheries Service developed the National Artificial Reef Plan (NARP) in 1985 and updated it in 2007. The NARP recommends the Guidelines for Marine Artificial Reef Material (GMARM) produced by The Gulf State Marine Fisheries Commission (GSMFC) in 1997 and updated in 2004 as a source of information on reef materials. The NARP includes the GMARM as an appendix. The GMARM provides a comprehensive guideline for artificial reefs including in-depth analysis of the attributes of common substrate options. The GMARM is cited by many sources on artificial reefs, including the Artificial Reef Management Plan for Maryland (ARMP). The Maryland Department of Natural Resources (MDDNR) adopted the ARMP in 2007 to provide guidance in the construction of artificial reefs. "*Specifically, it outlines criteria for program management and coordination, reef site selection, material selection and acquisition, funding, monitoring and evaluation requirements, and other aspects of artificial reef development.*" The ARMP is composed of three documents including GMARM.

Neither the NARP nor the GMARM provide criteria for the materials used. The stated purpose of the GMARM: *"is to provide a comprehensive discussion regarding a variety of materials that have been used in the development of marine and estuarine artificial reefs."* It does not discuss the selection of new material. The NARP states: *"Currently, no federal agency provides any form of certification of material against established environmental standards. This document does not explore this issue in detail. Executive agencies will interpret and clarify such roles under existing statutes."* The NARP does describe four criteria for the selection of reef material: function, compatibility, stability, and durability. The section defines the characteristics and their importance but gives no defined criteria. For example the section on durability states:

> *Artificial reef materials should be resistant to deterioration and breakup. Durable materials will retain the desired structure and configuration in the marine environment*.

While these help in developing criteria they are not in themselves criteria. Other comments on material are limited to general guidelines such as the need the need to carefully inspect material and ensure that they are "… environmentally safe and structurally and physically stable…."

In Maryland, the Maryland Department of Natural Resources' Artificial Reef Initiative produced the ARMP. However it is not the guiding document for other departments within the state or other divisions within the department. In the absence of a certification process, the use of materials for artificial reefs is approved on a per project basis. The project associated with the material must be approved, thereby giving approval to the material by default.

The placement of artificial reefs in marine and estuarine systems is overseen by a myriad of state and federal entities. Each entity is guided by its own and often overlapping enabling legislation. A total of nine federal agencies have regulatory authority over the placement of marine artificial reefs.

- U.S. Fish and Wildlife Service
- Minerals Management Service
- National Marine Fisheries Service
- Regional Fishery Management Councils
- National Ocean Services
- Office of Ocean and Coastal Resource Management
- U.S. Army Corps Of Engineers
- U.S. Coast Guard
- Environmental Protection Agency

In Maryland, artificial reefs construction is administered through the Maryland Department of the Environment except for those used in aquaculture, which are permitted through the Department of Natural Resources. There are nine state agencies with an impact on project approval.

- Department of Natural Resources
- Department of the Environment
- Department of Health
- Board of Public Works
- Department of Planning
- State Highway Administration
- Critical Area Commission
- Aquaculture Review Board
- Maryland Sport Fish Advisory Commission

The State of Maryland has two structures to mitigate the alphabet soup of approvals. The first is the Joint Federal/State Application for the Alteration of Any Floodplain, Waterway, Tidal or Nontidal Wetland in Maryland. This application provides a single point of entry for artificial reef construction. The second is the formation of two review boards that bring together many agencies at a single meeting to review applications. The two review boards are the Aquaculture Review Board and the Joint Evaluation meeting. The aquaculture review board focuses primarily on oyster aquaculture-related projects. The joint evaluation meetings are designed to provide a one-stop shop for reef projects. At the meeting the project is presented to members of the relevant agencies for review and comment.

Community structure

Community effects

There is well-documented literature on the effects of habitat characteristics on community structure (Eggleston et al. 1998) (Sebens 1991). Variation in substrate characteristics such as complexity or material type can result in differential habitat value (e.g., ICES. 2012). The resultant habitats can impact population parameters, such as growth, survival, recruitment and community structure (Eaton 1994) (Austin 1958). When species of shrimp from the same genra were given a choice of five different substrates, each species exhibited substrate-specific preference. In the Chesapeake Bay, Davis (Davis et al. 2006) compared the community composition of oyster shell and four other substrates: vegetation, woody debris, bare sediment, and granite riprap. They placed replicate mounds of each substrate in shallow subtidal waters. There were significant differences in ecological function among substrates "… vegetation served the greatest nursery function, oyster reef provided the greatest refuge for species like blue crabs, riprap hosted the greatest proportion of older life-history stages, and all four hosted different suites of species."

Oyster reefs provide habitats that play an important role in estuarine systems by supporting diverse communities of benthic organisms such as crabs, shrimp, mollusks, and fishes. As a keystone species, the presence of oysters can facilitate colonization, survival, and growth of a suite of other organisms (Bruno et al. 2003). This community of oyster reef-associated organisms can further serve as a food source and/or nursery site for numerous ecologically and commercially important aquatic species. As the ecological and economic importance of oyster reefs has become widely acknowledged, increased efforts have been made to create new oyster reef habitat through restoration efforts to counteract the loss of natural reefs. While some oyster restorations may be targeted specifically to increase oyster production for commercial purposes, the goal in most cases is to restore multiple ecosystem services associated with natural oyster reefs. Restored reefs can enhance habitat function and oyster populations (Coen et al. 1999, Rodney and Paynter 2006, Luckenbach et al. 2005, Weimin et al. 2012). As a result, oyster reef restoration has the potential to enhance populations of many species, including commercially and recreationally valuable fishes (Kennedy et al. 2011).

Reefs are traditionally constructed by placing oyster shell on the bottom. One common obstacle to these programs is a lack of oyster shell (MacKenzie 1989; Breitburg, et al. 2000). Various materials have been used as alternative substrate (Brodtmann 1991). These include clam shell (Nestlerode

2007), gypsum (Haywood and Soniat 1992), coal ash (O'Beirn et al. 2000), slate (Haven et al 1987), shale and tires (Mannet et al. 1990), and, most commonly, limestone (Chatry et al 1986, Lenihan and Grobowski 1998, Soniat et al. 1991, Lavergne and Diagne 2004, Ippolito 2010).

Comparison of the habitat value of artificial oyster reefs is hindered by a lack of standard methods and the breadth of motivations and entities creating the reefs. (Kennedy et al. 2011). For example, *Kennedy et al. (2011) found data to be dispersed, difficult to access, and widely varying in statistics and formats, which ultimately hindered evaluation of the success of specific oyster restoration activities and techniques, in Maryland and Virginia. Related areas of data paucity have been highlighted by others: quantitative data (Bohnsack and Sutherland 1985), post-construction monitoring (Carter et al. 1985), examination of effects by structures (e.g., jetties, pipelines, oil rigs) unintentionally mimicking reefs (Feary et al. 2011).*

In an attempt to understand the impacts of reef restoration material and techniques, Brown et al. examined 16 reefs along the northern coast of the Gulf of Mexico from Copano Bay in Texas to Mobile Bay in Alabama. They measured community structure and other factors that might be used to assess restoration success. The reefs were selected in categories by age, new and old, and substrate, shell and rock. However they combined limestone and concrete rubble as 'rock' in their analysis so it is not possible to separate the limestone reefs from the concrete reefs. Nor is it possible to determine the size of the concrete. They did find that overall there was little differences between substrate types with some noted exceptions among larger motile fish.

In a related study, one of the authors Furlough (2012) found the interaction between sample method and substrate type had an effect on fish abundance.

> *It is possible that these old rock reefs differed in the size and number of interstitial spaces as compared to other treatments, to the extent that these reefs provided more suitable refuge space for small organisms.*
> *This may be a function of created reef location with rock and reference reefs being placed either by design or by chance in locations more suitable for good oyster recruitment.*

<u>Oyster population</u>

Comparisons of reefs built with artificial substrate typically compare oyster population characteristics such as recruitment, abundance and age distribution to shell reefs. La Peyre et al. (La Peyre et al. 2014) examined 16 reefs along the northern coast of the Gulf of Mexico from Copano Bay in Texas to Mobile Bay in Alabama. They found more adult oysters on rock reefs, while more young of the year oysters were found on shell reefs. However, with spatial scale so large relative to oyster population dynamics, it is hard to generalize from this data as the authors point out: "Whether differences in spat recruitment were related to local hydrodynamics, unmeasured bathymetric differences, differences in actual substrate availability, or bio-fouling (Lukens et al., 2004) are difficult to determine without intensive sampling and better understanding of small and large scale population dynamics."

<u>Setting</u>

Compared to post setting effects there is considerable literature on the impacts of substrate on setting behavior. A number of studies have compared C. *virginica* setting on oyster shells materials to setting on other materials. These studies supported the popular notion that oysters will set on anything hard. Studies that did direct comparisons – tire chips and expanded shale (Mann et al. 1990), gravel, glass, concrete, polyurethane, PVC – found preference for oyster shells. Similar results have been found for other species. For example Polyethylene terephthalate bottles and clay tiles were compared for mangrove oysters, and higher set was on the oyster shell (Nalesso et al. 2008).

Researchers found a range of responses between and among substrates e.g., ground glass had twice as much settlement as smooth glass. Larvae prefer concave to convex surfaces (Taylor et al. 1998). The most studied variation is substrate orientation.

The orientation of the substrate was found to have a profound effect on oyster settlement. Preference for the underside of surfaces has been shown by a number of researchers (Schafer 1937, Cole and Knight-Jones 1939, Hopkins 1935, Gastsoff 1962). Baker found that this preference was independent of inner or outer surface of oyster shell (Baker 1997). Researchers have also found a number of factors that can medicate the effect of surface. Butler found higher setting on the upperside on plates nearer the surface (Butler 1955). Shaw found that when substrates were four inches apart, oysters settled on the underside, but when plates were one inch apart they settled on the top (Shaw 1967). Light and turbidity have also been identified as factors that can mediate a preference for settling on the underside of surfaces (Kennedy 1980), (Kalyanasundaram 1992).

METHODOLOGY

Task 1: Meeting with Management Agencies

The objective of this Task was to meet with those resource management agencies responsible for permits related to oyster aquaculture. These meetings were to discuss our project and identify any issues that would need to be addressed in order to proceed to a large-scale field test in the next phase of this project.

At the end of the Phase I study, the research team had several conversations with the Maryland Department of Natural Resources (DNR) and the Baltimore District Army Corps of Engineers (ACOE). These conversations helped to formulate our research approach for this Phase II project and identify opportunities for joint collaboration. Throughout Phase II project, the research team continued meeting with the Maryland DNR and the Baltimore District ACOE. Both of these agencies have management responsibility related to permitting activities related to oyster aquaculture. These meetings helped identify lessons learned from their activities, identify areas of common interest, and facilitate the implementation of Phase III project. In addition to direct meetings with these agencies, the interactions with the Oyster Advisory Council (OAC) and the Maryland Oyster Restoration Group were the focus. The OAC provides guidance to DNR on oyster issues. The Maryland Oyster Restoration Group has a mandate for large-scale reef construction that would be of the greatest benefit and provide the most sustainable support for RCA use.

Task 2: Community impacts

The objective of this task was to characterize the structure of oyster reef faunal communities (e.g., small benthic crustaceans, mollusks, and demersal fishes) in the RCA and natural oyster shell treatments. Specifically, the patterns in abundance, and community composition of infaunal organisms were compared between the treatments of RCA materials with natural oyster shell treatment to assess the suitability of RCA as an alternative material for oyster restoration and aquaculture.

To test the impacts on community structure, 18 crates – six with RCA, six with RCA and a veneer of oyster shell, and six with oyster shell – were placed at two sites in the Chesapeake Bay, Md., and then sampled for their associated fauna.

Sites: The comparison of community structure between RCA and shell was tested at two locations with different salinities. The bay is divided into three salinity zones: oligohaline (0.5-5 ppt), mesohaline (5-18 ppt), and polyhaline 18-30 ppt (DNR). Because of the natural fluctuation of conditions within each salinity zone, a uniform mixture of organisms and predators is to be expected. Thus, while similar community structure within a zone was expected, because of the different salinity ranges, differences exist between salinity zones. Since oyster growth is inhibited in the oligohaline zone and oyster aquaculture in Maryland occurs in the moderate and high salinity zones, sites aimed at sampling within each of those two zones were selected.

The crates were deployed at oyster aquaculture sites. They were chosen because they provided increased protection from human interactions; they were already permitted for deployment of the structures; and the high density of adult oysters at the facilities would increase the possibility of testing larvae recruitment. The first site was on the Patuxent River just north of Broomes Island on an oyster lease owned by Patuxent Seafood. The second location was on the Eastern Shore of Maryland in Fishing Bay on an oyster lease owned by Chesapeake Oyster Company. Depths at both sites ranged from approximately 2.4-3.0 meters.

Environmental factors, such as salinity and chlorophyll *a* concentration, as well as water temperature, have critical influences on oyster settlement, survival, and community structure (Soniat and Burton 2005, Paul and Tanner 2012, Seaman 2007, Nestlerode et al. 2007, Ortega and Sutherland 1992, Wilson et al. 2005). So, in this study, the environmental factors at the two study sites were monitored to explore possible mechanisms that could impact oyster settlement, survival, and community structure.

Experimental Units: The experimental units were 6-gallon plastic milk crates. The crates measured 48.3cm X 33cm X 28cm and contained approximately 0.04m ^{3} of material. Each crate was lined with ¼-inch Vexar® plastic netting to simulate the flow in an oyster reef and collect organisms at the end of the experiment.

Treatments: Each crate had one of three treatments: shell, RCA, and equal parts RCA and shell layer. The shell was aged oyster shell taken from supplies held at the PEARL. The RCA was sourced from pile created from Flanigan and Sons' normal crushing operations. RCA is a material of opportunity and its source is driven by project. Flanigan and Sons was chosen in part because it is a road construction company and the largest portion of its RCA comes from those activities. Further Flanigan and Sons has worked with Maryland Department of Environment and has received approval for the use of its RCA as road base materials. While the RCA should not contain asphalt other bituminous material, it was visually inspected prior to use and none was found. The RCA was approximately 2 to 4 inches in size. All material was clean and free of organic material when placed in the crates. The 2-inch to 4-inch size was used as it is the smallest size produced that does not contain fines or present interstitial spaces too small to promote oyster survivorship. A number of studies attributed the differences in recruitment and settlement success between substrates to the number and size of interstitial spaces. In one of the earliest studies, Lunz (1958) found that oyster shell that contained large amounts of small fragmented shells had lower recruitment than those less fragmented pieces. O'Beirn et al. (2000) found equal recruitment but lower survivorship on alternative substrates. The authors noted that the alternative substrates had much fewer and smaller interstitial spaces than oyster shells. These smaller spaces would provide equal recruitment sites, but their refuge value would decrease as the oyster grew. Larger size pieces do not provide the interstitial spaces of natural oyster reefs that promote recruitment and growth. The topography associated with the large pieces also interferes with watermen's activities, most notably crabbing. The concrete that can be used is based on standards set by the State of Maryland and Army Corps of Engineers and the Maryland Department of the Environment.

Design: Each site had four replicates of each treatment. The treatments were placed in four rows with each treatment distributed randomly in the row. At each site the crates were approximately 10 feet apart. The crates were placed on the bottom, in the Patuxent in June, 2013 and in Fishing Bay in July, 2013, and each were fished after 3.5 months.

Data Collection and Analysis: After 3.5 months the crates were removed to the PEARL and placed on sorting trays to collect organisms that fell or walked out of the crates. One third of all material was removed and placed on the table. The material was rinsed with river water. All water, sediment, and organisms were washed through a 500-micron sieve. Organisms were counted, measured, and identified to the lowest practical taxonomic classification. The RCA and shell were visually inspected for attached organisms. All fish and crabs were measured to the nearest millimeter. At the Fishing Bay site, spat attached to either shell or RCA were counted and measured to the nearest millimeter. Population parameters for each species with sufficient numbers were compared with a one-way ANOVA on abundances and a chi-square goodness of fit test for size classes. Community parameters were analyzed with a Shannon index for diversity.

Task 3: Commercial Harvest Methods Testing

To test watermen hand tonging on RCA and to get their impressions of the substrate, a mesocosm at PEARL was filled with RCA and oyster shell to a depth of one foot. The tank (measuring 3m X 7.6m X 1.2m) was divided in half. RCA was placed in one half and shell in the other half. On top of each substrate approximately 500 adult oysters, both singles and some clumps, were placed. The tank was then filled with Patuxent River water drawn from a seawater intake located ¼ mile offshore. Boards were placed from one side of the mesocosm to the other simulating washboards on a boat and allowing the watermen a platform on which to tong. New oyster hand tongs were purchased and used for this test. These tongs had standard heads and 12-foot (3.7m) shafts, allowing the watermen to tong in the mesocosm.

Watermen were recruited around the region. Each waterman tonged at least four times on each substrate. The time to fill up the tongs with material on each substrate was recorded. At the end a questionnaire was given to the watermen with questions relating to their time in the business, their years in the business, and their impressions of tonging on each substrate. A section at the end was provided for additional comments. All RCA and oysters tonged up were returned to the tank in the general location where tonged.

RESULTS AND DISCUSSIONS

Task 1: Meeting with Management Agencies

The focus on our activities with the OAC was to identify agency mechanisms for approving the use of RCA in oyster reef construction. The OAC has convened a substrate committee to provide recommendations to DNR relating to the need for substrate.

Dr. Kelton Clark is a member of the OAC's Alternative Substrate Workgroup that is chaired by Claire O'Neil, formerly of the Army Corps of Engineers. At the August 2013 meeting of the subcommittee, he discussed recycled concrete and was tasked with providing the committee with information on the value of recycled concrete. In the summer of 2014 the workgroup made recommendations to the DNR on oyster substrates. Dr. Clark used results from this project to provide the workgroup data on the characteristics of RCA. He has also included a recommendation that DNR develop procedures for the assessment of substrate suitability.

A permit to place material in the tidal waters of the Chesapeake Bay water requires sign-off from MDE, DNR, Maryland Department of Health, Maryland Board of Public Works, ACOE, Coast Guard, in some cases the U.S. Fish and Wildlife Service (USFWS), and (rarely) the Department of the Interior. The authority guiding most of the participating agencies has to do with the structure or placement of the reef. MDE may restrict placement of reefs in areas of high bacteria counts. The U.S. Coast Guard reviews include the placement relative to channels and boating activities. Other agencies may have questions on the impact of aquatic species of interest. USFWS, for example, has in the past expressed concerns over impacts on spawning grounds.

The three agencies managing the large-scale placement of oyster reefs in the Maryland portion of the Chesapeake Bay are the Army Corps of Engineers (USACE) through its Baltimore District, the National Oceanographic and Atmospheric Administration (NOAA) through the Chesapeake Bay Program Office, and the Maryland Department of Natural Resources (DNR) through its Fishery Service. Federal agencies have mandates from The Chesapeake Bay Protection and Restoration Executive Order (E.O. 13508), which includes requirements for the restoration of oysters in the Chesapeake Bay by 2025. USACE and NOAA have been designated as co-lead agencies to achieve the oyster restoration goals and have mandates from The ACOE Native Oyster Master Plan on essential fish habitats (legislation) and restoration in the Chesapeake Bay (legislation and executive order). DNR's mandate is broader and is defined by an array of actions.

The three agencies have created a working group consisting of an appointed staff from each of the agencies. Dr. Clark has talked regularly with the group members. During this period the ACOE representative retired. The new USACE representative recommended to the group that they assign one of the members as a liaison between Dr. Clark and the working group. They assigned the DNR member who is also staff for the Oyster Advisory Commission. The MDDNR liaison raised new concerns about the use of RCA. DNR is concerned about the petroleum products associated with road surfaces that might still be attached to the RCA. Dr. Clark has set a meeting with DNR and MDE to address these concerns. It may be possible to allay these concerns within the meeting. More likely MDE may request the development of a sourcing mechanism to ensure the safety of the RCA. Dr. Clark is expressing his concern to the working group and DNR on the piecemeal objections to RCA. Last quarter, DNR raised concerns about the response of the watermen. That concern was addressed in Phase II. This year they are raising concerns about petroleum byproducts.

Task 2: Community Impacts

2.1 The environmental parameters at two study sites

Water quality parameters were measured using a YSI continuous data logger at the water intake near Morgan State University Patuxent Environmental and Aquatic Research Laboratory (PEARL) to monitor chlorophyll *a* concentration, surface water temperature, salinity and dissolved oxygen concentration (Figure 2.1 and Table 2.1). Because of the maintenance of instruments, data were only available from the middle of July 2013 to the end of study period.

In general, the chlorophyll *a* concentration ranged from 0.5μg/L to 11.95μg/L with an average of 2.53μg/L. Chlorophyll *a* values were relatively high during the summer months and then decreased toward the end of study period. Salinity increased from the summer months toward the fall, with the average of 11.75ppt. Dissolved oxygen did not exhibit any seasonal variation; with an average of 6.99mg/L. The water surface temperatures were higher during the summer months with relatively low temperature during the late spring and fall seasons.

There is no continuous monitoring data for the Eastern Shore site, so the data from a nearby NOAA continuous monitoring station (38.5563N, 76.4147W) located at the mouth of Little Choptank River were used in this study. Even with the proximity of the monitoring station to our Eastern Shore site, the data presented here can only represent a general pattern during the testing period. Compared to the Patuxent River site, the salinity at the Eastern Shore site was higher (Figure 2.2, table 2.2), with an average of 15.37 ppt. The average concentration of chlorophyll *a* at the Eastern Shore site was also higher than the Patuxent River site; however, the large variation made this difference not significant at the 95% level.

The higher salinity and chlorophyll *a* concentrations at the Eastern Shore site provide a more favorable environment for oyster larva. The Patuxent River site is much closer to the lower limit of the reported 10ppt-29ppt salinity range for oyster larvae. Chlorophyll *a* concentration is an indicator of food supply. However food availability is above saturation levels at both sites. It is likely that other factors had a greater impact on the differences in oyster settlement between the two sites. Of particular import is the interaction between site locations, larvae behavior and flow dynamics within the Bay. For example; a model (North et al. 2008) linking these factors predict a heavier spat set at the Eastern Shore site under average flow conditions.

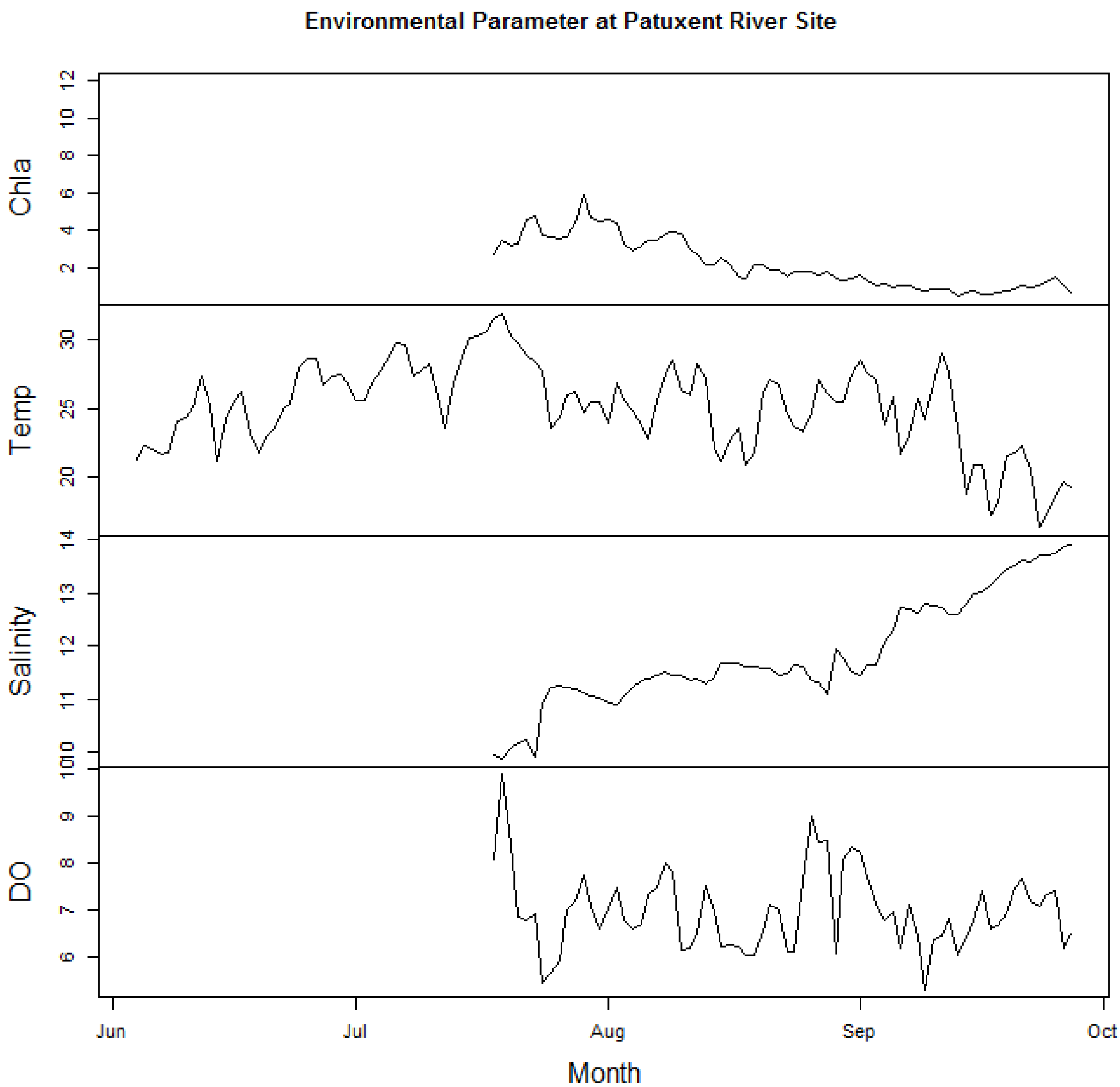


Figure 2.1: Environmental parameters (DO, water temperature, salinity, and Chl *a* concentration) at the Patuxent River site from June to September 2013 (data from a YSI continuous data logger at the water intake near Morgan PEARL).

Table 2.1 Summary of the Environmental parameters at the Patuxent River site from June to September 2013

Parameters	**Average**	**Minimum**	**Maximum**	**Standard deviation**
Chl *a* (µg/L)	*2.53*	*0.50*	*11.95*	*2.08*
Temperature (C)	*25.09*	*16.33*	*32.01*	*3.25*
Salinity (ppt)	*11.75*	*9.88*	*13.92*	*1.05*

Dissolved oxygen (mg/L)	*6.99*	*5.34*	*9.86*	*0.81*

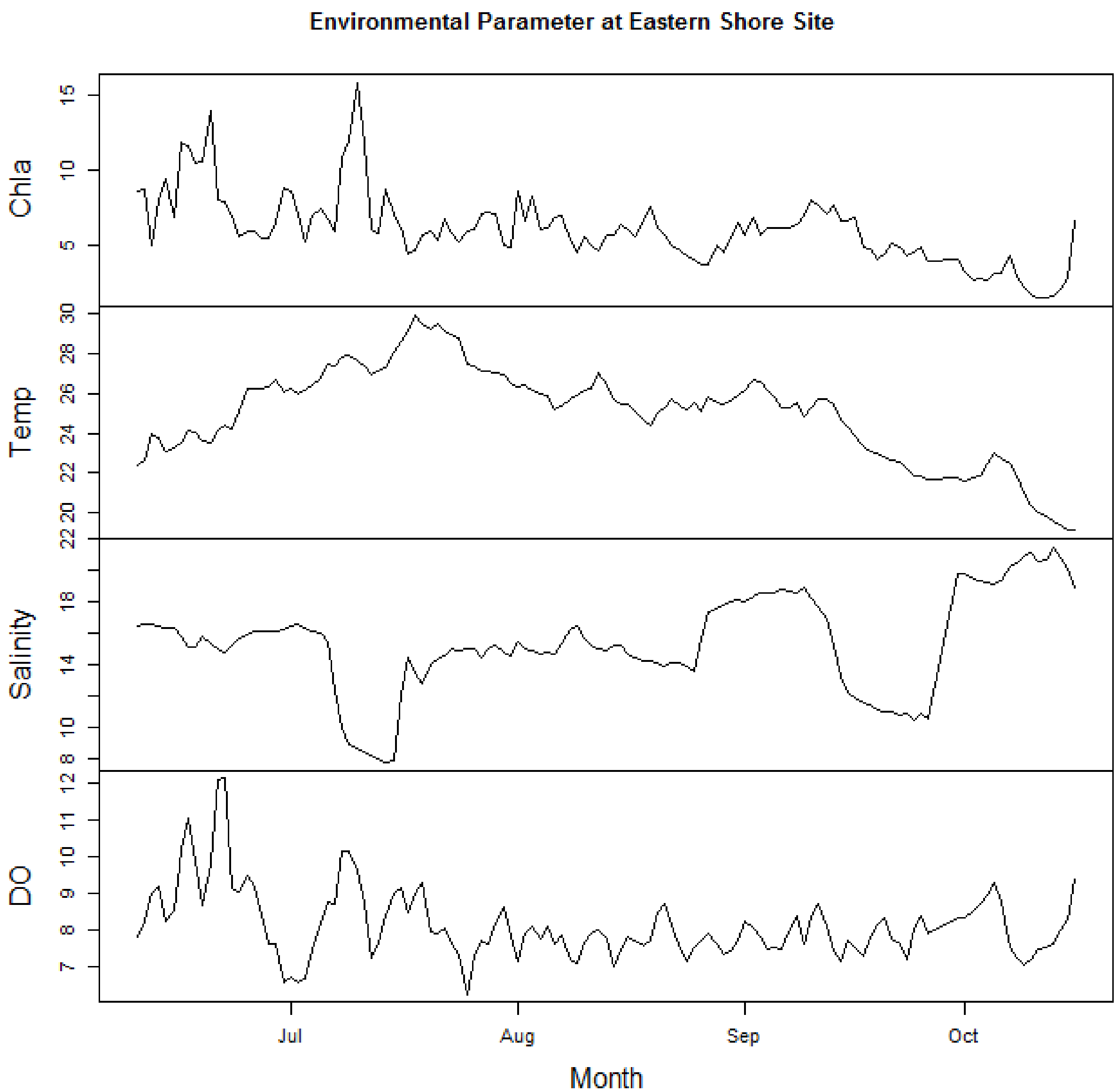


Figure 2.2: Environmental parameters (DO, water temperature, salinity, and Chl *a* concentration at the Eastern Shore site from June to October 2013 (data from the Chesapeake Bay interactive buoy system off the mouth of Little Choptank River).

Table 2.2 Summary of the Environmental parameters at the Eastern Shore site from June to October 2013

Parameters	Average	Minimum	Maximum	Standard deviation
Chl *a* (μg/L)	*6.07*	*1.45*	*15.90*	*2.41*
Temperature (C)	*25.07*	*19.16*	*29.61*	*5.58*
Salinity (ppt)	*15.37*	*7.83*	*21.46*	*3.08*
Dissolved oxygen (μg/L)	*8.14*	*6.27*	*12.12*	*0.96*

2.2 Benthic faunal assemblages:

Overall: Nine species accounted for >96% of all organisms collected: American eels *Anguilla rostrata*, striped blennies *Chasmodes bosquianus*, sea squirts *Molgula manhattensis*, hooked mussels *Ischadium recurvum*, anemones *Diadumene leucolena*, bay barnacles *Balanus improvises*, naked gobies *Gobiosoma bosc*, mud crabs *Rhithropanopeus harrisii,* and eastern oysters *Crassostrea virginica*. At the Patuxent River site, gobies and mud crabs were the dominant mobile species, with an abundance of above 100 per crate. Barnacles were the most abundant sessile species found at this site, followed by mussels and sea squirts. The abundance of anemones and oysters were relatively low (Figure 2.3). At the Eastern shore site, gobies and mud crabs were again the most abundant mobile species found; however, no eels were found at the Eastern shore site. Sea squirts were the dominant sessile species at the Eastern Shore site, with an abundance of more than 1500 per crate (Figure 2.4).

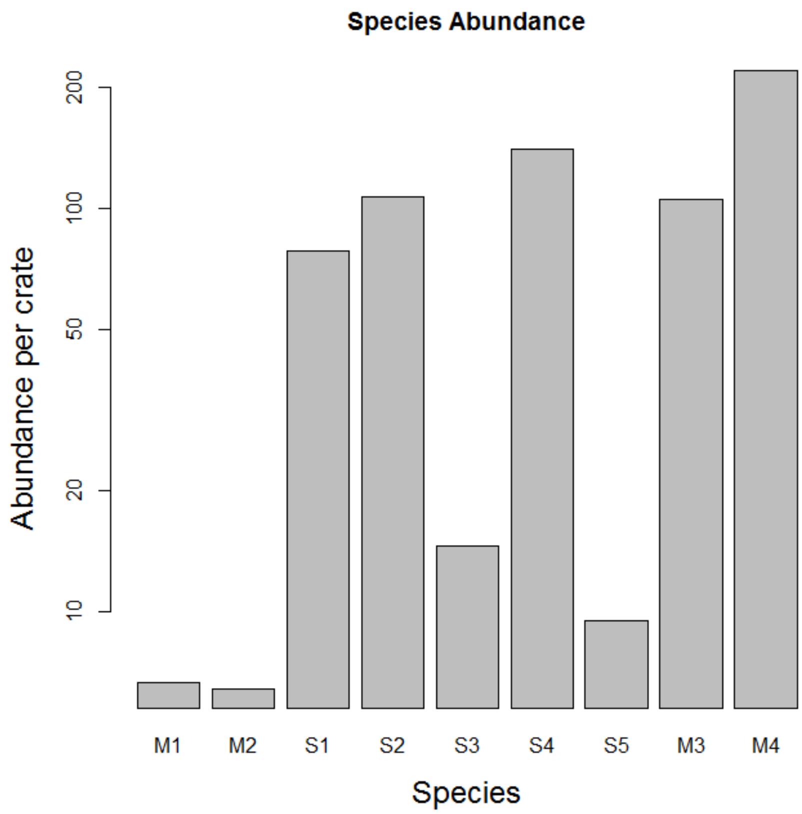


Figure 2.3: Mean abundance of the dominant faunal species at the Patuxent River site. (M1 = Eels *Anguilla rostrata*, M2 = Blenny *Chasmodes bosquianus*, S1 = Tunicate *Molgula manhattensis*, S2 = Mussel *Ischadium recurvum*, S3 = Anemone *Diadumene leucolena*, S4 = *harrisii*, S5 = Eastern Oyster *Crassostrea virginica*, M3 = Goby *Gobiosoma bosc*, and M4 = Mud crabs *Rhithropanopeus harrisii).*

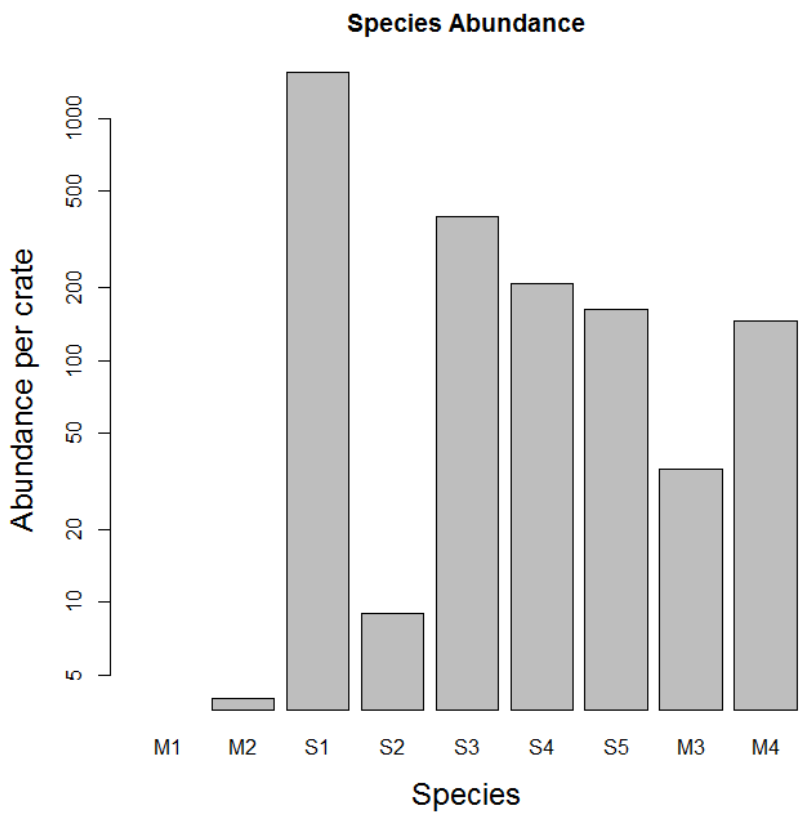


Figure 2.4: Mean abundance of dominant species at the Eastern Shore site. (M1 = Eel *Anguilla rostrata*, M2 = Blenny *Chasmodes bosquianus*, S1 = Tunicate *Molgula manhattensis*, S2 = Mussel *Ischadium recurvum*, S3 = Anemone *Diadumene leucolena*, S4 = *harrisii*, S5 = Eastern Oyster *Crassostrea virginica*, M3 = Goby *Gobiosoma bosc*, and M4 = Mud crabs *Rhithropanopeus harrisii).*

<u>Substrate</u>: There was an interaction between site and substrate type on the abundance of the two most abundant organisms, gobies and mud crabs. In the Patuxent River the abundance of gobies on the shell substrate was significantly ($P < 0.05$) higher than on RCA materials, while, the abundance of mud crabs did not exhibit any significant difference among the three different substrates (Figure 2.5). In contrast, at the Eastern Shore site, the mean abundance of gobies on the shell substrates was significantly higher ($P < 0.05$) than on RCA substrate. However, there was no significant difference in the mean abundance of mud crabs among different substrates. (Figure 2.6)

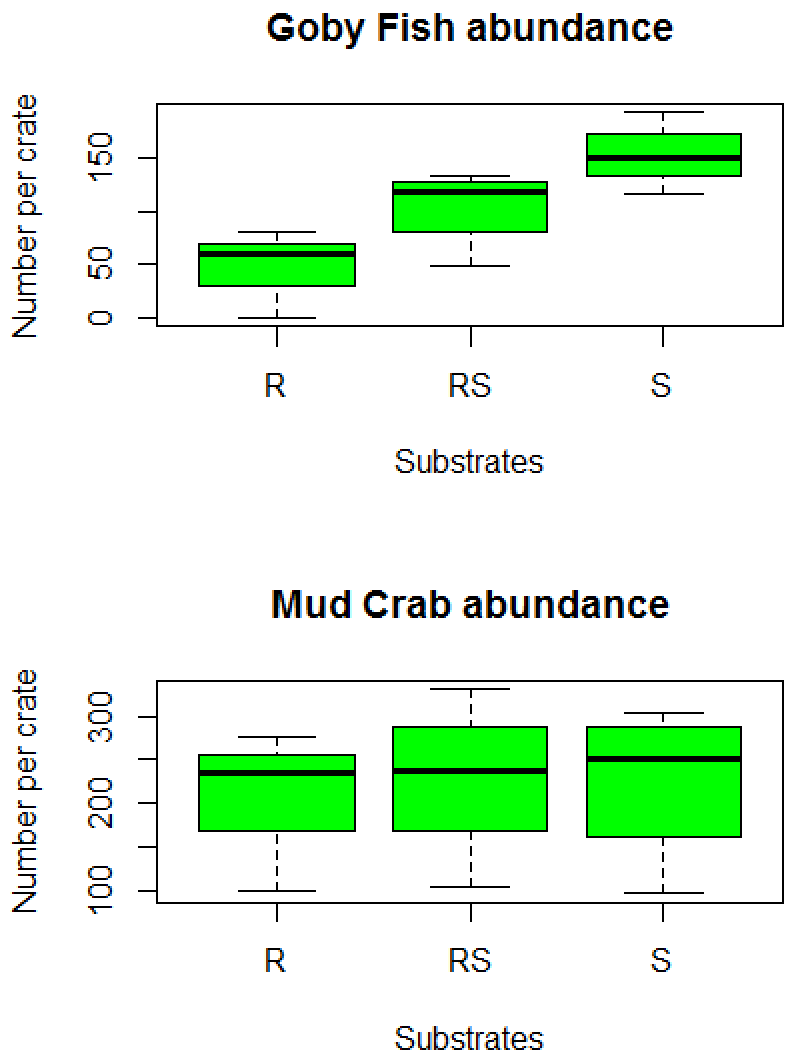
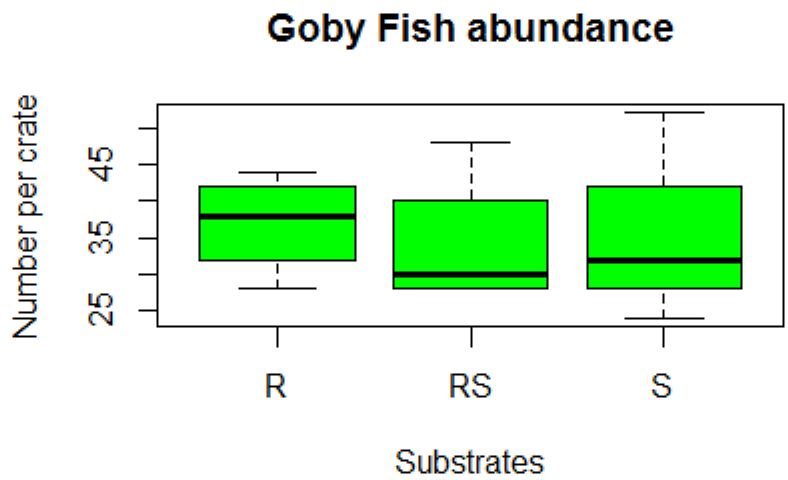


Figure 2.5: The mean abundance of the Goby *Gobiosoma bosc* and the Mud crab *Rhithropanopeus harrisii* on three different substrates at the Patuxent River site (R = RCA treatment, RS = RCA and oyster shell mixture, and S = oyster shell treatment).



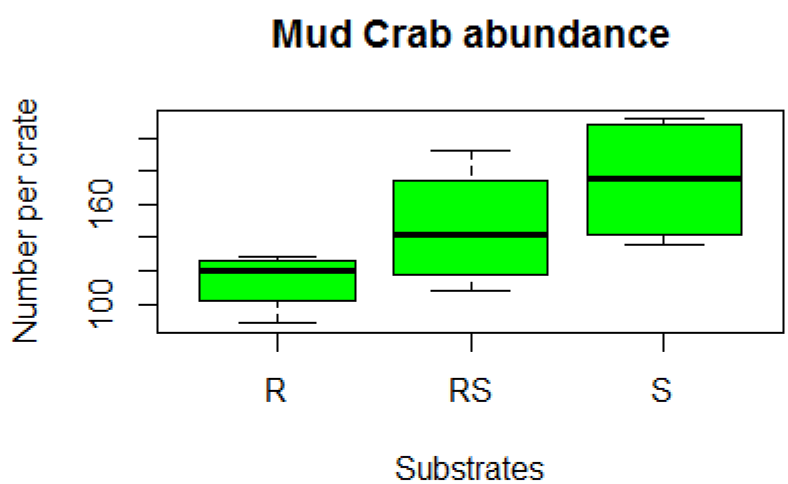


Figure 2.6: The mean abundance of Goby *Gobiosoma bosc* and Mud crab *Rhithropanopeus harrisii* on three different substrates at Eastern Shore site (R = RCA treatment, RS = RCA and oyster shell mixture, and S = oyster shell treatment).

Size structure: The size distributions of gobies and mud crabs on the substrates at the Patuxent River site are shown in figure 2.13 and 2.14. The goby population was dominated by individuals with body length between 30 to 35 mm, and the mud crab population was dominated by individuals between 5 to 10 mm in length. Both the goby and mud crab populations at this site exhibited similar size distribution patterns on all three substrates.

Similar findings were also observed at the Eastern Shore site, with both goby and mud crab populations exhibiting similar size distribution patterns on different substrates. However, the body size of these mobile faunal species at the Eastern Shore site was larger than at the Patuxent

River site, with the most frequent goby length between 40 to 45 mm, and the most frequent length of mud crabs between 10 to 15 mm.

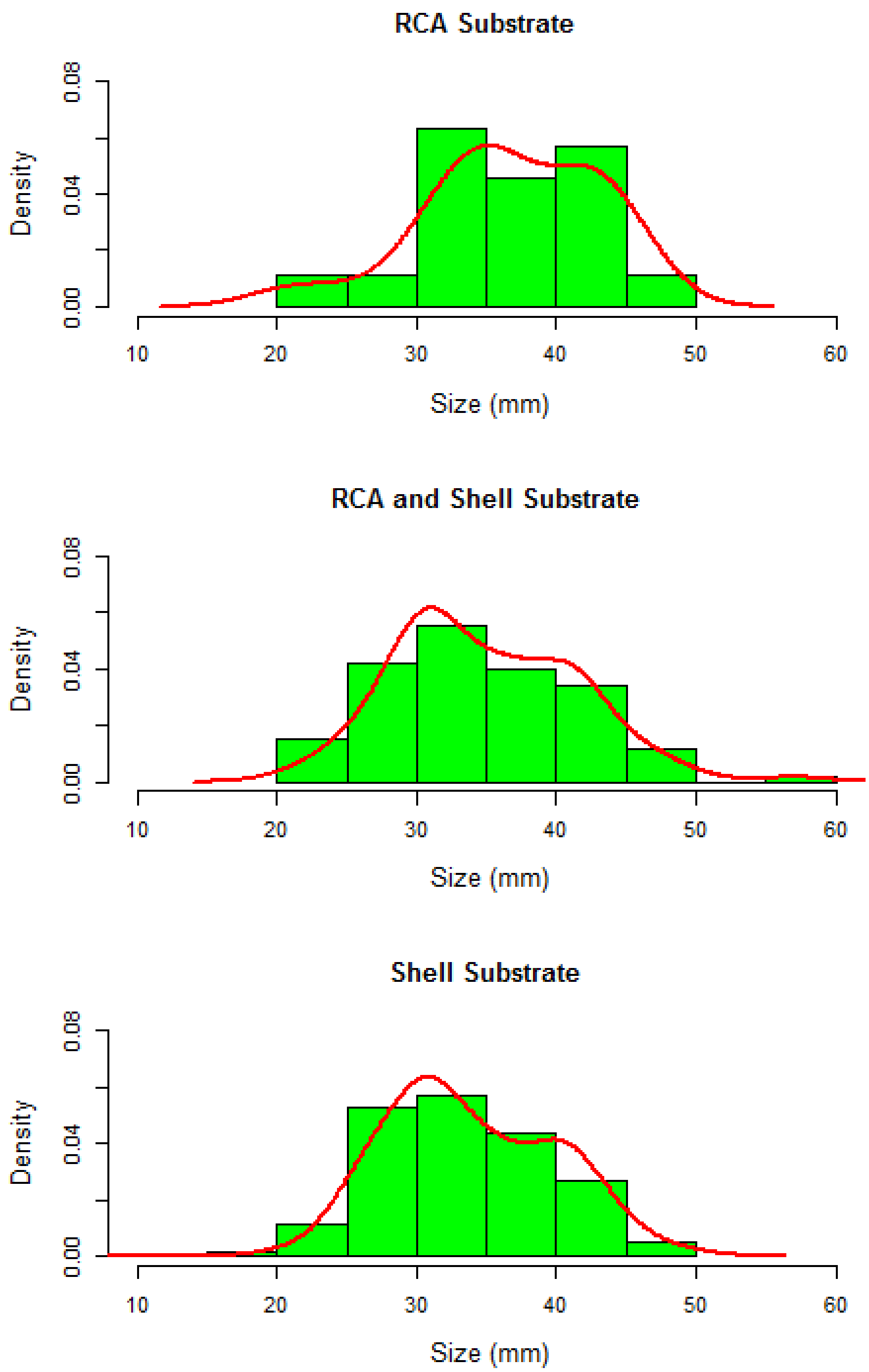


Figure 2.7: The size distribution of Goby in Patuxent River site in different substrates.

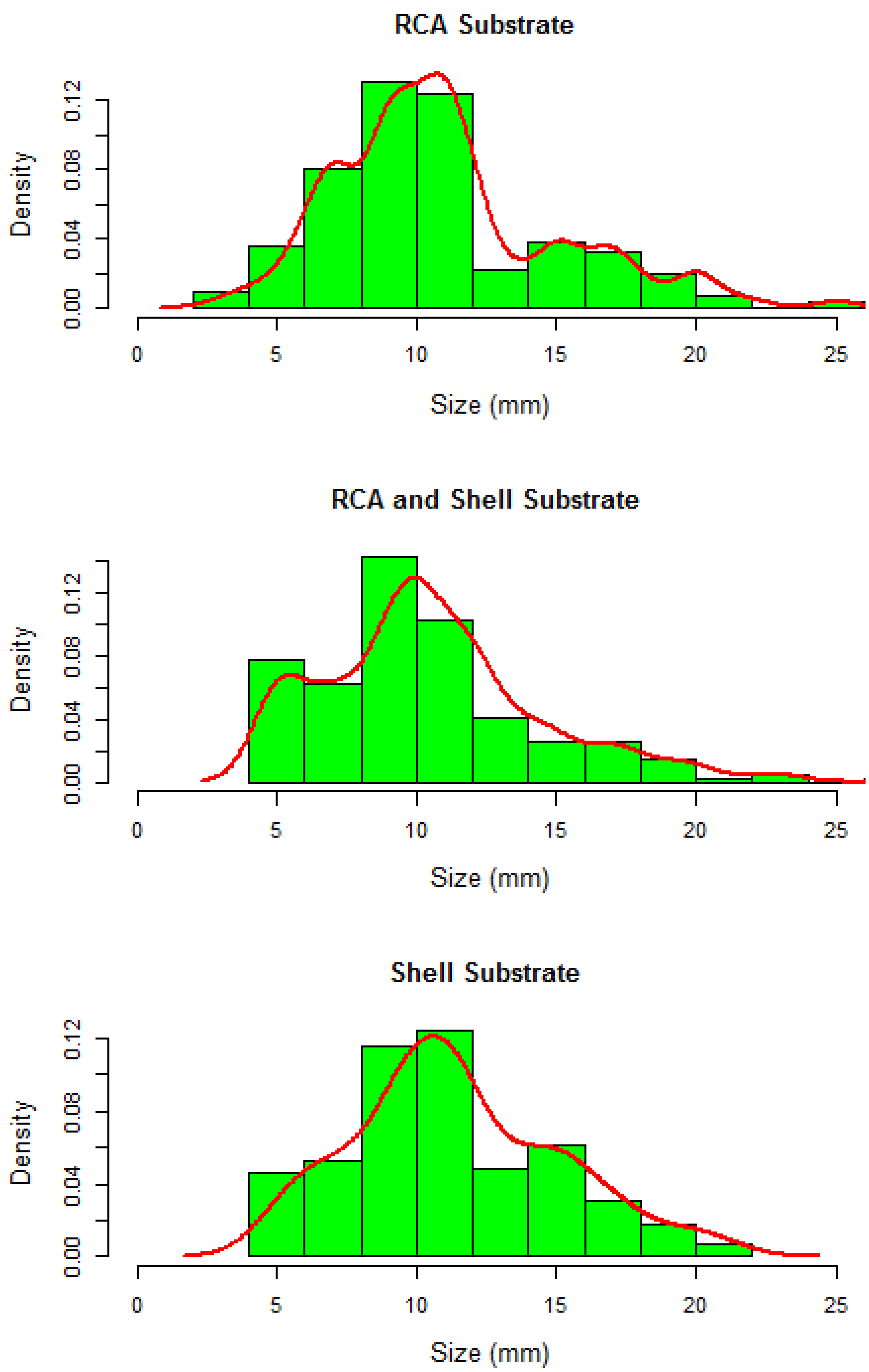


Figure 2.8: The size distribution of Mud crab in the Patuxent River site in different substrates.

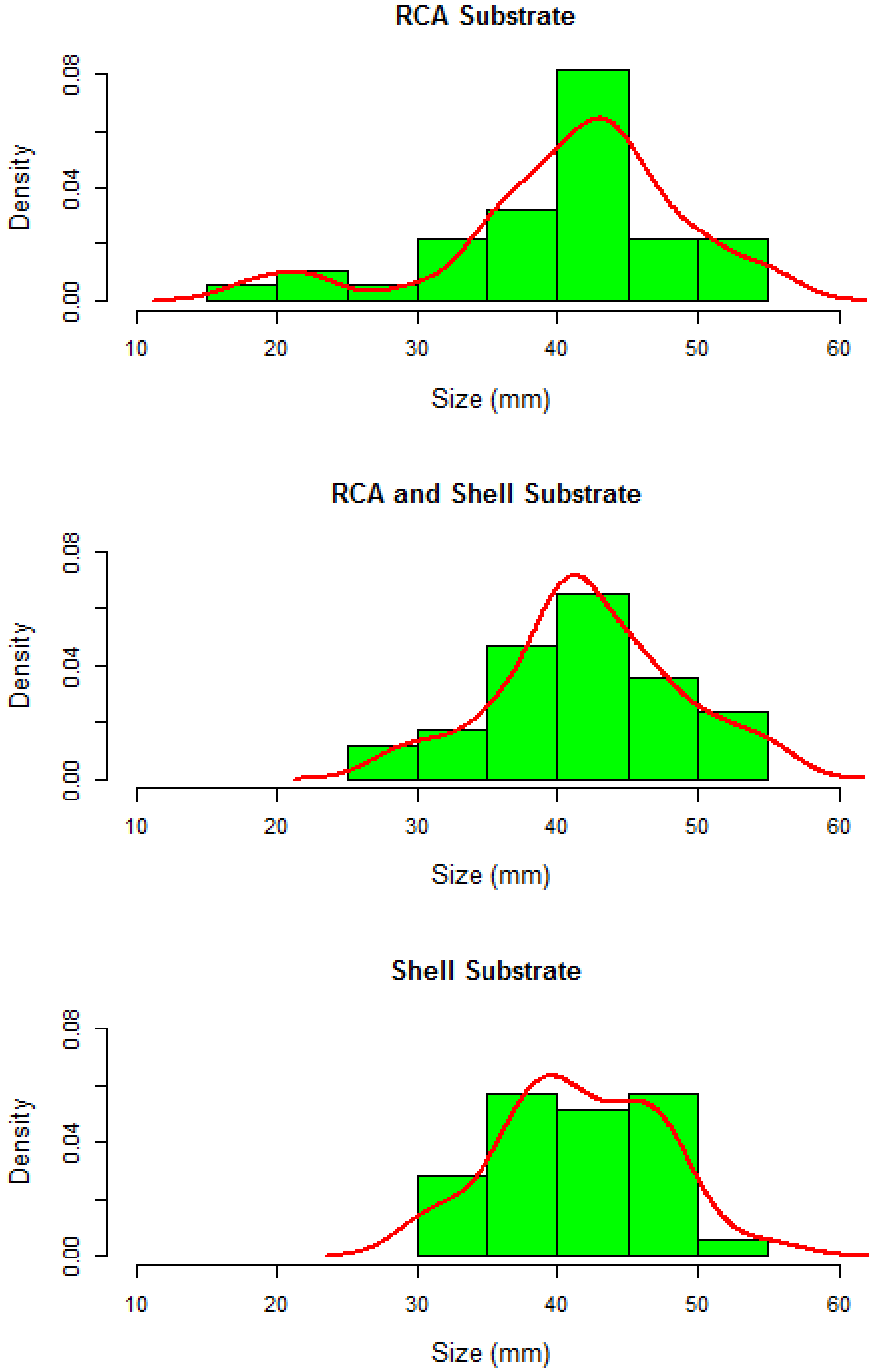


Figure 2.9: The size distribution of Goby at the Eastern Shore site on different substrates.

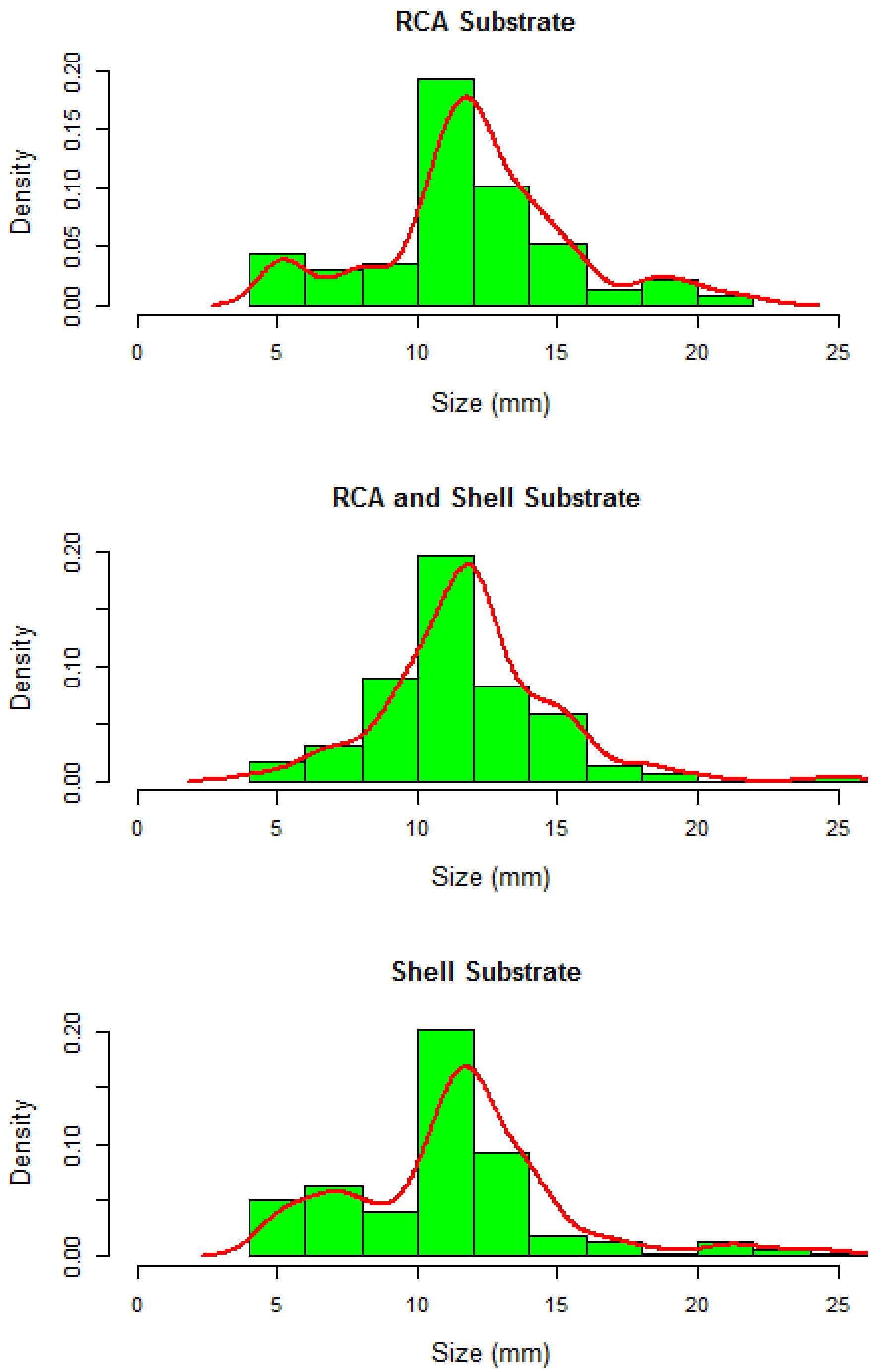


Figure 2.10: The size distribution of Mud crab at the Eastern Shore site on different substrates.

2.3 Community diversity:

Substrate type had no effect on community diversity (p=0.16) nor was there an interaction between substrate and site (p=0.57). Site, however, had a strong impact on diversity (Table 2.3). The community Shannon diversity index was significantly higher (P =0.001) at the Patuxent River site than the Eastern Shore site (Figure 2.11).

Table 2.3 Table of the two-way ANOVA results on Community diversity (Shannon index) at two different sites:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Substrate	2	0.10759	0.05380	1.9284	0.175883
Site	1	0.42229	0.42229	15.1373	0.001175
Substrate:Site	2	0.03208	0.01604	0.5750	0.573262
Residuals	17	0.47426	0.02790		

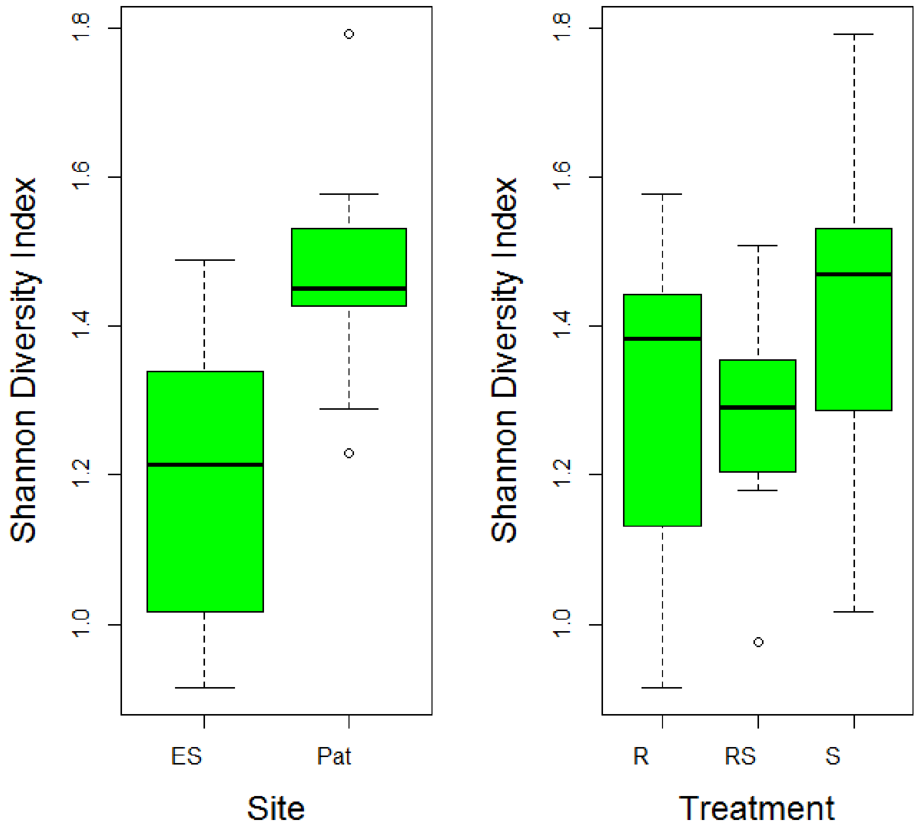


Figure 2.11: The influence of site and substrates (pooled across the different sites) on Shannon Community diversity index. (ES = Eastern Shore site, Pat = Patuxent River site; R = RCA treatment, RS = RCA and oyster shell mixture, and S = oyster shell treatment).

The visual analytics of the within site comparisons suggest an effect of substrate on diversity (Figure 2.12 and 2.13). A one-way ANOVA on each site was conducted to increase the power of the test. The results of the analysis showed no significant effect of substrate type on community diversity at either the Patuxent River (Table 2.4) or the Eastern Shore site (Table 2.5).

Table 2.4 Table of the one-way ANOVA results on the influence of treatments on species diversity in Patuxent River site:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	2	0.095283	0.047642	3.03	**0.1048**
Residuals	8	0.125786	0.015723		

Table 2.5 Table of the one-way ANOVA results on the influence of treatments on species diversity at Eastern Shore site:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	2	0.03495	0.017475	0.4513	**0.6504**
Residuals	9	0.34847	0.038719		

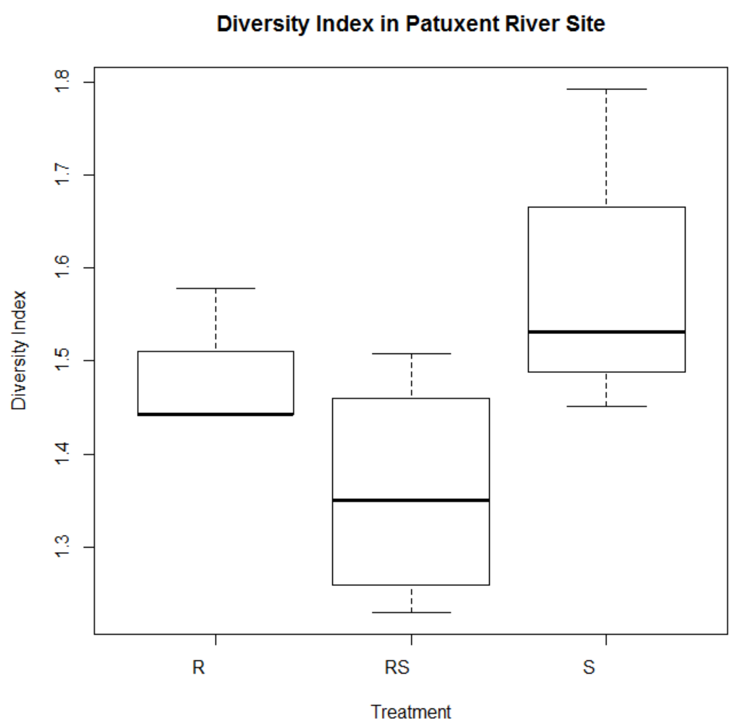


Figure 2.12 Comparison of the species diversity at the Patuxent River site among three different treatments (R = RCA, RS = RCA and oyster shell mixture, S = oyster shell).

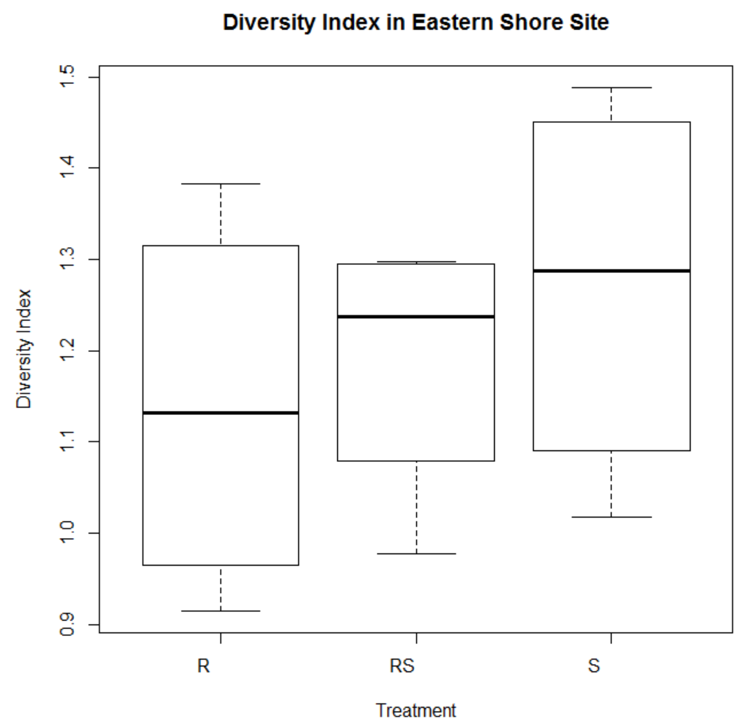


Figure 2.13: Comparison of the benthic community species diversity at the Eastern Shore site among three different treatments (R = RCA treatment, RS = RCA and oyster shell mixture, and S = oyster shell treatment).

2.4 Oyster recruitment on different substrates:

There was no effect of substrate ($P = 0.38$) on oyster settlement, nor was there an interaction between the site and treatment ($p=0.09$). There was an effect of site on spat settlement (Table 2.6). Spat settlement rate at the Eastern Shore site was significantly ($P < 0.01$) higher than the Patuxent River testing site (Figure 2.9).

Table 2.6 Table of the two-way ANOVA results on the oyster spat settlement at two different testing sites:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	2	2985	1492	1.0312	0.37785
Site	1	136137	136137	94.0680	**2.419e-08**
Treatment:Site	2	7987	3993	2.7593	0.09167
Residuals	17	24603	1447		

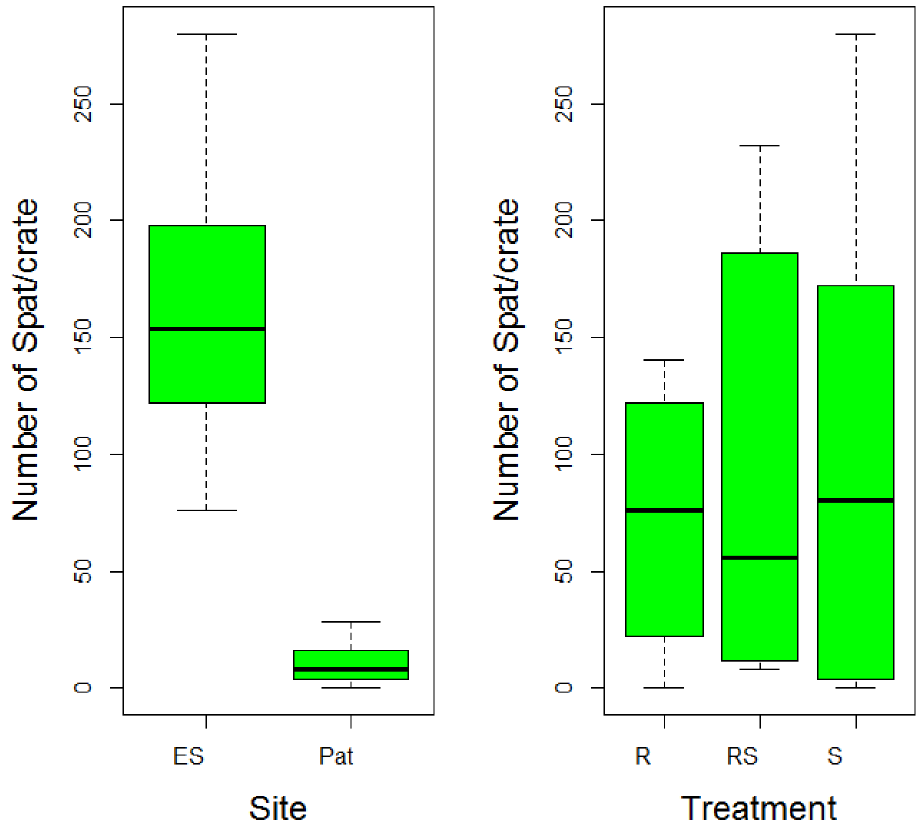


Figure 2.14: The influence of site and substrates (pooled across the different sites) on oyster spat settlement (ES = Eastern Shore site, Pat = Patuxent River site; R = RCA treatment, RS = RCA and oyster shell mixture, and S = oyster shell treatment).

Visual analytics seem to indicate an effect of substrate at the Patuxent River (Figure 2.15) and the Eastern Shore (Figure 2.16) sites. We verified the impacts with a one-way ANOVA on each site (Tables 2.7 and 2.8).

Table 2.7 Table of the one-way ANOVA results on the influence of different substrate on oyster spat settlement at the Patuxent River site:

Analysis of Variance Table

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	2	274.06	137.030	2.3291	**0.1595**
Residuals	8	470.67	58.833		

Table 2.8 Table of the one-way ANOVA results on the influence of different substrate on oyster spat settlement at Eastern Shore site:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	2	13867	6933.3	2.5858	**0.1296**
Residuals	9	24132	2681.3		

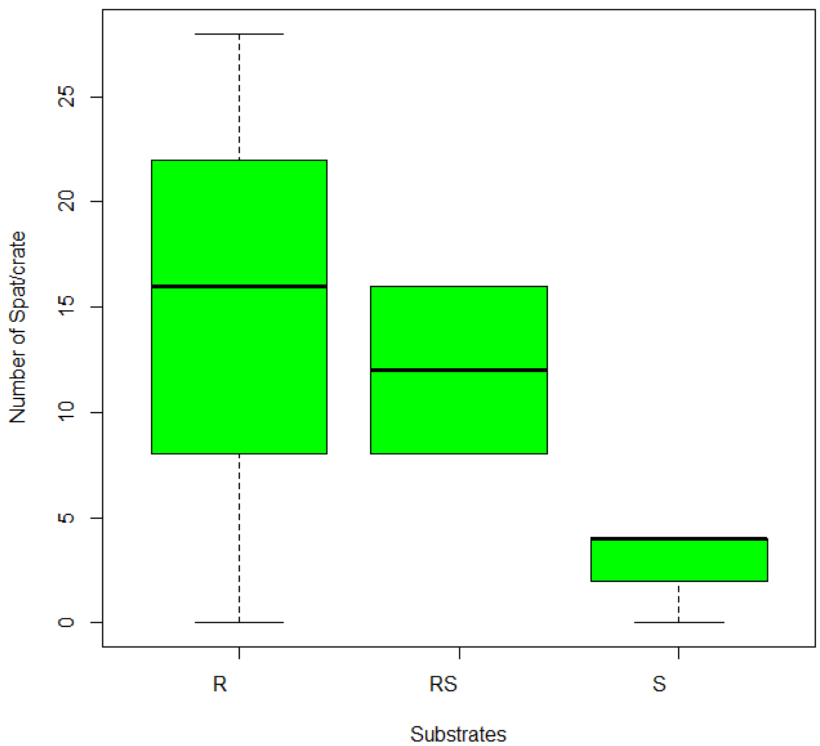


Figure 2.15: Comparison of the oyster spat settlement at the Patuxent River site among three different treatments (R = RCA treatment, RS = RCA and oyster shell mixture, and S = oyster shell treatment).

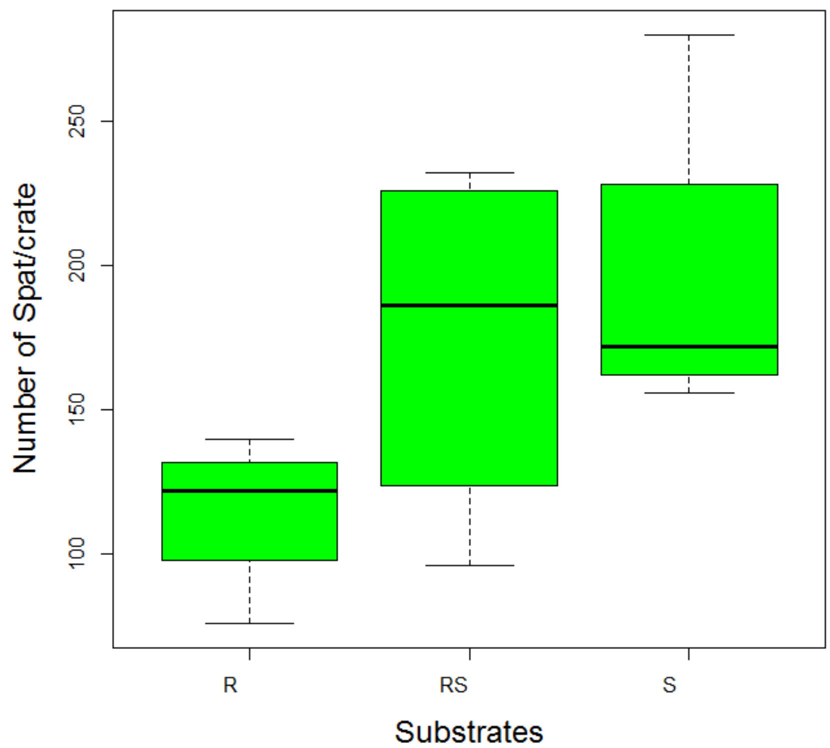


Figure 2.16: Comparison of the oyster spat settlement at the Eastern Shore site among three different treatments (R = RCA treatment, RS = RCA and oyster shell mixture, and S = oyster shell treatment).

Task 3 Commercial Harvest Methods:

Figure 3.1 and 3.2 show the participating fishermen's years in business and their annual harvest. Overall, the participants exhibited a comprehensive representation of the local oyster fishermen community. The duration in oyster business varied from less than five years (40%) to more than 20 years (50%). The annual oyster harvest of the participants also varied from less than 100 bushels (40%) to more than 500 bushels (40%). The broad representation of the local oyster community by these participants ensured the results from this field test could reflect the real responses and attitude toward using RCA as an alternative substrate for oyster restoration and aquaculture.

In general, the attitude toward tonging oysters on the RCA substrate is neutral to negative among the participating fishermen, with more than 50% unfavorable to tonging oysters on the RCA substrate (Figure 3.3). More than 70% of survey participants indicated that RCA materials were heavier than oyster shell, making it more difficult to work with. A paired *t*-test was performed on the time to acquire a full tong of oyster on recycled concrete aggregates (RCA) and on oyster shell substrates, and the results indicate it takes significantly ($p<0.01$) longer time to acquire a full tong of oysters on RCA than on shell (Figure 3.5). While this paired *t*-test confirms that RCA might not be a suitable substrate to oyster collection, it does not mean that RCA material cannot be used in oyster restoration and aquaculture. In their comments, many fishermen suggested the RCA could be a suitable material to build up the foundation of oyster reef, with a layer of oyster shell veneer on top of the RCA material.

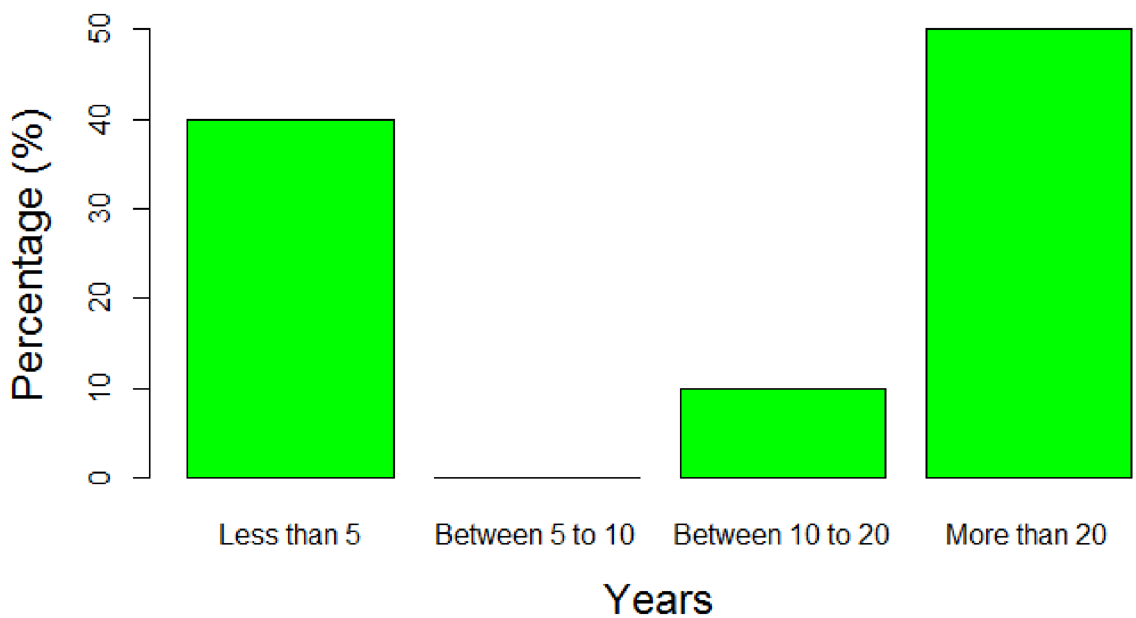


Figure 3.1: The number of years in the oyster industry for the participating fishermen in this survey.

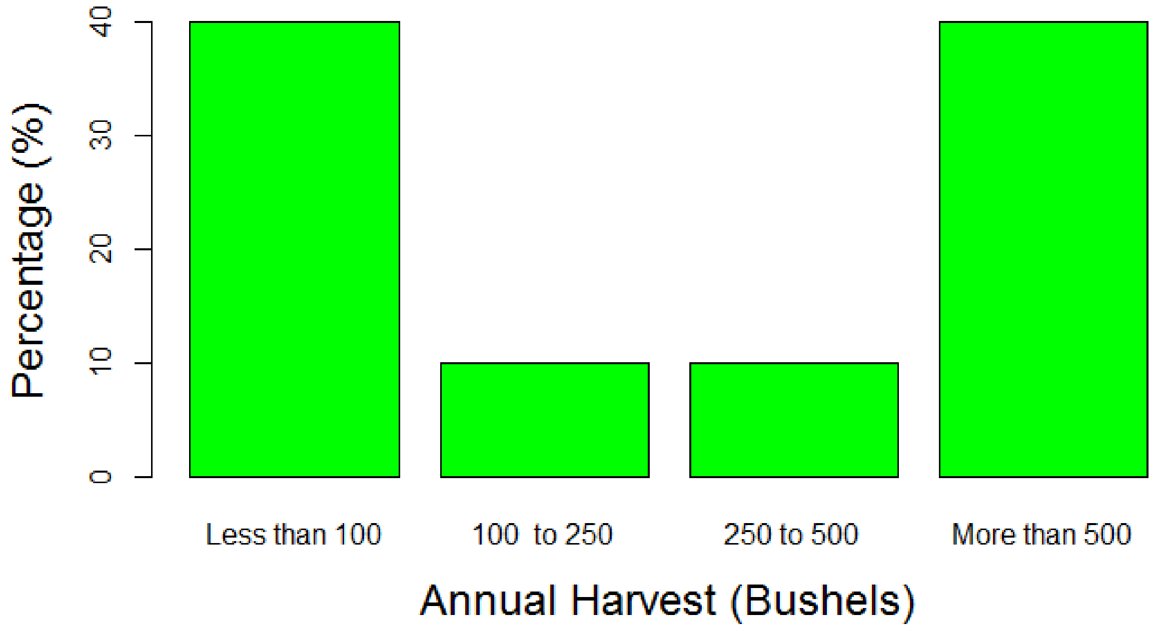


Figure 3.2: The number of oyster (bushels) caught per year by the participating fishermen in this survey.

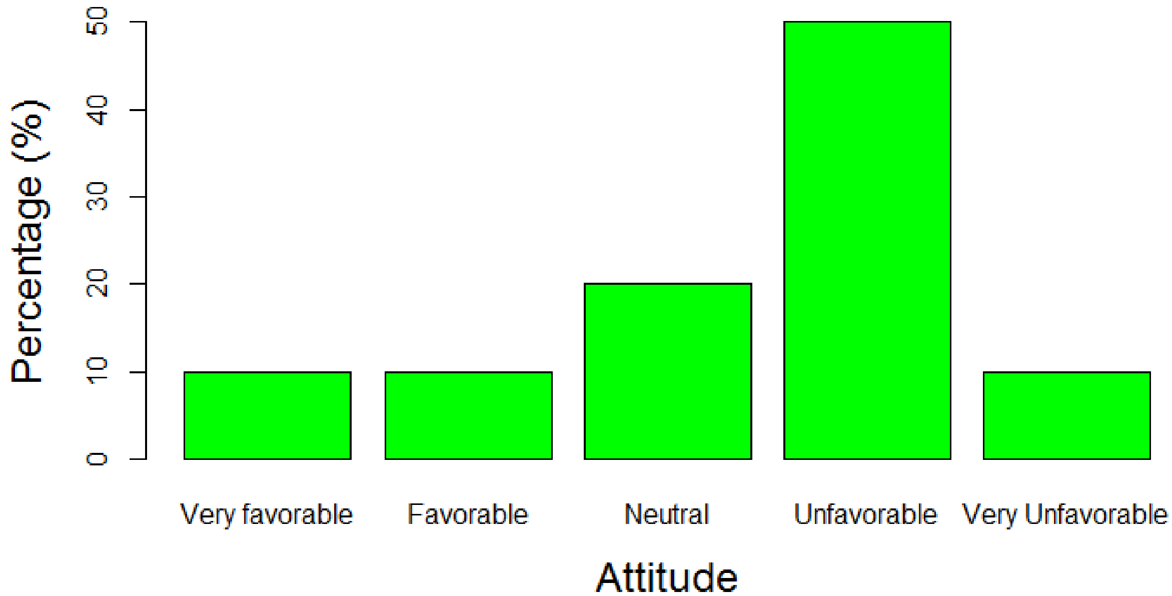


Figure 3.3: The opinion of tonging oyster on RCA when using it as an alternative substrate for oyster aquaculture in this survey.

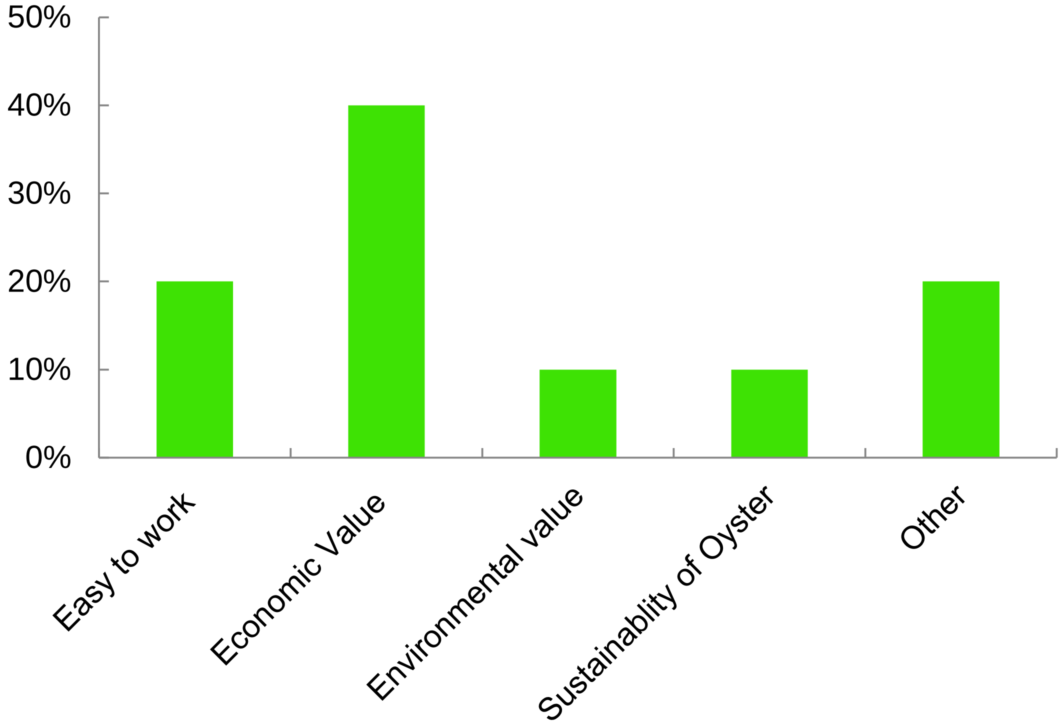


Figure 3.4: Factors affecting the acceptance of RCA as an alternative substrate for oyster aquaculture.

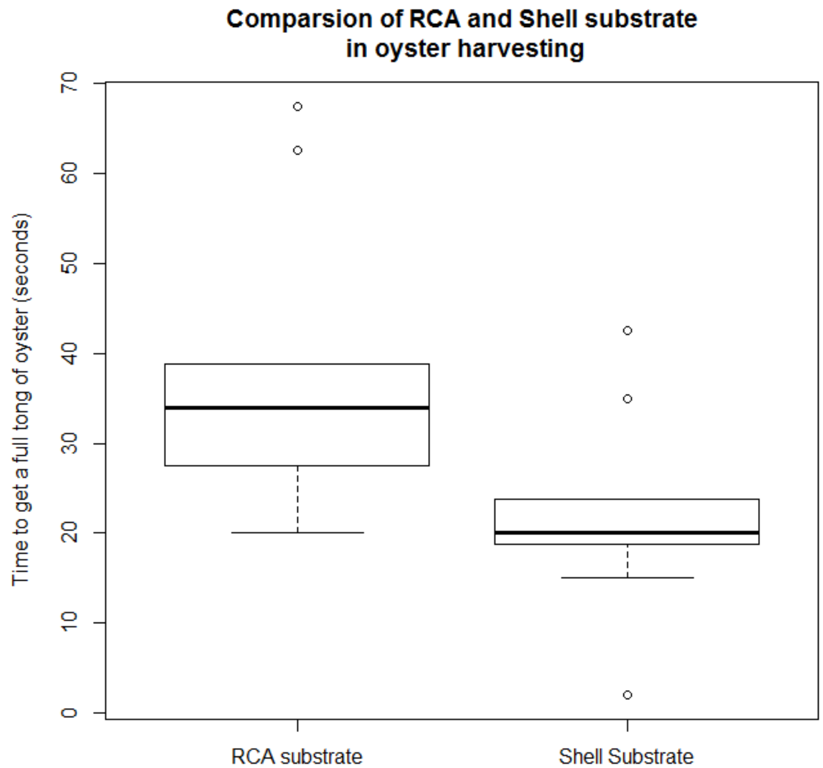


Figure 3.5: Comparison of the time to acquire a full tong of oyster on recycled concrete aggregates (RCA) and on oyster shell.

CONCLUSIONS

Approval Process for Using RCA as an Artificial Reef Material

The State of Maryland has no criteria established for artificial reef materials. In order to facilitate the adoption of new materials, the State of Maryland would need to develop and publish specifications for materials to be used as oyster reef substrate and a protocol for the assessment of these materials. The criteria should include criteria from the federal and state agencies with oversight over artificial reefs. With established criteria for substrate material, the DNR will have a basis for supporting choices on material used and the private sector will be able to develop product to meet DNR's needs.

In the absence of established criteria, to establish RCA (or other material) as viable for oyster restoration in the Maryland portion of the Chesapeake Bay, a pilot or demonstration project must be submitted for approval. The process required to obtain a permit includes approval from the relevant agencies as well as input from the public.

RCA's Community Impacts

Overall there was no effect of RCA on the community structure or on oyster settlement. The dominant mobile fauna of gobies and mud crabs are similar to findings from other studies of oyster reef communities (County et al. 2011, Brown 2012). The results indicate no significant difference between substrate type (RCA, oyster shell) and benthic community structure, oyster recruitment, and the abundance and size distribution of key faunal species. Oyster spat densities varied across sites, and were more closely correlated with salinity than substrate type. As an alternative material, RCA is thus generally similar to natural oyster shell with regard to ecosystem services provided, and could be used in the oyster restoration and aquaculture projects in the Chesapeake Bay region.

Commercial Harvest Methods
The general attitude toward tonging oyster on RCA was negative among the participating fishermen. The major complaint was the weight of RCA relative to oyster shells. However, the watermen did suggest that the RCA could be used if a veneer of oyster shell was placed on top or if the RCA was used on reefs that were not going to be tonged.

This report provides an overview of the survey results, and the baseline information on the attitude toward using RCA as an alternative substrate in the oyster business by local oyster fishermen. It is hoped that fishermen and resource managers could use this information to anticipate the socioeconomic impacts of changes in oyster restoration and aquaculture, and to facilitate the best management in the oyster business.

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