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Fish Utilization of Created vs. Natural Oyster Reefs (*Crassostrea virginica*)

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Abstract

Once viewed as an inexhaustible fishery resource, eastern oyster reefs (*Crassostrea virginica*) have been dramatically depleted. In North Carolina alone, eastern oyster harvests have declined by 90% since the early 1900s. However, eastern oyster restoration and management efforts have substantially increased since the 1970s. Oyster reefs provide habitat and refuge for organisms, improve water quality, and decrease erosion. Oyster restoration projects aim to construct reefs that function similarly to their natural counterparts. Therefore, post-creation monitoring of these reefs is crucial in determining restoration success. However, monitoring is often lacking or focused only on oyster density and size rather than ecosystem functions such as nekton utilization. This study examines nekton utilization among created reefs compared to natural reefs in an estuary in Wilmington, North Carolina. The objective was to determine whether the created reefs function similarly to the natural reefs in abundance, species richness, and fish size. Using seine nets and Breder traps, reefs were sampled over a 5-month period. No significant difference was detected among reefs for nekton abundance, species richness, and standard length. This is a promising result for future management, indicating that created and natural reefs can support similar communities of fishes and shrimp.

Keywords Restoration · Intertidal · Management · Estuary · Ecosystem services

Introduction

The eastern oyster (*Crassostrea virginica)* is an important ecosystem engineer in estuarine and coastal systems throughout the southeastern and gulf coasts of the USA. Throughout its range, there is much variation in reef characteristics, such as oyster density, reef geometry, and tidal position (Powers et al. 2009). It builds both emergent intertidal and subtidal reefs that range from the mid-Atlantic US to the Gulf of Mexico and the Caribbean (Byers et al. 2015). The Southeastern estuaries of North Carolina, including Masonboro Sound, are characterized by mostly intertidal reefs with fewer subtidal in nature (Posey et al. 1999).

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Oyster reefs function as a biogenic habitat with multiple important ecosystem effects, influencing the health and stability of many southeastern estuaries (Byers et al. 2015). Through suspension feeding, oysters are able to reduce estuarine eutrophication, as well as remove suspended organics and detritus from the water column, leading to decreased turbidity and improved water quality (Peterson et al. 2003). Several state and local governments have implemented oyster restoration programs with the goal of improving coastal water quality (Dewberry and Davis Inc. 2002). Additionally, oyster reefs provide habitat, refuge and foraging for commercially and recreationally important fishes, benthic invertebrates, and mobile crustaceans (Meyer et al. 1996). Oyster reefs have been shown to reduce predation on smaller fishes and in turn increase faunal abundance in estuaries (Peterson 1979). Reefs also provide a passageway for nekton movement among reefs (Micheli and Peterson 1999). Highlighting the influence of reef habitat on faunal communities, one study determined that 10 m^2 of restored oyster reef habitat will create an additional 2.6 kg of fish and large crustaceans annually, due to enhanced recruitment rate and shelter from predators (Peterson et al. 2003). Using this rate, it was then determined that the commercial fish value of a hectare of oyster reef equated to $4123 per year in 2011 (Blair et al. 2015).

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However, oysters and the reefs they create have become dramatically depleted due to disease, overfishing, environmental degradation, and poor management (Beck et al. 2011). Specifically, North Carolina eastern oyster harvests have seen a 90% decline since the 1900s (Jackson et al. 2001). Although oyster reefs have long been viewed as an exploitable fishery resource, restoration and management efforts have also increased in recent years and are taking a more holistic, conservation-oriented approach (Powers et al. 2009).

With the increased awareness of other environmental problems such as coastal erosion and fishery stock loss, oyster reef restoration is being utilized as a tool to combat these large issues. North Carolina has over 19,000 km of estuarine shoreline, which has already experienced significant erosion, some areas eroding at average rates of over 6 m a year (Fear and Currin 2012). Coastal wetland fishery stock has also declined and the decline is predicted to be heightened by sea level rise (Nicholls et al. 1999). The loss of nekton biodiversity in these ecosystems is also expected to increase with changes in habitat (Kennish 2002). In an effort to reduce coastal erosion processes and increase fish habitat, managers and homeowners are taking advantage of the eastern oyster and the services these reefs provide through a coastal erosion management method termed "Living Shorelines." This involves creating oyster reefs as natural buffers to dissipate wave action and stabilize the sediment (Scyphers et al. 2011; Meyer et al. 1997). While there are few studies on the coastal defense value of these reefs, the results of these studies are promising, suggesting the effectiveness of oyster reefs as a coastal erosion mitigation method in some areas (Piazza and Banks 2005). Additionally, if constructed correctly, oyster reefs have a high potential for sustainability due to new oyster larvae settlement with each incoming tide (Piazza and Banks 2005).

With the increasing implementation of oyster reef restoration projects, the successful construction of these created oyster reefs will be crucial to their longevity. Many factors affect the growth of a created oyster reef, such as reef height, density, larval settlement in the area, tidal position, and materials used (O'Beirn et al. 2000). The materials used for reef construction vary based on availability, cost, and management goals. Recycled oyster shell, or cultch, is an ecologically friendly and common substrate used in reef construction (Fan and Clark 2015). However, other hard materials have been utilized when oyster shell is limiting, including limestone, granite, gravel, and concrete (Brumbaugh and Coen 2009). One study found that recycled concrete aggregate was equally successful in spat settlement as traditional oyster shell (Fan and Clark 2015).

Construction techniques of oyster reefs are varied, with the most common methods including bagged cultch, caged cultch, loose cultch, vertical stakes, and cement oyster domes (Brumbaugh and Coen 2009). Bagged cultch uses aquaculture grade mesh to create bags that are filled with cultch material. Caged cultch is similar in design to crab traps and is filled with cultch to form blocks that can be anchored. Loose cultch is the placing of loose shell directly on the estuary floor in a particular shape. Vertical stakes are grooved PVC enriched with calcium carbonate and cement domes are molded cement half spheres with holes originally designed for coral reef restoration. The appropriateness of each technique will depend on management goals and differences in site; for example, loose shell would not be an appropriate method for areas with high wave energy and caged cultch is often used when shoreline protection is a project goal (Brumbaugh and Coen 2009).

After construction, monitoring of created oyster reefs is often lacking or short term, usually focused on oyster density and size and rarely on the local nekton communities that utilize these structures (Coen and Luckenbach 2000; Coen et al. 1999). This study attempts to highlight and quantify utilization of patch reefs by nekton, organisms that can swim independently of water currents, such as fishes and shrimp. Specifically, we compare nekton utilization between created and natural oyster reefs. One of the management goals of constructing an oyster reef is for that reef to function with the same benefits to the nekton community as the naturally occurring reefs. This study compares created oyster reefs to naturally occurring oyster reefs through nekton abundance, species diversity, and standard length. We hypothesized that established created reefs will resemble their adjacent natural counterparts in terms of nekton abundance, richness, and standard length in a North Carolina estuary.

Methods

Site Selection Eight intertidal reefs of *C. virginica* were chosen for sampling in Hewletts Creek Estuary, which is located in Masonboro Sound, North Carolina (Fig. 1). The site location is protected from harvest by a North Carolina Division of Marine Fisheries (NCDMF) oyster management area proclamation. The site was part of a restoration project initiated by the North Carolina Coastal Federation, with four seeded patch reefs established in 2005 (Finelli et al. 2013). One goal of the restoration project was to monitor both seeded and unseeded reefs and look for differences in oyster recruitment, structure, and disease (Finelli et al. 2013). These reefs were constructed with the loose cultch method of 250 bushels of shell, measuring 7 m in length and 0.3 m high. Post construction monitoring of the nekton communities utilizing these reefs was not monitored until now. Also included in this estuary were four naturally occurring reefs, which were used as the natural, reference reefs.

Gear Breder traps and seine nets were used to sample the nekton associated with natural and created oyster reefs (Breder 1960). Breder traps have been used successfully in

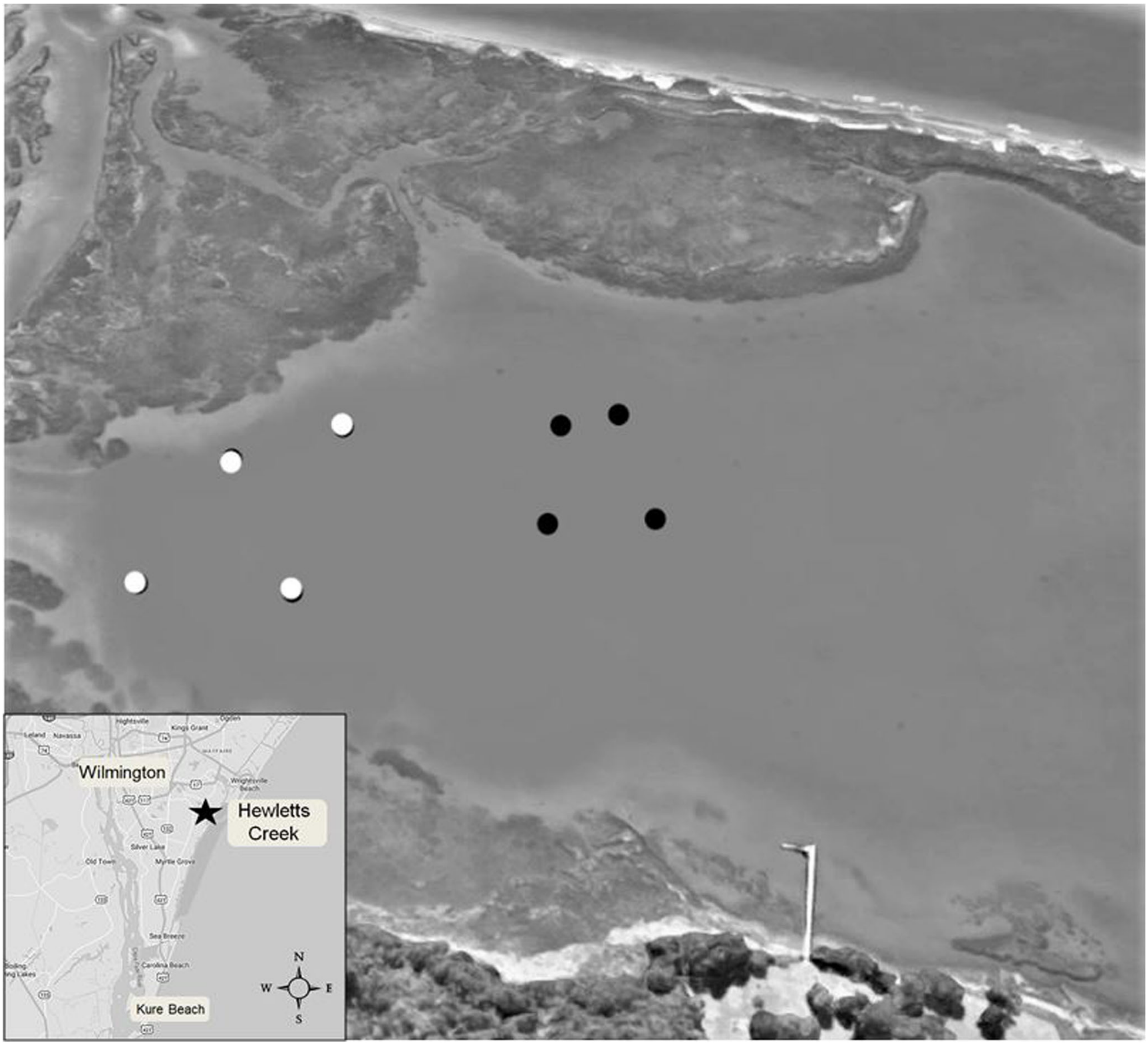

Fig. 1 Hewletts Creek estuary in Masonboro Sound, Wilmington, NC. Oyster reefs are represented by black and white circles. White circles represent naturally occurring oyster reefs while black circles represent the oyster reefs created by the NCDMF in 2005. The smaller image in the left hand corner is part of the North Carolina coastline with the star representing Hewletts Creek. Images obtained from Google Maps

other studies of nekton utilization and allow for reef sampling in a restricted sampling window and with less labor than other methods may demand (Posey et al. 1997; Alphin and Posey 2000; Posey et al. 1999; Griffitt et al. 1999). Breder traps often catch active, benthic species. Breder traps were constructed of clear acrylic boxes measuring 31 cm long, 15 cm wide, and 16 cm tall. Each acrylic box had a corresponding acrylic wing with a hole in the middle that was placed inside the box to guide and capture the nekton into the trap. Seine nets were 12 m in length and are an active sampling method to catch larger nekton that may be higher in the water column.

Deploying Breder Traps Breder traps were deployed at low tide. Breder traps were not deployed if the height of the water was twice the height of the Breder trap, as this would defeat the purpose of the fishes being brought in and trapped with the incoming tide. Breder traps were placed within 1 m of the fringing oyster bed on the flattest marsh surface found. Each Breder trap wing had two rubber bands secured around them, for the purpose of attaching lipped stakes through the rubber bands diagonally into the marsh sediment. The stakes helped to secure the wings in their correct position when the tide flooded the marsh. The Breder trap boxes in which the wings were placed were secured with bungee cords placed across the box with J-shaped rebar on either side holding the bungee firmly in place across the Breder box. A fishing buoy tied to monofilament was attached to the rebar for purposes of retrieval. Six Breder traps were placed at each of the four out of eight reefs, two natural and two created reefs. Two Breder traps were placed at a 90° angle from each other at the front right and front left corners of each oyster reef. Two Breder traps were also placed with wings in opposite directions from each other in the back middle of each oyster reef. The Breder trap orientation allowed for possible capture of fishes utilizing the reef in all directions. Breder traps were allowed to fish for two hours once completely submerged by the incoming tide.

Seine Netting While the Breder traps fished over a two hour window, seine nets were pulled at the other four reefs that were not fishing with Breder traps. The seine net was outstretched to 12 m in length and pulled within 1 m from the end of the fringing oyster reef. Seine nets were pulled along a standardized 10 m length, previously marked with PVC poles that could be seen at high tide. Before each seine haul, there was a wait period of a few minutes to lessen the disturbance of walking to the oyster reef with the gear. Due to the placement of the reefs in the middle of the marsh with no nearby vegetation stable enough to hauls seines onto, seine nets had to be pulled onto floating cement trays where nekton could then be recorded. Once the 10 m distance was covered, the poles of the seine net were brought together forming a closed loop. The poles were then twisted in on each other, slowly shortening the distance of the seine net and allowing for fishes to be corralled into the bag of the seine net. Once the seine was fully twisted, the bag was manually closed and brought out of the water and placed onto a floating cement tray. The wings and bag of the seine net were then slowly unraveled, checking for nekton throughout this process.

Duration and Nekton Retrieval To prevent recapture of the same nekton, sampling replicates were in days. Sampling events always took place during the daytime. Temperature and salinity measurements were recorded each sampling. Eleven sampling events took place from July to November 2015, with three samplings in July, three in August, three in September, one in October, and one in November. For each gear type, nekton was counted, identified, the standard length was measured and then released. For each new species caught, one reference fish was returned to the lab and preserved for verification.

Statistical Analysis Statistical analyses were performed using R v. 3.3.3 (R Core Team 2017). To determine if the response variables (abundance, richness, and fish size) differed between natural and created reef types, three generalized linear mixed models (GLMM) were performed using the 'lme4' package (Bates et al. 2015). The first and second models with richness and abundance as the corresponding response variables had Poisson distribution errors and a log link function. The model with fish size as the response variable had gamma distribution errors and an inverse link function. These models were appropriate due to the nature of the response variables (count data vs. continuous data) and the non-normality found through qqplot fits to five different distributions. All mixed models included reef type, gear type, and block (nested in gear type) as fixed effects, with time ($n = 11$) as a random effect. Statistical significance was assessed by Wald statistics (Bolker et al. 2009).

Results

Catch Data Throughout the duration of this study, 448 individuals were caught at created reefs and 405 at natural reefs, totaling 853 individuals with an average of 10 fishes caught per reef type each sampling event (Fig. 2). Breder traps were responsible for 56.8% of the catch (485 individuals) and seine nets 43.2% (368 individuals). Fourteen different species were caught over the 5-month period, with nine species caught at the created reefs and 12 species at the natural reefs, with an average richness of three species per reef type each sampling event (Fig. 3). *Lagodon rhomboides,* the pinfish, was the dominant species caught throughout the 11 sampling events, with *Eucinostomus argenteus, Fundulus heteroclitus,* and *Leiostomus xanthurus* following behind (Table 1). Other species caught include *Penaeus setiferus, Anchoa mitchilli, Mugil curema, Symphurus plagiusa, Paralichthys dentatus, Paralichthys lethostigma, Dasyatis sabina, Ctenogobius shufeldti, Opisthonema oglinum,* and *Synodus foetens*. The average fish size caught at natural reefs was 47.8 mm SL and 46.5 mm SL at created reefs (Fig. 4).

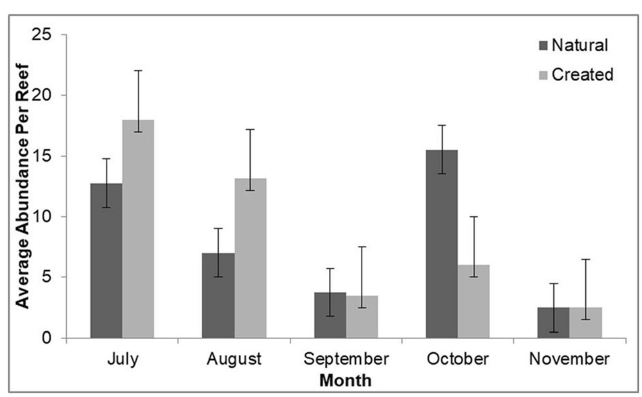

Fig. 2 Average fish abundance caught per reef per collecting event with seine net and Breder traps at natural and created reefs. As there was no significant difference in fish abundance between gear types, these data were combined. Standard error bars are shown

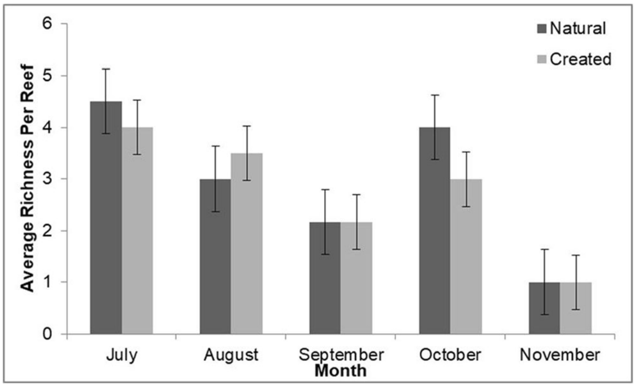

Fig. 3 Average fish richness caught per reef per collecting event with seine net and Breder traps at natural and created reefs. As there was no significant difference in fish richness between gear types, these data were combined. Standard error bars are shown

Mixed Models There was no significant difference between the replicate reefs (block) in terms of the amount of nekton caught and the species diversity ($\chi^2 = 2.47$, $p = 0.12$). There was also no significant difference in the amount or species diversity of nekton caught between gear types ($\chi^2 = 0.008$, $p = 0.92$). However, there was a significance difference in the size of fishes caught between gear types ($\chi^2 = 5.35$, $p = 0.02$). On average, seine nets caught larger nekton, averaging 53.32 mm SL (Fig. 4a), while Breder traps caught nekton averaging 41.03 mm SL (Fig. 4b). For between reef type comparisons, there were no significant differences found in nekton abundance ($\chi^2 = 0.36$, $p = 0.55$), richness ($\chi^2 = 0.67$, $p = 0.41$), and size ($\chi^2 = 0.08$, $p = 0.77$) between natural and created reefs.

Table 1 Mean nekton abundance caught per reef (4 natural, 4 created) between species over the 5-month sampling period

Mean abundance per reef		
Species	Created	Natural
Lagodon rhomboides	79.75	75.25
Eucinostomus argenteus	14	9
Fundulus heteroclitus	1.75	1.75
Leiostomus xanthurus	2.75	2.5
Penaeus setiferus	1	3
Anchoa mitchilli	1.5	1.5
Mugil curema	0.75	0.5
Symphurus plagiusa	0.5	0
Paralichthys dentatus	0	0.25
Paralichthys lethostigma	0.25	0
Dasyatis sabina	0	0.25
Ctenogobius shufeldti	0	0.25
Opisthonema oglinum	0	0.25
Synodus foetens	0	0.25

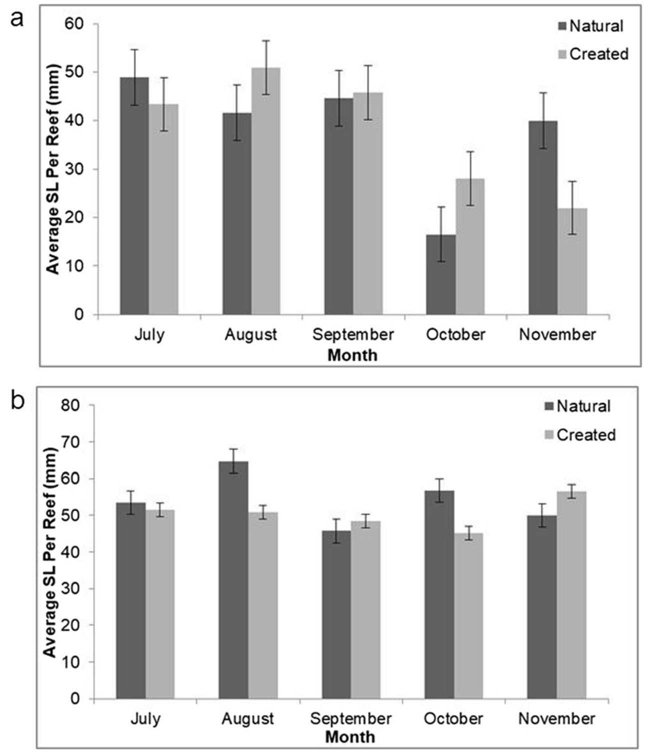

Fig. 4 Average fish size measured in standard length caught per reef per collecting event with **a** Breder traps and **b** seine net at natural and created reefs. Standard error bars are shown

Discussion

With the rise in oyster reef restoration methodology, it will be crucial to determine the impact these created structures will have on local communities of fishes and if they can function as equally suitable habitat and eventually provide the same ecosystem services as natural reefs. This study attempted to quantify any differences in nekton communities utilizing these reefs. The results of this study found no significant difference in the three different metrics of nekton utilization; size, species composition and abundance since construction 11 years ago.

The non-significance determined between the natural and created reefs in this study can be attributed to a variety of variables. One explanation could be time since creation. Built in 2005, these created reefs have had 10+ years to grow and develop. The results of this study indicate that these created reefs are fully established and functioning as naturally occurring oyster reefs in terms of nekton utilization. The size and location of the created reefs also likely contributed to the similarity in nekton utilization. Fairly small in size (~ 7 m in diameter) and in close proximity to other reefs, these reefs could develop more quickly than larger reefs and act as additional and intermediate habitat for foraging and refuge (Griffitt et al. 1999, Meyer et al. 1996). It has been suggested that reefs built as a series of patches will enhance movement of fishes across the estuary (Breitburg et al. 2000). Location in the intertidal zone is also a contributing factor, as tidal and reef height are important features in the development of oyster reefs and can impact how the faunal community will utilize them (O'Beirn et al. 2000). Opportunistic nekton species will likely take advantage of the short window of intertidal submersion and could be less particular when choosing foraging sites than a subtidal reef with longer times of submergence.

The results of this study are promising for future management and restoration efforts, indicating the potential for similar reef function in fish utilization. These results suggest that current reef-building methodology may be adequate for restoring the same ecosystem services that natural reefs provide. Additionally, these results suggest that small, patch reefs may be successful in promoting nekton utilization. However, these results will likely not be consistent across time and differing environments. Further studies should be conducted on the influence of reef spacing, size, and proximity to other habitats as well as in different estuarine systems under various tidal regimes, with different reef-building techniques, with varying times since creation and through different times of day and season. Oyster reef restorations have and will likely vary in their degree of success and feasibility (Mann and Powell 2007).

As previously mentioned, post-creation monitoring of reefs to determine success has been largely based on oyster density and size. It will be important for management efforts to consider the multiple variables that will affect not only the establishment of the reef, but the local communities that will utilize them. Oyster reef characteristics such as shell cover within a reef, vertical relief, and edge characteristics are all important in the settling of oyster larvae, but also likely affect their habitat functions (O'beirn et al. 2000). Greater vertical relief may provide greater habitat quality for fishes utilizing the reef as refuge. Greater oyster densities have been shown to enhance water quality effects, which in turn has important ecosystem functions for the surrounding faunal communities (Nelson et al. 2004).

Additionally, the majority of species caught in this study represent transient species, which utilize the oyster reefs as one location for shelter and foraging. These include pinfish (*L. rhomboides*), spot (*L. xanthurus*), and the spotfin mojarra (*E. argenteus*), which were caught in the highest abundances in this study. Other commercially important transient species caught in this study were white shrimp (*P. setiferus*), summer and southern flounder (*P. dentatus* and *P. lethostigma*), and white mullet (*M. curema*) (FAO 1980). Far fewer resident species, that utilize the estuary and reefs year long, were caught in this study, with the mummichog (*F. heteroclitus*) and blackcheek tonguefish (*S. plagiusa*) being the only two. Therefore, it may be worthwhile for future studies to incorporate additional gear methods to catch a broader community of nekton.

With the economic and ecological benefits oyster reefs provide, it is important to restore reefs with the same ecosystem functions they would provide naturally. This study found that, 11 years post-creation, reefs can function with similar nekton utilization as their natural counterparts, providing suitable habitat to estuarine fishes and shrimp in Masonboro Sound.

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