COASTAL RECREATIONAL FISHING LICENSE
FINAL PERFORMANCE REPORT

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Category	Year 1	Year 2	Total
Personnel	$50,512.16	$66,842.67	$117,354.83
Fringe	$4,657.46	$13,720.96	$18,378.42
Travel	$0.00	$1,750.00	$1,750.00
Equipment	$0.00	$0.00	$0.00
Supplies	$19,448.07	$7,393.70	$26,841.77
Construction	$0.00	$0.00	$0.00
Contractual	$0.00	$0.00	$0.00
Other	$0.00	$1,571.64	$1,571.64
Total Direct	$74,615.69	$91,278.97	$165,894.66
Indirect	$11,192.36	$13,691.85	$24,884.21
TOTAL	$85,808.05	$104,970.82	$190,778.87

Final Project Summary:

Despite a general appreciation for the importance of high quality habitat in promoting healthy fisheries, few studies have rigorously considered within-habitat variability in fish utilization or landscape-scale (i.e., habitat patch size, connectivity with other habitats) effects on the nursery function of estuarine habitats such as seagrass meadows, saltmarsh creeks, intertidal oyster reefs or subtidal mudflats. This, among other factors, has limited managers' ability to quantitatively link habitat availability and fisheries population dynamics, and has therefore precluded the formal inclusion of habitat in to fishery management plans involving "estuarine-dependent" species. The overarching theme of this CRFL-funded research program has been to quantitatively evaluate the nursery function of seagrass meadows, saltmarsh creeks, intertidal oyster reefs and subtidal mudflats in North Carolina waters for juvenile fishes such as pigfish, southern flounder, gag, gray snapper, speckled trout and red drum. To accomplish this, a number of structural and functional metrics have been considered for both the overall fish community and key recreational species within each habitat. Specific questions have included: (1) At the landscape level, how does isolation/connectivity among different habitat types affect the distribution of juvenile fishes seeking nurseries? (2) How does the proximity of seagrass meadows or saltmarsh affect the evolution and fishery habitat value of restored intertidal oyster reefs? And (3) Using acoustic tagging technology, what can be learned regarding the movement of sub-adult fishes (i.e., red drum and sheepshead) within complex estuarine habitat mosaics, and how much diversity in habitat selectivity can be observed within a species?

The data suggest that habitat utilization by fish and decapod crustaceans is highly context dependent, meaning that use of any particular habitat is affected by proximity of other habitat types, time of day, tidal level and fish age/size. For instance, juvenile gag grouper, gray snapper and lane snapper partition the use of seagrass meadows in relation to how isolated (more lane snapper) or connected (more gag and gray snapper) seagrass habitat is to other structured environments (i.e., saltmarsh). Similarly, sheepshead appear to make ontogenetic migrations from shallow, more protected seagrass meadows to deeper, more isolated seagrass patches with increasing size. These results complicate but also inform how to value seagrass as fishery habitat. Among restored intertidal oyster reefs, landscape setting and habitat connectivity appear equally important in determining the utilization of structured habitats by fishes and crustaceans. For instance, the fine-scale movement patterns of acoustically tagged red drum revealed that oyster reefs adjacent to saltmarsh or seagrass meadows were utilized proportionally much more than equally productive (based on oyster biomass and infaunal invertebrate counts) oyster reefs on isolated mudflats. Notably, however, individual variability in fish behavior/movement was obvious, and complicates the evaluation of habitat "dependency" of fishery species.

The approach summarized in this report - combining intensive community-level surveys with targeted experimental work - has focused on identifying and designating critical (species-specific) fisheries habitat among and within seagrass meadows, saltmarsh creeks, intertidal oyster reefs and subtidal mudflats located in different landscape settings. Results provide a more complete understanding of the factors that drive nursery habitat 'quality' for fishery species in North Carolina. Ultimately, these data are needed to "*identify* [strategic habitat areas] *and recommend management actions to protect and restore habitats critical to North Carolina's coastal fishery resources*" (North Carolina Coastal Habitat Protection Plan; CHPP).

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General Introduction and Background

Coastal estuarine ecosystems have been recognized as important nursery habitats for many of the world's fishery species, and greater than 75% of the United States' commercial landings consist of estuarine-dependent species. Beyond this, however, there remain many questions about what exactly constitutes high-value, even critical, habitat for juvenile fishes. For instance, the North Carolina Coastal Habitat Protection Plan (CHPP; Deaton et al. 2010) states: "*More research is needed on the use of SAV* [as well as other coastal habitats] *as a nursery; by determining optimal conditions for* [ecologically/recreationally important] *species, additional success criteria may be developed for restoration projects.*" Similarly, the 2008 North Carolina Red Drum Fishery Management Plan indicates: "*More field research along North Carolina's coast is needed to determine juvenile habitat preference and examine if recruitment is habitat limited."*

North Carolina estuaries are mosaics of spatially heterogeneous but functionally connected habitats such as seagrass meadows, oyster reefs, saltmarshes and mudflats that each have consequences for many of the processes that affect recruitment to adult stocks and overall population dynamics such as foraging, growth, predator avoidance and refuge from abiotic stress. Because early life-history stages are thought to contain many of the bottlenecks that regulate population size of fish species, understanding how species use and benefit from individual habitat types early in life is critical for the proper management of coastal ecosystems and fish populations. Presently, estuarine habitats in North Carolina waters are subject to a number of large- and local-scale stressors such as eutrophication, global climate change and mechanical disturbance (CHPP). Thus, there is a very real need for research that can identify habitats most conducive to rapid growth and/or increased survival of juvenile fishes. This is particularly true as managers move toward ecosystem-based approaches that take into account age-specific habitat associations and ontogenetic movement patterns that affect recruitment pulses to adult stocks.

North Carolina's Division of Marine Fisheries (NC-DMF) does an excellent job of surveying juvenile fishes over unstructured soft-sediment habitat (Pamlico Sound Survey) and within designated Primary Nursery Areas (PNAs, Estuarine Trawl Survey). Notably, these PNAs are confined to the western, mainland sides of Pamlico and Albemarle Sounds, as well as the narrow sounds south of Cape Lookout. Thus, the dominant seagrass meadows (*Zostera marina*, *Halodule wrightii*) and coastal saltmarshes (*Spartina alternaflora* lined marsh banks/creeks), which stretch from Bogue Sound to Roanoke Island along the inland side of the Outer Banks, are not well surveyed. Oyster reefs are similarly difficult to survey using standard fishery independent gears such as trawls or gillnets, although some survey work inside North Carolina's oyster spawning sanctuaries has occurred. As a result, their function as nursery habitat for ecologically and recreationally important species is not well defined, nor quantitatively comparable to other perceived nurseries. In fact, the most recent community-level assessment of seagrass-associated fishes from North Carolina cited by the CHPP was drawn from the 1970s and early 1980s. This is somewhat surprising given that over global scales these habitats are thought to have tremendously high value as natural capital, particularly due to the provision of nursery habitat for fishes and crustaceans. A partial list of fishes that may be highly dependent on seagrass and saltmarsh habitat in North Carolina waters includes pigfish (*Orthopristis*

chysoptera), gag grouper (*Mycteroperca microlepis*), gray snapper (*Lutjanus griseus*), flounder (*Paralichthys spp.*), spotted seatrout (*Cynoscion nebulosus*) and red drum (*Sciaenops ocellatus)*.

With these concerns and opportunities in mind, we proposed to examine the nursery function of SAV and tidal creek saltmarshes within the high-salinity environments of North Carolina. In addition to their expected nursery value, we identified these habitats for research due to the expertise of our research team, and the fact that these habitats are currently undersampled in fishery-independent programs. Although we initially proposed to not sample oyster reef habitats due to expected incompatibilities with our sampling gears (i.e., trawls) and potential redundancies with other ongoing oyster-reef-based studies, we ultimately decided that any rigorous examination of the value of structured estuarine habitats must be done by employing a holistic, comparative design. Furthermore, we were able to leverage funding from the North Carolina Sea Grant Blue Crab and Shellfish research program to expand the types of gears we included in our sampling (e.g., acoustic tagging), thereby permitting us to sample habitat use of fishes among seagrass, saltmarsh, oyster reef and mudflat habitat. Including oyster reefs as a focal habitat also allowed us to consider the value of restored habitat for fishery production (see Part 2 below).

Perhaps the most dependable avenue for sustaining populations and assuring continued provision of natural ecosystem goods and services is to preserve critical habitat. In marine ecosystems, understanding of the goods and services provided by estuarine and marine habitats is still evolving as degradation from destructive fishing practices, land development and reduced water quality threaten the biointegrity of estuarine habitats. Reliance on marine habitat preservation is imperiled by dramatic alterations in the environmental and biological quality of coastal ecosystems such that habitat recovery from impairment is often inhibited and in some instances, habitat restoration may be the only solution. Assessment of whether degraded or restored habitats provide the biological functions associated with intact natural habitats will assist evaluations of the efficacy of conservation and restoration efforts.

Oyster reef (*Crassostrea virginica*) habitat is an example of an estuarine habitat which has been so widely reduced that natural recovery has been impeded in many regions by a lack of suitable settlement habitat and accelerated adult mortality rates. Management of oysters as a single-species resource to be exploited rather than as a habitat to be preserved resulted in the current threatened status of this critical habitat. According to the North Carolina Oyster Restoration and Fishery Management Plan, the United States oyster fishery was one of the most valuable fisheries in the nation, traditionally ranking among the top 10 species in total annual value. Currently, oyster harvest levels in North Carolina are roughly 1/20 of what they were at the beginning of the 20th century. The decline in harvest levels is a consequence of a combination of factors, including destruction of habitat from harvesting practices, overfishing, disease, reduced water quality, and siltation. While the relative impact of each of these factors has been debated, habitat degrading harvest techniques such as mechanical dredging and hand tonging have been attributed as the primary cause of the fishery collapse by removing the vertical relief characteristic of historical reefs. Oyster reefs are biogenic habitats in which settling oyster larvae continue to build upon the foundation established by previous generations of oysters. Fishing activities over the past century reduced not only the adult oyster population but also reduced the amount of available substrate for settling oysters. Given that traditional harvesting techniques

remove the foundation necessary for sustaining plentiful oyster harvests, large-scale harvesting of oysters results in the destruction of the very habitat the fishery depends on and affects species associated with this estuarine habitat. In addition, factors such as oyster diseases, poor water quality, and siltation exacerbate the cumulative effects of harvesting practices and combat the recovery of oyster populations to historical levels.

If harvested oysters are not replaced by a similar substrate, the future availability of oysters will continue to decline. Restoration initiatives have been developed in an attempt to return degraded habitats such as oyster reefs to their original state. These programs introduce previously harvested shell resources or man-made shell alternatives into the estuarine system to compensate for harvested habitat. In order to combat the continuing decline of the oyster fishery, North Carolina annually allots $500,000-1,000,000 to restore shellfish habitat. Over the last decade, annual harvest value of the entire NC oyster industry (natural and restored) has ranged from $1,200,000-2,800,000 worth of oysters are harvested in the state each year (NC-Division of Marine Fisheries-Statistics). Fishery officials need to consider the economic value of additional benefits of oyster restoration to justify continued costs that probably exceed the market value of oysters harvested from restored reefs.

In addition to supporting a valuable fishery in North Carolina, oysters provide a number of ecosystem services including the stabilization of neighboring saltmarshes, improvement of water quality, carbon sequestration (see attached manuscript), and the provision of refuge, food, and nursery grounds for estuarine animals. Natural oyster beds also support more algae, and invertebrates than the surrounding soft-bottom environment. Recently, research on *subtidal restored* reefs found that a major ecological and economic service of oyster reefs is the provision of bottom habitat for commercially valuable species. In a comprehensive review of all available literature that provides quantitative data on abundance of fish and crustaceans on oyster reefs and adjacent unstructured bottom, UNC-based researchers estimated that deep, subtidal oyster reefs augment fish production over adjacent habitats by 2.5Kg/10 m^2. However, the potential value of oyster beds as habitat for economically important species in the intertidal region in close proximity to SAV and saltmarsh habitats has not been adequately addressed. A clear understanding of this value is necessary in order to make informed policy decisions regarding the true costs and benefits of oyster restoration.

Despite indications that oyster reefs also provide valuable ecosystem services, they continue to be managed as a single-species fishery rather than protected as critical habitat. This oversight has resulted in the widespread destruction of an important estuarine habitat. Oyster reefs constitute the only natural hard substrate in the predominantly soft-sediment environment, providing essential habitat for many organisms including sessile, filter-feeding invertebrates. The highly irregular surface of oyster shells provides refuge for mobile invertebrates and small fish by allowing organisms to operate in three dimensions. Additional research on the role of oyster reef habitat and the economic value of its services to estuarine ecosystems is necessary in order to determine an appropriate balance between utilization and protection.

The transient nature of the intertidal region of estuaries and beaches requires many mobile organisms to utilize multiple habitat patches in response to the tidal cycle and other factors. Various shallow water and intertidal estuarine habitats exist within estuaries, forming a unique

patchwork mosaic of 'landscapes'. While traditional studies have focused on interactions within one specific habitat or patch, several mobile invertebrates and fish species are not limited to an individual patch or habitat. Thus, studies within these systems are not appropriately scaled, and we designed our experiments to fill gaps in our understanding of habitat diversity in supporting robust fishery stocks. Furthermore, the natural tidal cycle common to Atlantic estuarine systems necessitates that a fish foraging on an intertidal reef or within a saltmarsh at high tide seek refuge in nearby subtidal habitat when these habitats emerge from the water at low tide. Thus, it is logical that the 'landscape' or arrangement of habitat patches in the intertidal region affects the distribution and abundance of organisms in that area. The size and distribution of patches is especially important for species that require patches of minimum size or a specific arrangement of patches. In order to restore the structure and function of a particular habitat, the habitat must be considered within the context of the larger landscape. Consequently, the protection of any economically valuable habitat or species relies on the linkages between all the habitats in a particular landscape. While landscape effects have been investigated in saltmarshes and seagrass beds in order to enhance management, research has not focused on managing oyster reefs from a landscape perspective. Oyster reefs are typically found in three environments in intertidal systems: on points extending outward from the ends of saltmarshes, on the fringes of saltmarshes with seagrass habitat on the other side (the lower end), and on bars isolated from vegetated habitats. An understanding of the linkages between oyster reefs and other intertidal and shallow subtidal estuarine habitats will help streamline management and protection of these areas and aid in restoration decisions.

Part 1: Initiation of seagrass and saltmarsh trawl survey to asses habitat use and nursery function

Objectives

The unifying theme of this component of our CRFL-funded research will be to quantitatively describe the nursery function of seagrass meadows, saltmarsh banks/creeks and shallow-water mudflat habitats. Our goal is that coastal fisheries and habitat managers can use these data to rank the "value" of individual habitats (on unit-area and overall bases) at the landscape level, and that this information can guide resource managers in prioritizing conservation plans to maximize ecosystem function and fishery production. Reaching this goal will be accomplished by examining interconnected metrics of habitat value: (1) What are the relative densities of fishes among nursery habitat alternatives within SAV and wetland landscapes? Furthermore, what are the biotic and abiotic correlates with the observed densities of key species within and among juvenile habitats? And (2) what are the relative feeding rates (stomach fullness and contents) and growth rates (daily otolith increment widths) of key finfish species among nursery habitat alternatives?

Methods

All field surveys and specimen collections occured within 2 study sites where each of our target habitats can be found (Fig. 1.1). The first site was located within the Rachel Carson National Estuarine Research Reserve, located in Back Sound near the Beaufort Inlet. The second site was located in the southwestern Core Sound. We selected these sites because they represent a range of environmental conditions (wave exposure, salinity, boat traffic, etc.). Within each site, we will designate 4 habitat types for study: seagrass meadows (eelgrass/shoalgrass mix); saltmarsh creek, seagrass-saltmarsh boundary; and mudflat. In Core Sound, we also sampled a fifth landscape: saltmarsh creek containing seagrass (shoalgrass, Fig. 1.1.) Within each of these landscapes, we identified 3 replicate stations (Middle Marsh total # samples per month = 2 samples per station * 4 habitats * 3 replicate stations = 24; Core Sound total # samples per month = 2 samples per station * 4 habitats * 3 replicate stations = 30). We include seagrass-saltmarsh boundary habitat to evaluate how landscape features (ie, habitat connectivity) impact the nursery-role of North Carolina estuaries. Previously, IMS-based researchers found that seagrass-saltmarsh interfaces provided blue crabs (*Callinectes sapidus*) with increased foraging opportunities. Whether this is true or not for fishes remains unclear, although it is thought that red drum are highly dependent on marsh edge habitat (CHPP).

To determine the relative abundance of fishes and decapod crustaceans (crabs, shrimps, etc) in seagrass meadows, saltmarsh creeks, seagrass-saltmarsh boundaries and mudflats, we conducted monthly sampling from May-Nov in each potential nursery habitat via trawl sampling. This window of time brackets when most winter and spring spawned fish occupy shallow-water habitats. During each monthly survey, 2 replicate trawls (5 m headrope) were made at each station (N = 54 total collections each month). All trawls occurred during daylight hours and were conducted from small (<8 m) research vessels (shallow-drafting skiffs) owned by the Institute of Marine Sciences. We typically made two-minute tows during each trawl deployment (with distances covered during each tow recorded using an onboard GPS), which is sufficient for

determining within- and between-patch variability in unstructured (mudflat) and structured (seagrass) habitats (Fodrie unpublished).

All fishes and crustaceans captured in trawls were enumerated and weighed (to the nearest 1 g). These collections allowed for determination of species-specific densities (ie, gear-specific catches-per-unit-effort), community diversity, as well as overall species composition (dominant taxa or guilds) and size structure in relation to habitat type. These data were used as components of a multifaceted approach for determining the nursery capacity of seagrasses, saltmarshes and mudflats.

At the completion of each trawl deployment, we recorded depth, temperature, dissolved oxygen and salinity using an onboard GPS, sonar, and handheld YSI. Qualitative observations of bottom type (seagrass or saltmarsh presence/absence and species type) were recorded at the end of each deployment using visual analysis. Also, an 11.4 cm^2 x 10 cm deep sediment core was taken from each station (N = 54) in June, 2012, to quantitatively measure local habitat characteristics (e.g., seagrass or marsh plant density and aboveground biomass, sediment TOC and mean sediment grain size). During July and Dec of 2010, an additional 11.4 cm^2 x 10 cm deep core was taken for enumeration of benthic macrofauna. Using standard univariate (ANOVAs) and multivariate (MDS, multiple linear regression, regression trees) approaches, we used these catch and environmental data to explore biotic and abiotic controls on the habitat utilization of juvenile fishes.

For each of the habitats we sampled to characterize juvenile fish distributions, we also collected specimens each month to generate measures of habitat-specific feeding and growth rates. In order to collect enough fishes for robust comparisons among habitats, our approach was to estimate growth and feeding rates for the three most abundant species collected during each month, regardless of their recreational value (eg, pinfish [*Lagodon rhomboides*]). Of all remaining species, we also selected the three most abundant recreationally targeted species for analyses, regardless of their overall ranked abundances (eg, summer flounder, speckled trout, red drum).

Estimates of habitat-specific growth are being generated [UNDERWAY, NOT YET COMPLETED] by measuring the widths of the final 14 daily increments deposited within the otoliths (ear stones) of individual fishes (ie, the last two weeks of growth before collection). Otoliths have already been extracted from each juvenile fish, and the left sagittal otoliths will be used for microstructure analysis. At the same time otoliths were dissected, stomachs were also removed and preserved in a –20º C freezer for stomach content analyses (see directly below). Sagittal otoliths have already been cleaned and rinsed with distilled water, and placed in labeled envelopes. These otoliths will be embedded in cyanoacrylate and polished along the sagittal plane with 30 and 3 μm lapping film as well as a wet polishing cloth. This will expose daily growth increments along the postrostral axis. Immersion oil will be used to clarify increments, and digital images of otoliths will be captured using a dissecting microscope and Media Cybernetics Evolution VF digital camera connected to a PC operating with ImagePro Plus (5.0) software available at the Institute of Marine Sciences. Two readers will determine increment patterns (widths) of the last 14 growth increments from each photo. Growth rates comparisons

among habitats will be made for each species during each month using standard univariate techniques (ANOVA, ANCOVA or non-parametric analogues).

Stomach contents of these same fishes have been analyzed in the laboratory using standard methods. Fish were blotted dry with paper towels and weighed to the nearest 0.001 g. The stomachs were then removed (as noted above), blotted and weighed as well. Prey items were extracted from each stomach, and the empty stomach and its contents were blotted and weighed separately (allowing us to calculate estimates of stomach fullness). Using a dissecting microscope, prey were separated and identified to the lowest taxonomic level possible. Blotted wet weights of prey taxa were recorded to the nearest 0.001g. The degree to which prey taxa were digested was also categorized (e.g., 20%, digested). Stomach content data have been entered in to an Excel database (included with our report), but we have not yet been able to include these data in our statistical analyses and therefore only report basic summary statistics below (see Results).

The use of indices (e.g., Index of Relative Importance) to describe patterns in fish diets has been criticized because these metrics tend to obscure patterns. Thus, comparisons among habitats and months will be made using MANOVA (using the weights of each prey taxa in juvenile fish stomachs) in order to explore the foraging opportunities associated with each habitat type.

Results

Our trawl surveys have resulted in the collection and enumeration of 139,663 fishes representing a minimum of 70 species (Table 1.1). By far, pinfish dominant these shallow-water communities, comprising 82% of all individuals we captured. Among economically prized species, spot (*Leiostomus xanthurus*), blue crabs (*Callinectes sapidus*), flounder (*Paralichthys spp*), sheepshead (*Archosargus probatocephalus*), gag grouper (*Mycteroperca microlepis*) and gray snapper (*Lutjanus griseus*) were all commonly encountered (Table 1.1). Red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), lane snapper (*Lutjanus synagris*), striped mullet (*Mugil cephalus* – which have particularly low capture efficiency in trawl nets), bluefish (*Pomatomus saltratrix*), black sea bass (*Centropristis striata*), kingfish (*Menticirrhus spp*), black drum (*Pogonias cromis*), stone crab (*Menippe mercenaria*) and black grouper (*Mycteroperca banaci*) were also collected from seagrass habitat, although at low abundances (Table 1.1).

Among our *a priori* landscape types [mudflat (MF), isolated seagrass patches (SG), seagrass-saltmarsh interfaces (I), saltmarsh creeks containing seagrass (MX) and saltmarsh creeks without seagrass (SM)], we observed notable differences in seagrass cover and correspondingly the catch rate of fishes. By shoot density, shoalgrass (Halodule wrightii) was the dominant seagrass species among all three seagrass landscapes (SG, I, MX; > 2,000 shoots m^{-2}), and was also recorded in sparse patches within saltmarsh creeks (SM; ~ 500 shoots m^{-2}). Within isolated seagrass patches and at the seagrass-saltmarsh interface, we also recorded eelgrass at average densities of ~ 500 shoots m^{-2}) (Fig. 1.2A). The average height of seagrass shoots also differed among sites, with the tallest shoots (~ 30 cm) observed along the seagrass-saltmarsh interface (Fig. 1.2B). These tallest shoots were mostly eelgrass. Shoots within isolated seagrass patches and within saltmarsh creeks (with seagrass) averaged ~ 20 cm high.

The overall catch rate (fishes per km towed: CPUE) was significantly affected by the density and character of seagrass. Between vegetated (SG, I, MX) and unvegetated (MF, SM) sites, catch rates were > 5 times higher in landscapes that were characterized as "seagrass dominated" (Fig. 1.3A). Furthermore, the catch rate of fishes among sites scaled nearly linearly with the average canopy height of seagrass (Fig. 1.3B).

Before considering how these factors affected landscape-scale habitat use of recreationally and commercially valued species, we note that considerable seasonal variability was observed and may affect how managers or scientists measure fish-habitat linkages. Across all species, CPUE was highest in the spring or early summer, with peak rates of 3,000 fishes km-towed^{-1} recorded in July. Subsequently, catch rates decreased consistently across months to a low of < 500 fishes km-towed^{-1} in November (the last month in our annual surveys). Likely, the steady decrease in catch rates after July reflects the seasonal senescence of eelgrass (particularly within the 'I' landscapes) – especially at the Middle Marsh study site (Fig. 1.4). Among species, clear unimodal seasonal maxima in catch rates were almost always observed, although the timing of maximum catch rates varied a considerable amount among individual taxa:

- Pinfish: represented the majority of our overall catch, it is therefore not surprising that their seasonality tracked that of our overall catch trends (Fig. 1.5).
- Spot: were most abundant in our surveys early in the year, with peak abundances (>400 fish km-towed^{-1}) in May. Densities quickly decreased to < 100 fish km-towed^{-1} by June and remained low throughout the remainer of the year (Fig. 1.5).
- Croaker: were most abundant during June, although catch rates were extremely variable during most months (Fig. 1.5).
- Pigfish: abundances peaked in July at > 100 fish km-towed-1, and then steadily decreased throughout the remainder of the year (Fig. 1.5).
- Red drum: were largely absent in our surveys until September, and we observed highest (although variable) catch rates during November. Although catch rates were low during the spring, our surveys suggested a mid-summer minimum in CPUE for this species (Fig. 1.6).
- Sheepshead: were primarily collected over a four-month period (June-September), with peak abundances during July and August (Fig. 1.6).
- Spotted seatrout: were collected beginning in August, with peak catch rates of juveniles observed during September (Fig. 1.6).
- Gray snapper: demonstrated similar seasonal catch patterns as spotted seatrout. We began collecting gray snapper in August and observed peak catch rates in September. Although never very common, catch rates remained relatively high during October and then began to decline in November (Fig. 1.7). As gray snapper are generally considered a more tropical species, it is unclear if these juveniles exit the estuary as temperatures decrease, or experience significant mortality due to thermal stress.
- Gag grouper: could be caught as early as June and were captured on a regular basis throughout September. Maximum catch rates were observed in July (Fig. 1.7).
- Lane snapper: were caught in low numbers during August and Sept, and reached a maximum CPUE later than most other species (October) (Fig. 1.7). As with gray snapper, lane snapper are generally considered a more tropical species, it is unclear if these

juveniles exit the estuary as temperatures decrease, or experience significant mortality due to thermal stress.

- Blue crabs: were most abundant during the spring, and decresed steadily in CPUE throughout the year in our surveys (Fig. 1.8).
- Penaid shrimp: demonstrated seasonal patterns similar to blue crabs, with peak abundance observed during May, followed by a steady decrease in CPUE during summer and fall (Fig. 1.9).

Averaged across months, overall catch rates were highest at the seagrass-saltmarsh interface sites we sampled, with saltmarsh creeks with seagrass and isolated seagrass patches also being represented by catch rates elevated over those observed in mudflat or saltmarsh landscapes (Fig. 1.9). However, the overall biomass of fishes did not differ among any of our vegetated landscapes (SG, I, MX). For all three of these landscapes, the capture rate of fish (and crustacean) biomass was nearly an order-of-magnitude greater than CPUEs observed within unvegetated landscapes (Fig. 1.10). Similarly, species richness was similar, and relatively high, among the seagrass, interface and creek-with-seagrass landscapes. Across all months, 6-7 species were typically captured during each two-minute tow within these landscapes (Fig. 1.11). Although not as densely populated, saltmarsh creeks without seagrass cover still produced > 5 species per two-minute tow. Mudflat habitats were typically defined by < 2 species captured in each individual tow (Fig. 1.11).

Among notable fishery species, fishes partitioned habitat use among landscapes in clear and interesting ways:

- Red drum: relied almost exclusively on saltmarsh creek habitat, but were notably more abundant in creeks that were characterized by significant seagrass (shoalgrass) cover (Fig. 1.12A).
- Spotted seatrout: were distributed similarly to red drum, although a small fraction of trout were collected from seagrass-saltmarsh interface habitat (Fig. 1.12B).
- Flounder: as a group include both summer and gulf species (and perhaps a small percentage of southern flounder too), but identifications on small individuals (< 30 mm) could not always be made in the field and therefore we have grouped all members of the genus *Paralichthys* together. Somewhat surprisingly, flounder were considerably more abundant in vegetated landscapes relative to unstructured habitat. Moreover, Flounder were twice as abundant in seagrass landscapes defined by some direct connection to saltmarsh (I, MX) relative to isolated seagrass patches (Fig. 1.12C).
- Sheepshead: demonstrated interesting ontogenetic patterns in habitat use. Among vegetated habitats, sheepshead densities were greatest in the most protected environments (MX), decreasing by factors of 2 (I) and 5 (SG) as we moved in to more open seagrass landscapes. Also, very few sheepshead were captured over mudflat bottom (Fig. 1.13A). Conversely, the highest catch rate of sheepshead biomass was within mudflat habitats, with catch rates of biomass declining rapidly as we moved toward saltmashes (regardless of seagrass presence) (Fig. 1.13B). These results indicate an importance difference in the size of sheepshead among landscapes – smaller fish utilized seagrass habitat in close proximity to saltmarsh, while larger individuals moved out towards open (unvegetated) bottom least connected to saltmarsh habitat.

- Gag grouper, gray snapper and lane snapper: are all species defined as estuarine residents only during the juvenile stage. Despite similarities in offshore-inshore habitat migrations among these species, however, we noted clear spatial partitioning of seagrass landscapes among juvenile gag and snappers. Gag were primarily collected from seagrass-saltmarsh interface habitat (I), and because gag recruit earlier in the year than most other species, they are able to occupy these sites when eelgrass cover is near its seasonal maxima (Fig. 1.14A). Most gray snapper were collected from saltmarsh creeks containing seagrass cover (Fig. 1.14B), while lane snapper were largely collected from isolated seagrass patches (Fig. 1.14C). The spatial partitioning of seagrass use between snapper species suggests the potential for competitive or agonistic behaviors to affect habitat selection within the genus *Lutjanus* in NC estuarine landscapes.
- Blue crabs and shrimp: were most abundant in saltmarsh creeks containing seagrass (Fig. 1.15A-B), although blue crabs demonstrated a more even distribution among structured habitats. As these invertebrates are common in the diets of red drum and spotted seatrout, the distribution of those predatory fishes are likely related to the distribution of their potential prey.
- Spot: were most common in saltmarsh creeks without seagrass cover, but were also relatively common in all three seagrass landscapes (Fig. 1.16A).
- Croaker: were rarely collected, with the only significant number of individuals being found within saltmarsh creeks that did not contain seagrass (Fig. 1.16B).
- Pigfish: were primary collected from vegetated habitats (SAV or saltmarsh), but were most commonly collected in seagrass habitat isolated from saltmarsh habitat. In general, pigfish catch rates appeared to decrease as the transition was made from seagrass to saltmarsh environments (Fig. 1.16C).

Interpretations (early)

At the community level, seagrass and saltmarsh habitats are consistently associated with elevated catch rates of fishes. Among species, however, landscape-level habitat associations were markedly different among taxa, and this could significantly affect how estuarine habitat is eventually integrated in to the fishery management plans of econically prized species.

Table 1.1. Percent abundance of captured species across all landscapes from 2010-2012 trawl sampling.

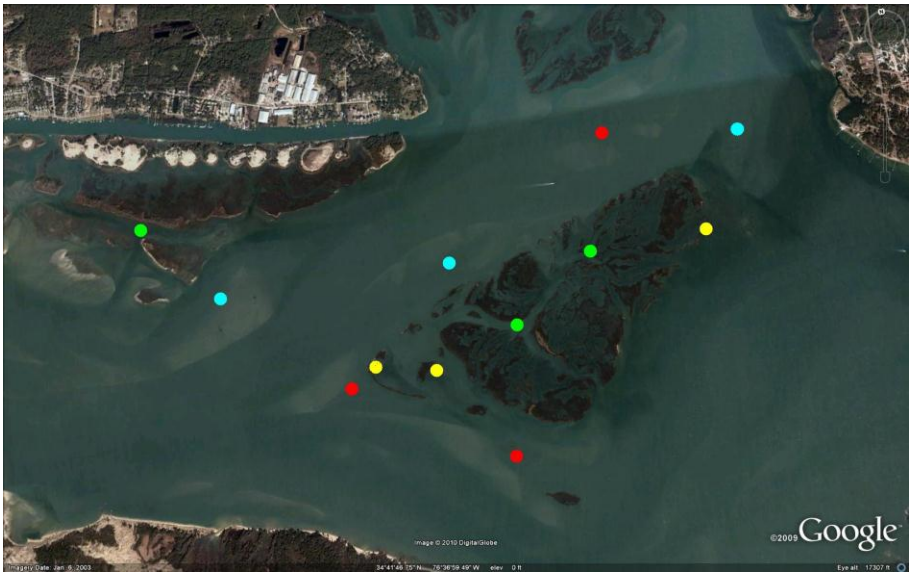
Scientific Name	Common Name	% Abundance
Lagodon rhomboides	Pinfish	81.98
Leiostomus xanthurus	Spot	5.63
Orthopritis chrysoptera	Pigfish	3.84
Penaeus spp.	Commerical Shrimp	2.35
Gerridae	Mojarra	1.55
Callinectes sapidus	Blue Crab	0.97
Paralichthys spp.	Flounder spp	0.86
Archosargus probatocephalus	Sheepshead	0.41
Bairdiella chrysoura	Silver Perch	0.34
Stephanolepis hispidus	Planehead Filefish	0.29
Diplodus holbrooki	Spottail Pinfish	0.25
Tozeuma carolinense	Arrow Shrimp	0.16
Opsanus tau	Oyster Toadfish	0.16
Palaemonetes spp.	Common Shore Shrimp	0.15
Anchoa spp.	Anchovy	0.14
Fundulus spp.	Killifish	0.12
Sygnathus spp.	Pipefish	0.10
Mycteroperca microlepis	Gag Grouper	0.08
Symphurus spp.	Tonguefish	0.06
Synodus foetens	Inshore Lizardfish	0.06
Hippolyte spp.	Grass Shrimp	0.05
Lutjanus griseus	Gray Snapper	0.04
Chilomycterus schoepfi	Striped Burrfish	0.04
Chaetodipterus faber	Spadefish	0.03
Libinia ferreirae	Spider Crab	0.03
Blenniidae	Blenny	0.03
Sesarma reticulatum	Marsh Crab	0.03
Sciaenops ocellatus	Red Drum	0.02
Cynoscion nebulosus	Speckled Sea Trout	0.02
Argopecten irradians	Bay Scallop	0.02
Sphoeroides maculatus	Northern Puffer	0.02
Lutjanus synagris	Lane Snapper	0.02
Citharichthys spp.	Whiff	0.02

Table 1.1. Continued.

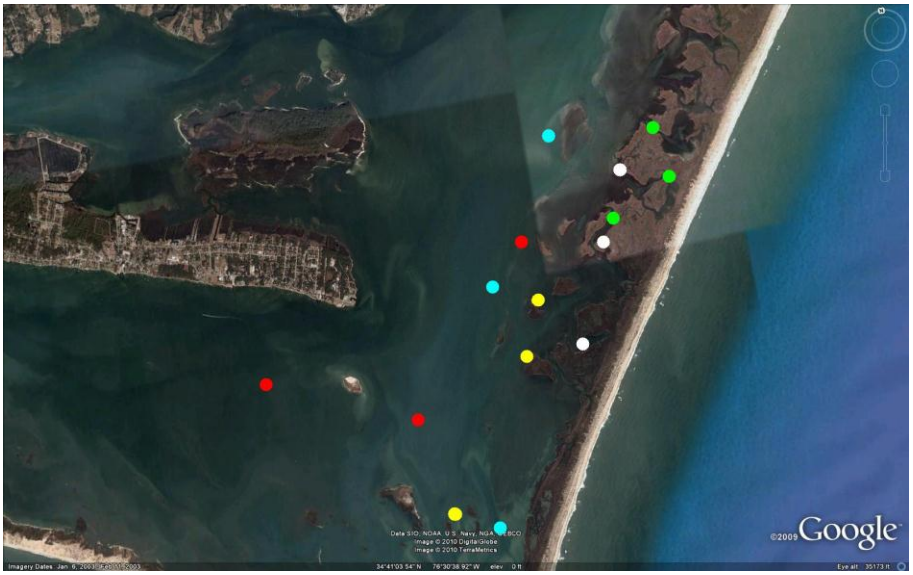
Lolliguncula brevis	Brief Squid	0.01
Alpheus heterochaelis	Ghost Shrimp	0.01
Dasyatis americana	Southern Stingray	0.01
Menidia spp.	Silverside	<0.01
Chloroscombrus chrysurus	Atlantic Bumper	<0.01
Sphyraena spp.	Sennet	<0.01
Portunus spinimanus	Blotched Swimming Crab	<0.01
Brevoortia tyrannus	Atlantic Menhaden	<0.01
Stenotomus caprinus	Longspine Porgy	<0.01
Gymnura micrura	Butterfly Ray	<0.01
Micropogonias undulatus	Atlantic Croaker	<0.01
Triglidae	Searobin	<0.01
Gobiidae	Goby	<0.01
Mugil cephalus	Striped Mullet	<0.01
Paralichthys oblongus	Fourspot Flounder	<0.01
Ophiodermatidae spp.	Brittle Star	<0.01
Tautoga onitis	Tautog	<0.01
Pomatomus saltatrix	Bluefish	<0.01
Trinectes maculatus	Hogchoker	<0.01
Hippocampus spp.	Seahorse	<0.01
Anguilla rostrada	American eel	<0.01
Centropristis striata	Black Sea Bass	<0.01
Aluterus heudelotii	Dotterel Filefish	<0.01
Dasyatis sabina	Atlantic Stingray	<0.01
Aluterus schoepfii	Orange Filefish	<0.01
Portunus gibbesii	Iridescent Swimming Crab	<0.01
Menticirrhus spp.	Kingfish	<0.01
Harengula jaguana	Scaled Sardine	<0.01
Squilla empusa	Mantis Shrimp	<0.01
Pogonias cromis	Black Drum	<0.01
Diplectrum formosum	Sand Perch	<0.01
Scomberomorus spp.	Mackerel	<0.01
Menippe mercenaria	Stone Crab	<0.01
Mycteroperca bonaci	Black Grouper	<0.01
Selene vomer	Lookdown	<0.01
Mustelus canis	Smooth Dogfish	<0.01
Myliobatis freminvillii	Bullnose ray	<0.01

Figure 1.1. Map of trawl survey sites in (A) Middle Marsh (Rachel Carson) and (B) Core Sound among (C) a number of seagrass and saltmarsh landscape types.

A.



B.



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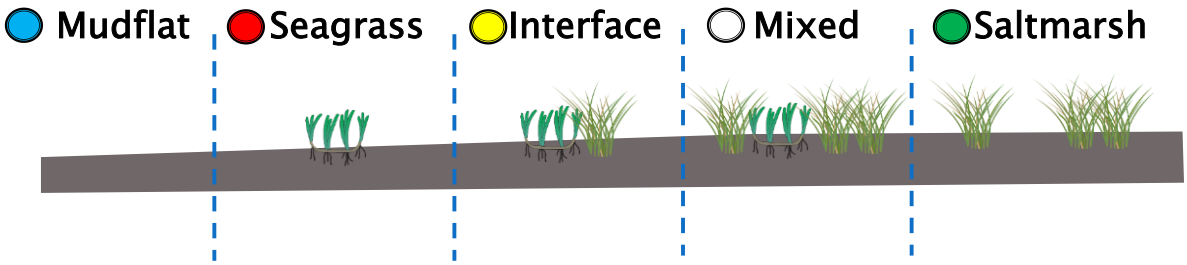
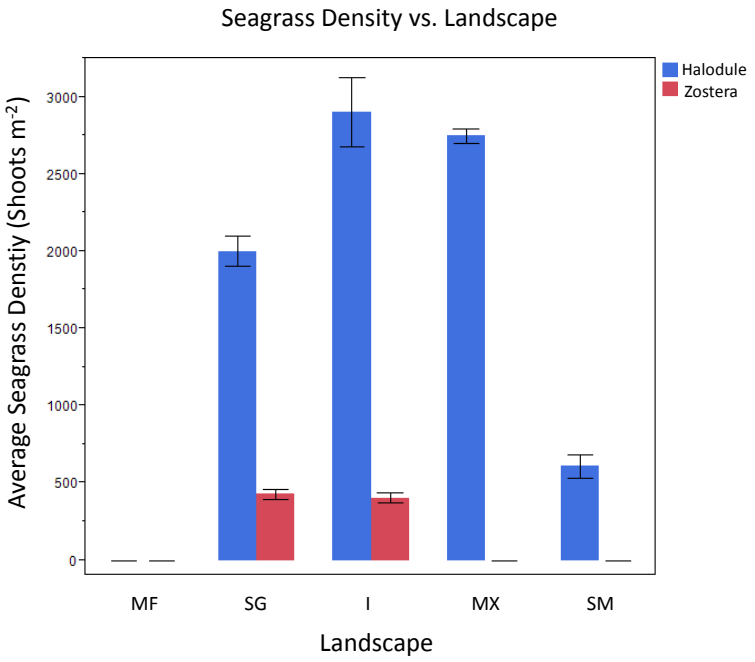


Figure 1.2. Seagrass shoot (A) density and (B) height across landscapes. Data are shown as means ± 1 standard error.

A.



B.

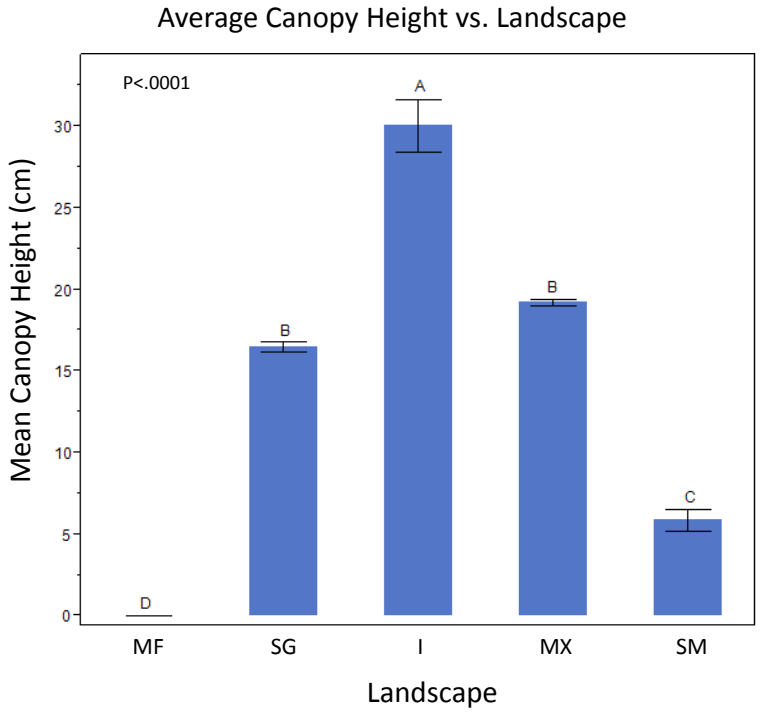
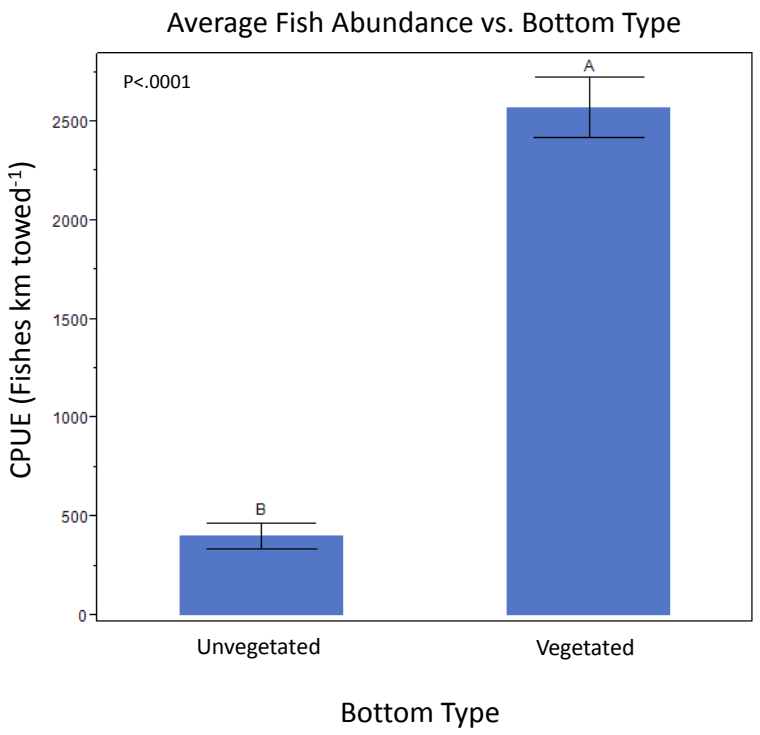


Figure 1.3. Relationships between overall fish catch rate and seagrass habitat characteristics (A: shoot density; B: shoot height). Data are shown as means ± 1 standard error.

A.



B.

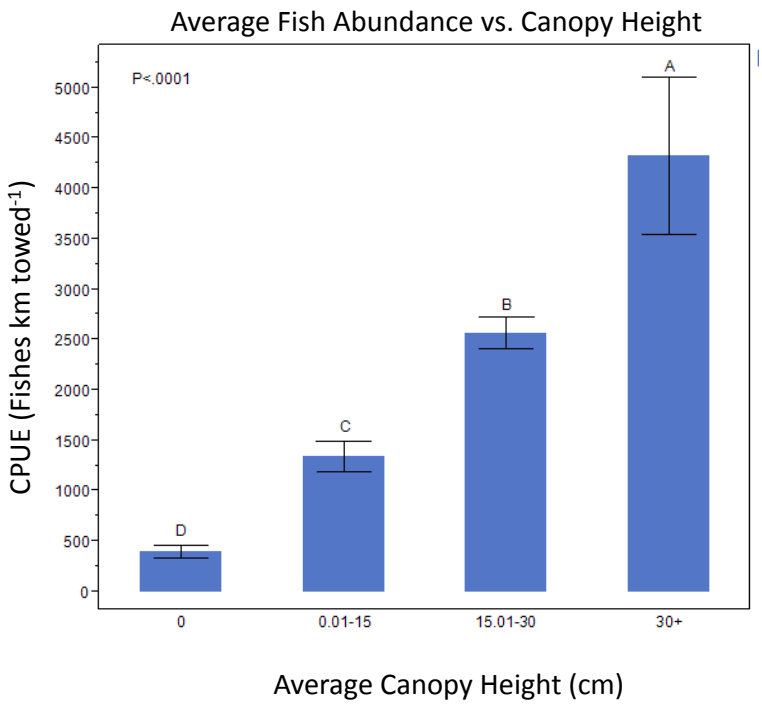


Figure 1.4. Seasonality of overall catch rate of fishes during 2010-2012. Data are shown as means ± 1 standard error.

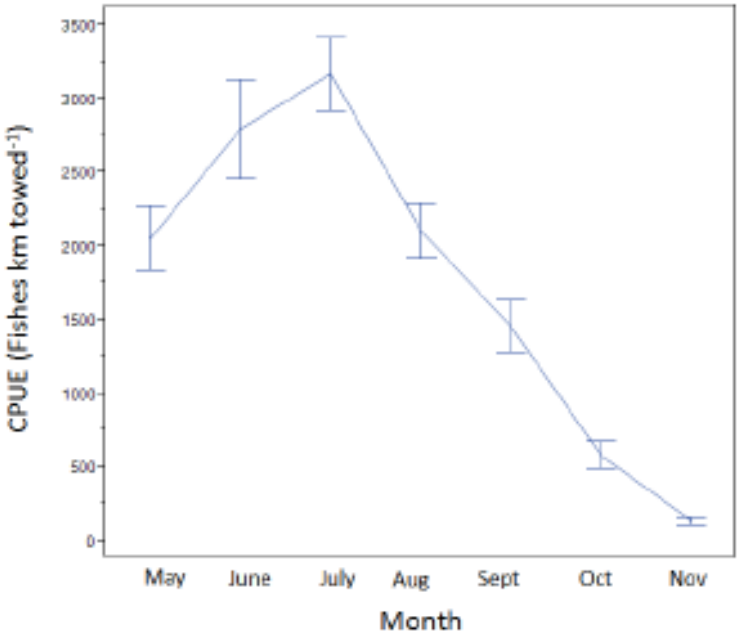


Figure 1.5. Seasonality of catch rate for select fishes during 2010-2012. Data are shown as means ± 1 standard error.

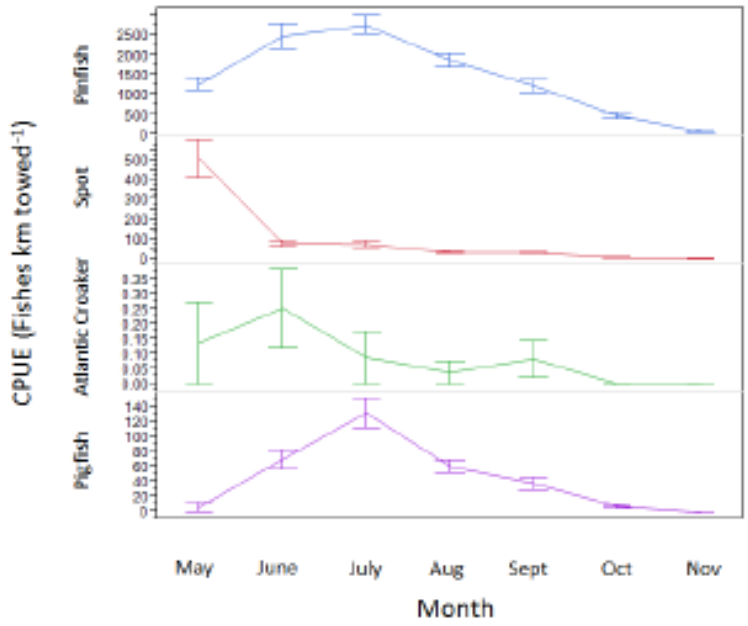


Figure 1.6. Seasonality of catch rate for select fishes during 2010-2012. Data are shown as means ± 1 standard error.

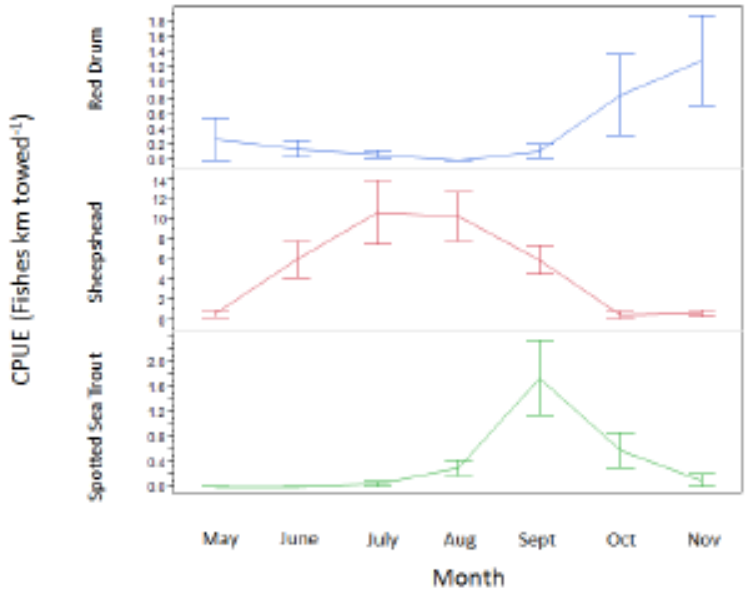


Figure 1.7. Seasonality of catch rate for select fishes during 2010-2012. Data are shown as means ± 1 standard error.

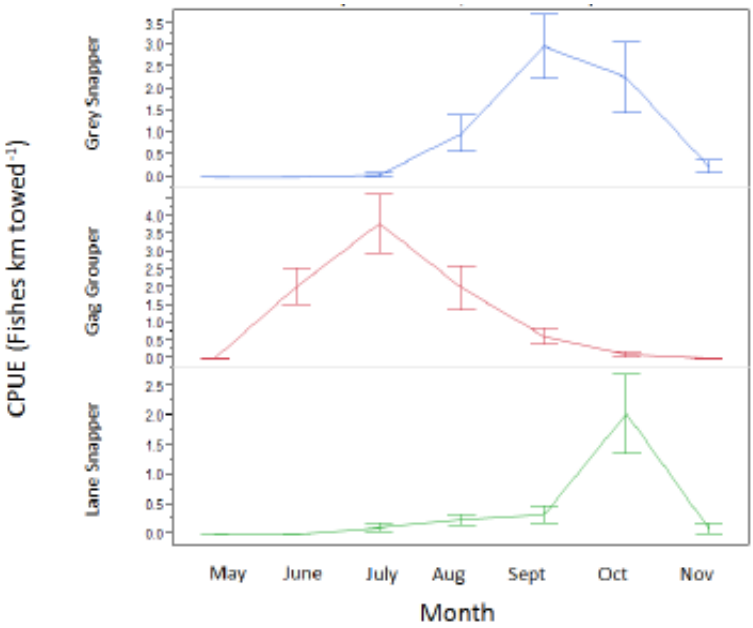


Figure 1.8. Seasonality of catch rate for select invertebrates during 2010-2012. Data are shown as means ± 1 standard error.

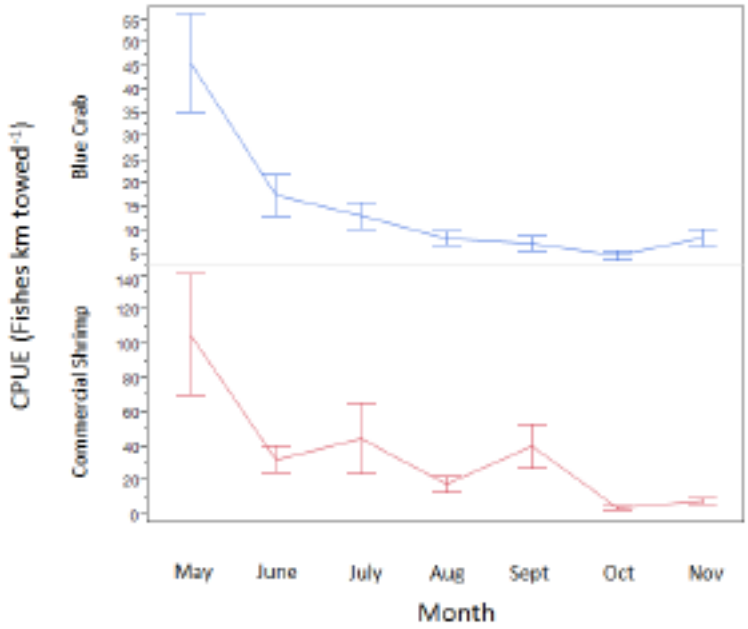


Figure. 1.9. Average catch rate of fishes and invertebrates across landscapes. MF = mudflat. SG = isolated seagrass meadow. I = seagrass-saltmarsh interface. MX = saltmarsh creek with seagrass. SM = saltmarsh creek without seagrass. Data are shown as means ± 1 standard error.

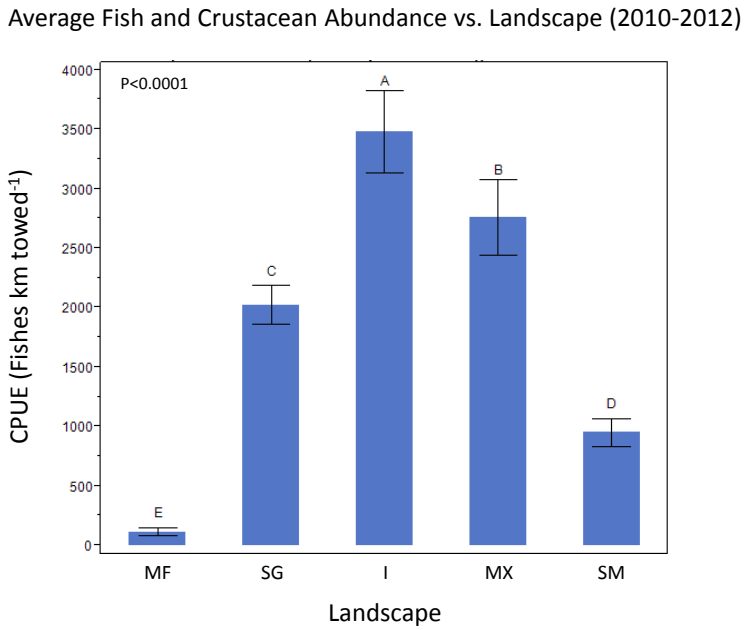


Figure 1.10. Average catch rate of fish and invertebrate biomass across landscapes. Data are shown as means ± 1 standard error.

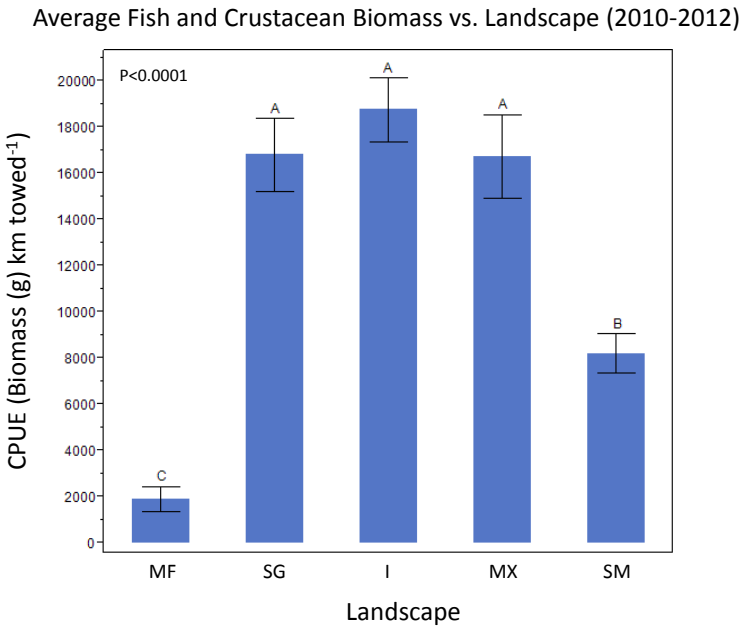


Figure 1.11. Average species richness per trawl sample across landscapes. Data are shown as means ± 1 standard error.

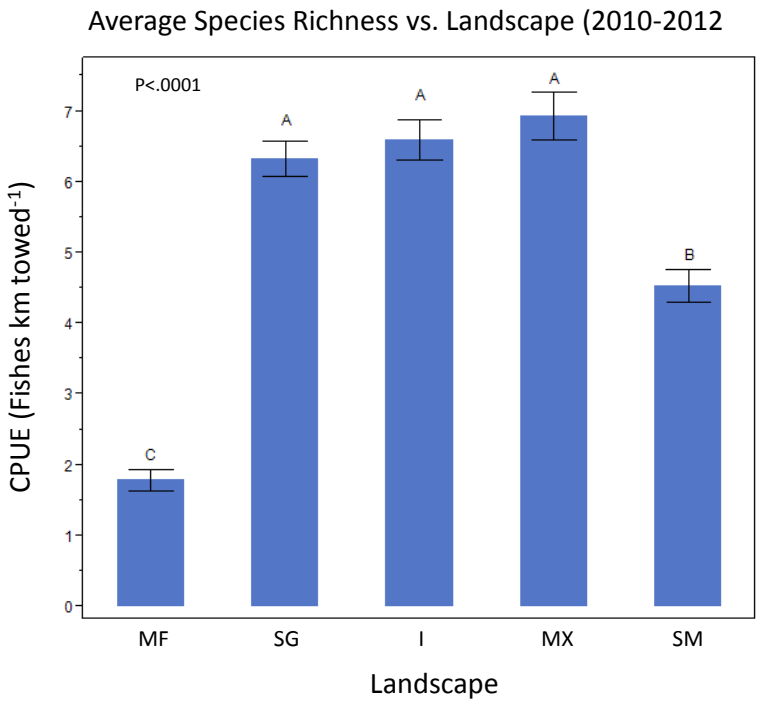
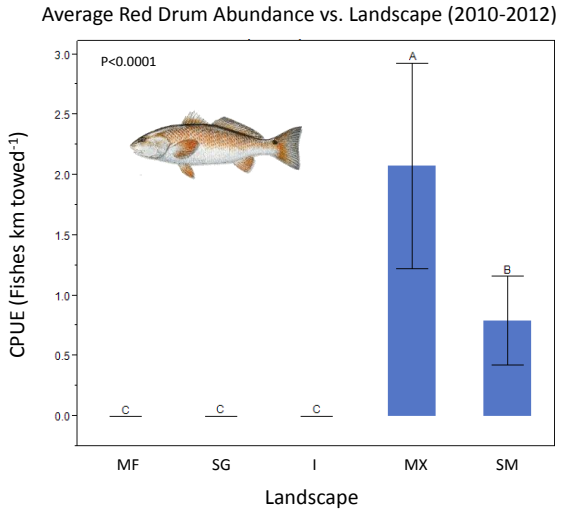
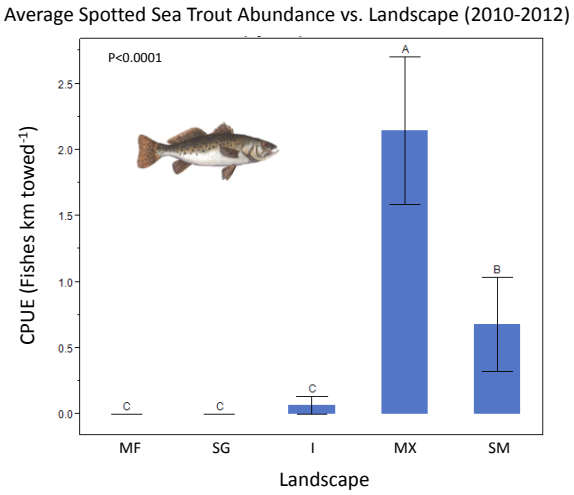


Figure 1.12. Average catch rate of recreationally important juvenile (A) red drum, (B) speckled seatrout and (C) flounder (Paralichthys spp.) among seagrass and saltmarsh landscapes. Data are shown as means ± 1 standard error.

A.



B.



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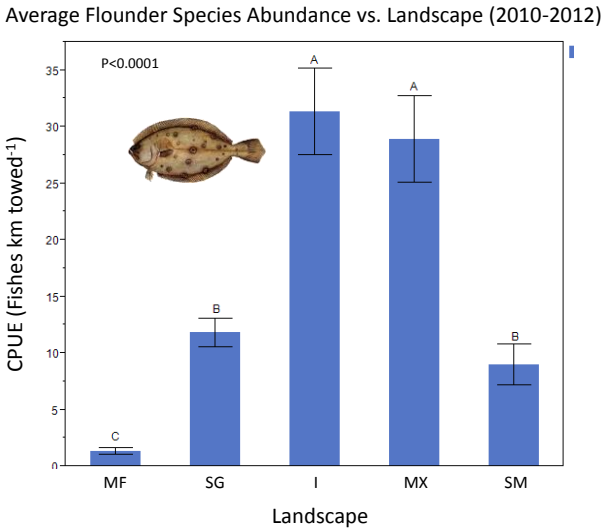
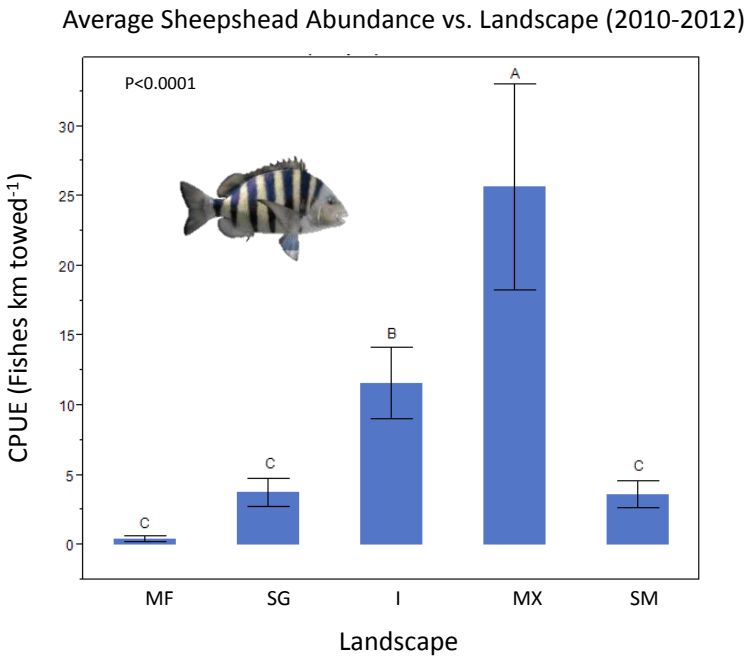


Figure 1.13. Average (A) catch rate and (B) individual biomass of sheepshead among seagrass and saltmarsh landscapes. Data are shown as means ± 1 standard error.

A.



B.

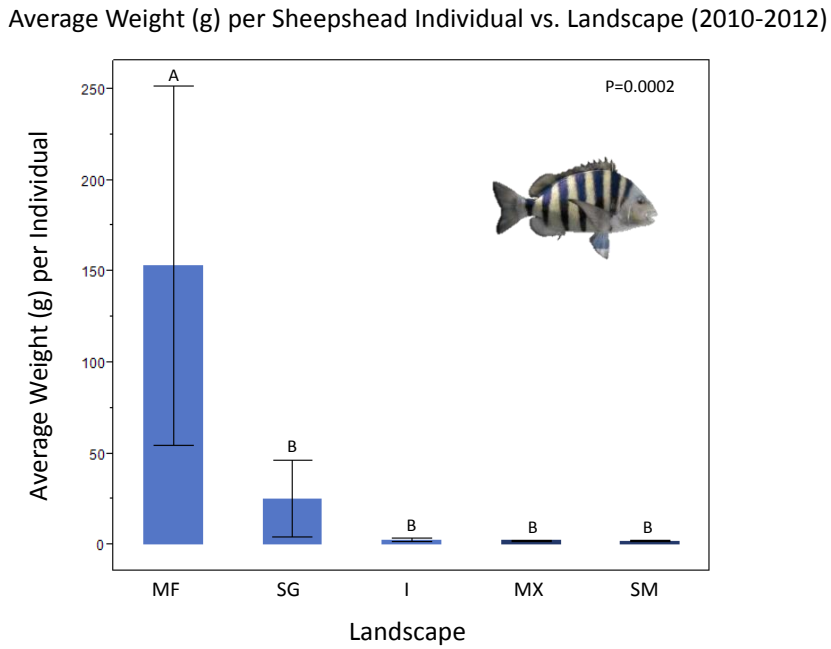
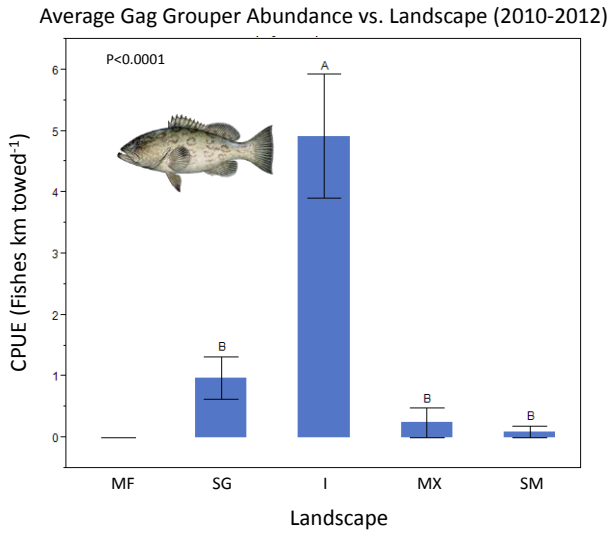
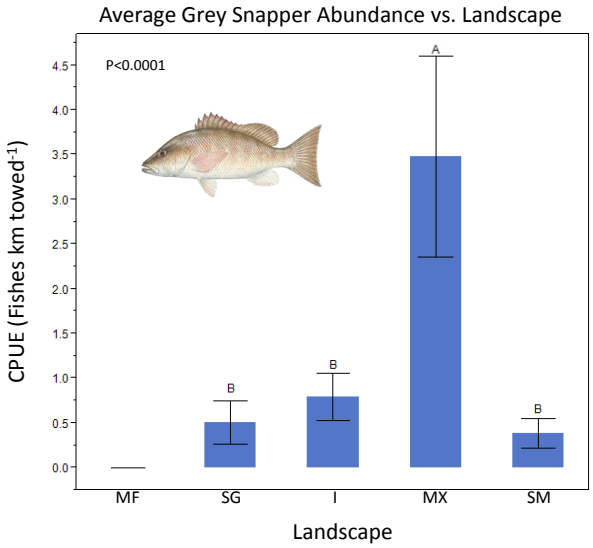


Figure 1.14. Average catch rate of recreationally important juvenile (A) gag grouper, (B) gray snapper and (C) lane snapper among seagrass and saltmarsh landscapes. Data are shown as means ± 1 standard error.

A.



B.



C.

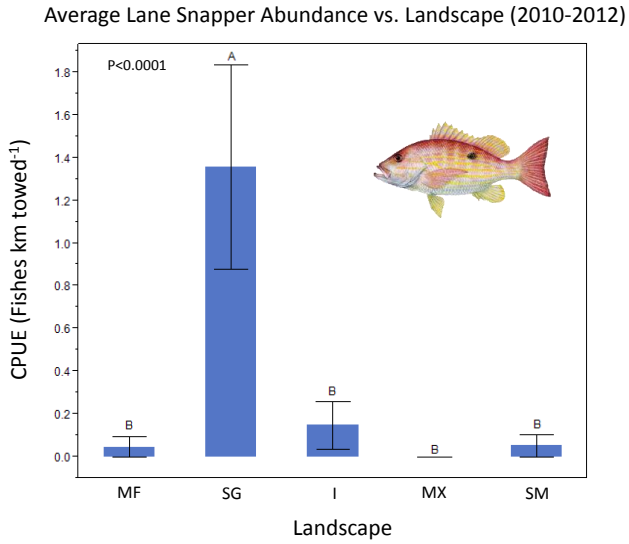
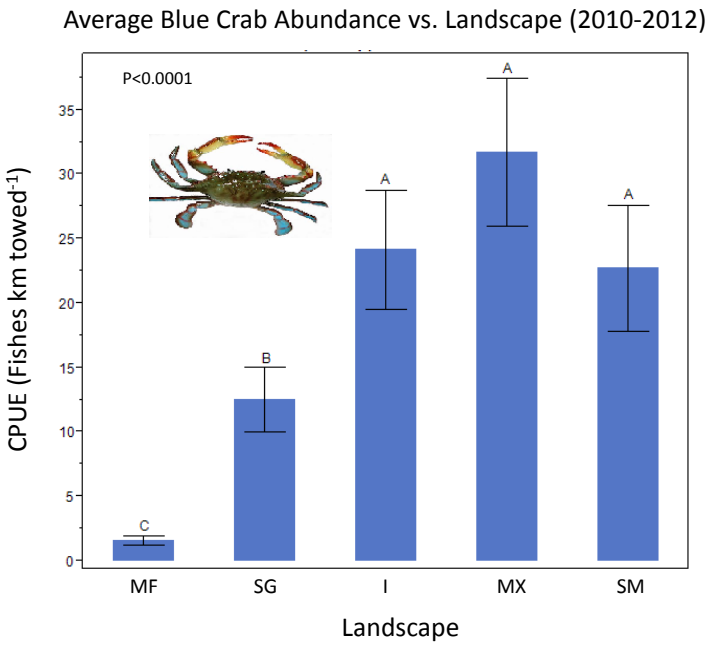


Figure 1.15. Average catch rate of (A) blue crab and (B) penaid shrimp among seagrass and saltmarsh landscapes. Data are shown as means ± 1 standard error.

A.



B.

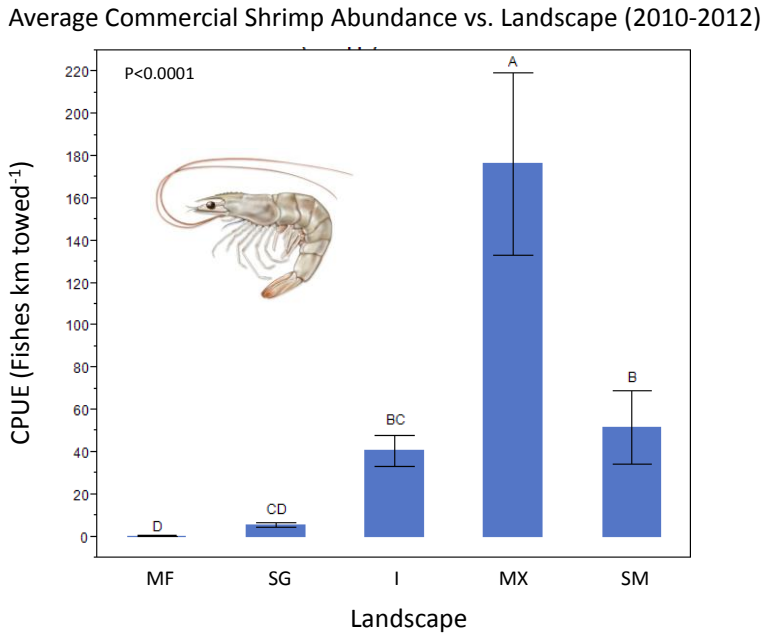
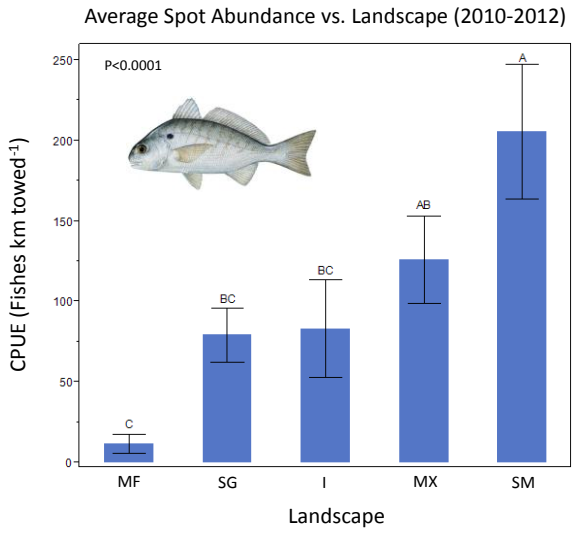
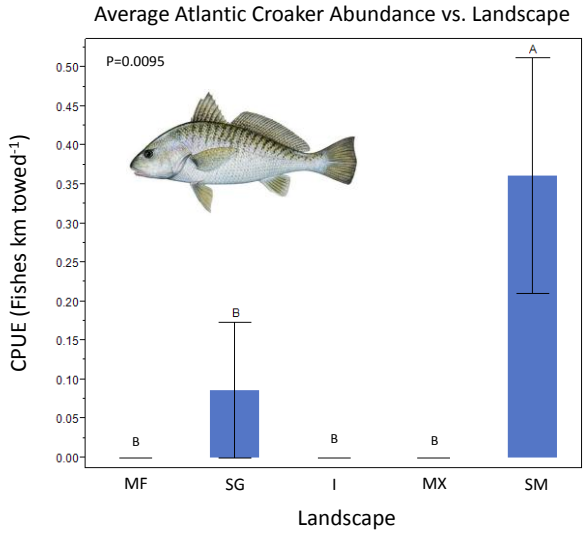


Figure 1.16. Average catch rate of (A) spot, (B) Atlantic croaker and (C) pigfish seagrass and saltmarsh landscapes. Data are shown as means ± 1 standard error.

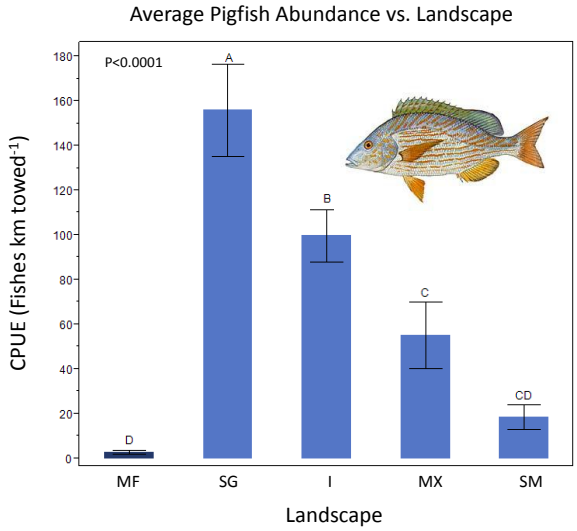
A.



B.



C.



Part 2: Long-term primary and secondary production value of decade-old, man-made oyster reefs: effects of proximity to seagrass and saltmarsh habitat

Objectives

To further explore the role of landscape in determining the "habitat provision" ecosystem service of structured habitats, we leveraged additional funding from the North Carolina Sea Grant Blue Crab and Shellfish program to test the effects of seagrass and saltmarsh proximity of the role of restored intertidal oyster reefs. This work combined NCSG (supplies, PI summer salary) and CRFL (supplies, technician time) support to expand the diversity of habitats we were able to consider to evaluate the fishery benefits of estuarine landscape mosaics. Although not included in our initial research plan, we content that this work dramatically improved the strength and rigor of our work.

Our overall goal for this component of our research was to explore the long-term (>1 decade) function of restored oyster reefs as essential habitat that promotes "secondary" production of fishes and decapods. To meet this goal, our 1st objective was to quantify the characteristics of restored oyster reefs constructed during the mid-to-late 1990s by NC-DMF and UNC-IMS. Our 2nd objective was to quantify/compare fish, shrimp and crab utilization of restored oyster reefs among various landscape setting.

Methods

We sampled reef and control landscapes in Middle Marsh, Carteret County, North Carolina (Rachel Carson National Estuarine Research Reserve), during July-Dec, 2010, to determine how small reef fish, piscivorous fish, bivalves, polychaetes, decapod crustaceans, etc. utilize restored reefs, and whether this suggest enhancement of overall fishery production in the area. In addition to benthic cores to sample resident (prey) flora and fauna, a combination of trapping, gillnetting and hook-and-line sampling was employed.

This study was conducted in the Middle Marsh region of Back Sound in Carteret County, North Carolina (Fig. 2.1). Twelve intertidal reefs were constructed in this area during June of 1997 using oyster shell provided by the NC-DMF. Each reef was constructed with approximately 60 bushels of oyster shell, resulting in initial reef dimensions of 5m x 3m x 0.30m (l x w x h). At the time of their creation, the restored reefs generally extended almost completely out of the water at low tide, corresponding with the tidal height of natural intertidal oyster reefs (0.1m above the mean low tide line). There were four replicate reefs of each of the three landscape patterns recognized as being common to North Carolina:

- On muddy and sandy bars isolated from vegetated habitat (referred to as mudflat landscape);
- On the fringes of saltmarshes and bordered by seagrass beds on the opposite side (referred to as seagrass landscape); and
- On the sandy points that extend outward from saltmarshes away from seagrass habitat (referred to as saltmarsh landscape).

The reef sites were compared to corresponding non-reef control treatments in each landscape configuration to determine how restored reef habitat affects utilization by the targeted species. Reefs were constructed in each of the three landscape patterns in four regions of Middle Marsh (12 reefs), and selected areas similar to each of the three landscapes as control sites where restoration did not occur. Arranging groups of all three reef and control treatments in four geographically isolated replicate blocks or sites tests whether possible environmental gradients exist between them (Table 2.1).

The abundance of living oysters and associated fauna (Table 2.2) on reefs was monitored twice – once in July, 2010, and once in Dec, 2010. Faunal excavations were conducted at reef and control sites in order to quantify and compare the resident faunal community. During each infaunal sampling period, two randomly chosen 0.25 m^2 plots were sampled by excavating the top 10 cm of infaunal shell. Excavated material was sieved with 1 mm sieves, after which all unattached bivalves, gastropods, crustaceans, etc. were separated from the remaining coarse material within the sieve, identified and quantified. The density and weight of legal (3") oysters per 0.25 m^2 also were quantified from each reef excavation.

In order to quantify both juvenile and adult fish (Table 2.3), shrimp, and crab utilization of and recruitment to the restored reef habitat, a variety of sampling methods was employed, including minnow pots, crab pots, fish traps, gillnets and hook-and-line sampling. Unfortunately, there is not one comprehensive method for sampling juvenile and adult fish, and each type of sampling gear has its own advantages and weaknesses. Collectively, however, the gear(s) we chose were intended to adequately sample the range of different sizes and types of mobile animals common to the estuaries of North Carolina. Sampling began in July, 2010, and continued each month until November, 2010. Sampling coincided with the season in which the target organisms traditionally are located in shallow waters within the estuaries of North Carolina.

Commercial crab pots, minnow traps (44.5cm long x 24.3cm diameter; 5mm mesh screen with two ~2.5cm openings), and modified Morton fish traps (0.7m long x 0.6m wide x 0.25m high, steel rebar frames with 5mm nylon mesh walls containing two opposing 7cm diameter tunnel openings) were used in order to assess juvenile fish, shrimp, and crab utilization of the restored reef sites. Two traps of each type were deployed on the reefs and corresponding controls. Traps were deployed at mid-flood tide and retrieved approximately 6 hours later at mid-ebb tide.

Gillnets (10m long x 1.5m tall; 3-inch stretch) were utilized to sample bottom-dwelling, larger fishes. Nets were stretched from one corner of the reef along the 5m wide edge away from the marsh and then drawn into the marsh. Nets were oriented with the current so that they opened during the flood tide when greatest catch rates were expected. During the Sept gillnet sampling, fish stomach contents were examined for all fishes landed from reefs or controls except for planktonic feeding fish (menhaden, *Brevoortia tyrannus*, and striped mullet, *Mugil cephalus*) [Data not yet analyzed but included in master Excel data file].

During retrieval of traps or nets, each captured organism was identified to species, quantified, measured, and released. Weather conditions (wind speed, direction, and ambient air temperature) were recorded during sampling to determine if variation in catch patterns covaries with any relevant physical parameters. The days each month selected for trap and gillnet sampling were

picked based upon the timing of high tides, with traps/nets generally deployed 3 hours before sunset and collected 3 hours after sunset.

Hook-and-line sampling was conducted during July-Nov, 2010. Select fishermen and volunteers identified by the North Carolina National Estuarine Research Reserve System assisted by routinely participating in fishing excursions to sample reefs (Table 2.4). With almost a dozen people participating in this sampling, including a wide range of people with different fishing abilities, reefs and controls were well sampled each month by hook-and-line. Optimal fishing days were selected for July-Nov, 2010 based on morning or evening high tides. At least one replicate site (i.e., three reef and three control trreatments) was sampled during each fishing excursion by each fishermen, and they fished all six treatments with the exact same bait or lure and identical fishing technique (in order to avoid use of different fishing gear between landscapes and reef conditions as a possible explanation for patterns in fish landings) for ten or more minutes within the selected site. All captured fish were identified, measured, and weighed.

The effects of reef restoration and landscape on: (1) the abundance and size of 2010 oysters, (2) densities of resident bivalve (oysters and all others separately), crustacean (decapods and all others separately), gastropod and soft-bodied infauna, and (3) densities of juvenile and adult fish and crabs were determined by Analysis of Variance (ANOVA, 1- or 2-way designs) or linear regression, as appropriate. We also tested the effects of month on invertebrates and fishes caught in gillnets using ANOVA. All data sets were tested for heterogeneity of the variance groups within each factor using Cochran's test when balanced and Bartlett's test when unbalanced. Heterogeneous data were transformed using square root transformations and then retested to assure homogeneous variance, or transformed again until heterogeneity was removed. Differences in abundance levels were considered significant at $p = 0.05$. Fisher's PLSD *post-hoc* tests were used to conduct pairwise comparisons of appropriate treatment groups for significant main effects and interaction terms.

Results

We collected 80 invertebrate taxa (Table 2.2) and 30 fishes (Table 2.3) during the course of our July-Dec, 2010, collections within the Middle Marsh reef and control sites. The effects of landscape on the abundance and mean size of living oysters were analyzed using separate ANOVA (Table 2.4). The effect of landscape on the abundance of oysters was significant ($p < 0.0001$). Mudflat reefs had higher oyster abundances than either saltmarsh or seagrass reefs (Fig. 2.2; SNK $p < 0.05$), while the latter two did not vary significantly from each other (SNK $p > 0.05$). Similarly, live-oyster mass was significantly higher at mudflat reefs relative to saltmarsh and seagrass reefs (Fig. 2.3; SNK $p < 0.05$), which did not differ from each other (SNK $p > 0.05$). Oysters on mudflat reefs and saltmarsh reefs, which did not differ from each other (SNK $p > 0.05$), were significantly larger ($p < 0.0001$; Fig. 2.4; Table 2.4) than those on seagrass reefs (SNK $p < 0.05$). Among and within reefs, live oyster density decreased with increasing depth (Fig. 2.5), and no live oysters were observed below -0.6 m NAVD88.

The effects of landscape and reef presence on the abundance of infaunal taxa that are common prey items in the diets of estuarine fishes (per 0.25 m^2 based on reef coring) were examined in a series of two-way ANOVAs with each taxon considered separately (i.e., bivalves - excluding

oysters, crustaceans – excluding decapods, decapods, gastropods, soft-bodied invertebrates). A significant interaction between landscape and reef presence on the abundance of infauna was observed for bivalves, decapod crustaceans and soft-bodied invertebrates ($p < 0.0001$; Table 2.4). In all three instances, the presence of reef habitat within the mudflat landscape resulted in considerable local enhancement of densities of these taxa. In particular, bivalve abundances were approximately two orders of magnitude higher within mudflat reefs than nearby control habitats (driven largely by ribbed mussel, *Geukensia demissa*), while no significant enhancement was observed reefs adjacent to saltmarsh or seagrass habitats (Fig.2.6). Similarly, decapod abundances were approximately two orders of magnitude higher within mudflat reefs than nearby control habitats (driven largely by the mud crab *Eurypanopeus depressus*, and to a lesser extent *Panopeus herbstii*). While the enhancement derived from reef presence was greatest within mudflat landscapes, decapod densities were also elevated on oyster reefs adjacent to saltmarsh and seagrass habitat, relative to controls (Fig.2.8). Trends for soft-bodied infauna, dominated by Nereid worms, were qualitatively identical to those described for the decapods (Fig. 2.10). Non-decapod crustacean densities were significantly elevated ($p = 0.0361$) in reefs relative to non-reef control sites (by a factor of 2-4; Fig. 2.7), but there was no apparent interaction between landscape and reef presence (Table 4). Compared with other taxa, densities of gastropods were low (< 15 individuals 0.25 m-*2*) and highly variable (Fig. 2.9). No significant differences in gastropod densities were observed as a function of landscape setting, reef presence or the interaction between these factors (Table 2.4).

The catch rates of invertebrates (Fig. 2.11A) and small, mostly juvenile, fishes (Fig. 2.11B) were not significantly different among landscapes, between reef and non-reef control sites, or as a result of an interaction between these factors ($p > 0.05$; Table 2.5) based on 2-way ANOVA results.

In gillnets, sampling larger mobile fauna, catch rates of invertebrates (primarily *Callinectes sapidus* and *Menippe mercenaria*) were interactively affected by landscape setting and reef presence ($p = 0.0588$; Table 2.6) based on 2-way ANOVA tests. Highest catch rates were observed in seagrass habitats (~ 1.5 specimens 6-hr^{-1}), while lowest catch rates were observed in nets set within mudflat landscapes (~0.5 specimens 6-hr^{-1}), regardless of reef presence. Along the edge of saltmarshes, however, the catch rates of invertebrates was strongly dependent of reef presence, as catch rates observed at control sites were approximately 4 times higher than catch rates observed at reef sites (Fig. 2.12). Throughout the study period, the catch rates of large mobile invertebrates in gill nets decreased ($p < 0.0001$) significantly (nearly linearly; Fig. 2.13) from a high of ~2 specimens 6-hr^{-1} in July to a low of ~0.25 specimens 6-hr^{-1} in Nov.

Similarly, the catch rate of piscivorous fishes in gillnets was interactively determined by landscape setting and reef presence ($p = 0.0814$; Table 2.6) based on 2-way ANOVA results. Highest catch rates were observed in seagrass habitats (~ 0.8 specimens 6-hr^{-1}), while lowest catch rates were observed from nets set within mudflat landscapes (~0.2 specimens 6-hr^{-1}), regardless of reef presence. Along the edge of saltmarshes, however, the catch rates of invertebrates was strongly dependent on reef presence, as catch rates observed at control sites were approximately 8 times higher than catch rates observed at reef sites (Fig. 2.14). Although the effect of time (month) on the catch rates of piscivorous fishes was statistically insignificant ($p = 0.2206$), we did note trends suggesting increasing catch rates from July through Sept (during

which time catch rates approximately doubled), followed by declining catch rates in the two subsequent months (Fig. 2.15).

In all, 9 recreational fishermen (Table 2.7), ranging in expertise from guide to casual enthusiast, sampled the reef and control sites to explore how reefs affected the catch rates of hook-and-line fishermen. In all, these fishermen sampled the 24 study sites (12 reefs and 12 controls) over the course of 135+ hours, capturing a total of 83 fish (Table 2.7). Although there was no statistically significant effect of landscape ($p = 0.9791$) or reef presence ($p = 0.2504$) on the catch rates reported by recreational fishermen (Table 2.8), we did note that the overall catch rates of fishes was 39% higher on mudflat oyster reefs relative to mudflat control sites, 27% higher on seagrass oyster reefs relative to seagrass control sites, and 17% higher on saltmarsh oyster reefs relative to saltmarsh control sites (Fig. 2.16).

Interpretations

As this component of our research was completed first (2010), we have had enough time to begin conceptualizing how these data fit in to the broader issue of landscape effects and the value of estuarine fish habitat. Interpreting the complex interactions that explain how communities organize remains not only a central theme for community ecologists, but also is imperative for applied researchers concerned about the health of our ecosystems. Applying our understanding of these processes to designing and conducting research on the recovery of disturbed and restored habitats hopefully will equip management personnel with the necessary tools to protect the services and goods provided by North Carolina's estuaries. This re-examination of a 1997 restoration project elicits the importance of landscape scale processes in the structuring of fish and mobile invertebrate communities residing within shallow estuarine habitats. Furthermore, it addresses questions regarding the role of oyster reef habitat within the greater context of the estuarine system. A wide diversity of mobile animals utilized restored oyster reefs as juveniles or throughout the summer and fall of 2010.

While these larger fishes and crustaceans may also utilize reefs as resting or refuge habitat, we were primarily interested in the role oyster reefs play in increasing/concentrating food availability and enhancing energy flow from estuarine primary production upwards to higher consumers. The number of living oysters on mudflat reefs during 2010 was nearly an order of magnitude higher than on either of the other two reef types constructed in close proximity to vegetated habitat. Among these living oysters, individuals sampled from mudflat reefs or saltmarsh-fringing reefs were ~ 25% larger than individuals collected on seagrass-fringing oyster reefs. Water flow within Middle Marsh is likely greater on mudflats away from vegetated structure, and is often very low within and in between seagrass beds and saltmarshes, perhaps explaining the observed patterns of oyster density and growth. Higher flow across mudflats could have enhanced larval oyster and food delivery on mudflat reefs resulting in higher oyster production. Reef burial might have also been greater on seagrass and saltmarsh reefs where slower currents permit greater particle rainout from the water column. Furthermore, vegetated habitats adjacent to constructed reefs likely contain a reservoir of small predators that contribute toward higher mortality of settling oysters. Recent observations in Middle Marsh (Fodrie, unpublished) indicate that oysters higher in the intertidal zone grow faster (mechanism unknown) and survive at higher rates, and this may explain why saltmarsh-fringing oysters were, on

average, larger than oysters on reefs adjacent to seagrass (within Middle Marsh, seagrass is excluded from the shallower flats that intersect saltmarsh).

Infaunal sampling revealed that several species of bivalves, crustaceans and soft-bodied invertebrates were common residents of oyster reefs. Bivalves were more abundant on mudflat reefs than on controls; however, restoring reef habitat had no effect on bivalve densities within the other two landscapes. Living oysters on mudflat reefs exhibited higher overall productivity rates than saltmarsh and seagrass reefs, resulting in the creation of more structural complexity within mudflat reefs. This structure is likely important for the settlement of bivalve veligers for species such as *Geukensia demissa*, and may have also dampened the foraging efficiency of small Xanthid crabs that prey on settling bivalves. Increased growth rates of bivalves resulting from high flow over mudflat reefs could have allowed reef-associated bivalves to enter size refugia more quickly and escape predation from Xanthid crabs.

Crustaceans (including decapods) and soft-bodied infauna were enhanced on all reefs, but were most abundant on oyster reefs constructed over mudflats. Again, this likely scaled with the structural complexity and niche space available on those reefs, as well as larval and food delivery among reefs. Collectively, oyster reefs host dense assemblages of small invertebrates that serve as important potential food items for economically and ecologically valuable finfish and more mobile macroinvertebrates.

Fishes may be separated into two categories based on Sept, 2010, stomach contents: those that ate predominately amphipods, bivalves, gastropods and polychaetes (spot, pigfish, and pinfish), and those that fed mostly on fish, shrimp and crabs (blacknose and blacktip sharks, gulf and southern flounders, red drum, speckled trout, gag, and bluefish). We designed our sampling to capture fishes within both of these feeding guilds. Small, juvenile fishes (pinfish, pigfish, spot) were caught at similar rates on reefs and control sites within all three landscapes. Restoring reefs adjacent to saltmarsh and seagrass habitats placed reefs adjacent to already structured vegetated habitats, and therefore it is perhaps not surprising that the catch rates of small fishes did not increase over control sites in similar landscape settings without reefs. The initial provision of habitat structural complexity, whether it is a reef, a seagrass meadow or a saltmarsh, is more important for juvenile fish communities than the addition of a second or third structurally complex habitat. However, this does not explain the similarity of catch rates of small fishes (and invertebrates) between mudflat reef and mudflat control sites.

Habitat utilization patterns of large, piscivorous fish and mobile crustacean recorded from gillnet sampling did not mimic patterns of prey distribution (small inverts or fishes) across landscapes or reef vs. control sites. Highest catch rates were observed in seagrass habitats, regardless of reef presence, and support the role of seagrass meadows as essential foraging or corridor habitat for recreationally important species. Within saltmarsh-fringing areas, catch rates of fishes in gillnets were significantly lower at reef sites than paired control sites. An obvious explanation for this is that at two of the four saltmarsh-fringing reefs, experimental reefs immediately adjacent to saltmarsh facilitated localized, seaward expansion of saltmarsh habitat. This landscape-level facilitation provided by shellfish reefs – not observed at paired control sites – can best be explained by recognizing that oyster reefs served as natural breakwaters, increasing sediment deposition and stabilization that raised the surrounding seafloor to a depth suitable for saltmarsh

plant (*Spartina alterniflora*) recruitment and growth. As a result, a marsh "curtain" surrounded some of the oyster reefs during our 2010, and even during flood tides could have reduced the accessibility of reef habitat for larger mobile predators. Conversely, IMS-based researchers previously reported decreased catch rate of larger, piscivorous fishes on mudflat reefs relative to control sites (1998-2000), but by 2010 our surveys indicated that catch rates were essentially the same on mudflat reef and control sites (perhaps even slightly enhanced on reefs). By 2010, mudflat reefs may have expanded to a size that was more easily located/intersected by large mobile fishes. Subsequently, increased utilization of mudflat reef by larger predatory fishes in 2010 (relative to 1998-2000) might explain the decreases in utilization of mudflat reefs by smaller juvenile fishes over this same time frame (i.e., a "trophic cascade" in habitat use). Thus, there is clear indication that the fishery benefits of restored/enhanced reef bottom cannot be fully understood until years, perhaps decades, after reefs are constructed and natural community processes of recruitment, growth and survivorship - that vary across depths and landscapes - dictate reef evolution and performance.

While adult fish abundance patterns may, in general, provide evidence opposing the importance of reefs for larger fishes, a few alternatives can be considered. First, a number of the important species caught in low numbers on reefs are not common within the estuary because of management issues such as overharvesting and reduced water quality. It will be difficult to address this problem until other areas where local populations of sciaenids, serranids, sparids and bothids have not declined are sampled or until our populations return to their historical levels. Second, the observed patterns are partially driven by economically less important species such as juvenile sharks and adult spot, the species that were typically caught on mudflat controls. Third, reefs might have different catch efficiencies than other shallow estuarine habitats (e.g., gill net panels might have snagged on the reef during sampling intervals or fish utilizing reefs might recognize the presence of an obstacle in the water column more readily, thereby reducing the efficiency of gill nets on reefs and resulting in underestimates of fish abundances on reefs in comparison to controls, see concerns regarding relatively mobility in next paragraph). We currently are conducting acoustic tagging/tracking experiments to address this potential source of bias (see "synergistic activities" below).

Interestingly, hook-and-line results did not mirror the results of gillnet sampling. While both gears provide windows in to the relative abundance of fishes, inherent biases and differences in selectivity of these gears should allow us to compare results and infer more about what all the data, in concert, suggest regarding habitat utilization of fishes. Gillnets are proven sampling gears, but like all collection approaches, may have interactions with treatment (landscapes, reef presence) that affect catch rates resulting in data artifacts. For instance, if fishes are in equal densities between two habitats, but are more mobile in one of the two habitats, the capture rate of fishes will be higher in the habitat with greater fish mobility, even though densities (utilization) are the same between habitats. While we do not expect this significantly affected our gillnet data, we make this point to reaffirm that gillnet data only reveal information about the relative abundance of fishes, and do not necessarily reveal why fishes are in an area. Conversely, hook-and-line data may not adequately reflect how many fishes are in an area if those individuals are not feeding. Rather, those data provide clues in to the integrated product of density and feeding behaviors. Taken together, our gillnet and hook-and-line data from Middle Marsh suggest that fishes were not more abundant of reef habitats, but among all landscapes, appeared more

interested in feeding opportunities while in the vicinity of restored oyster reefs (relative to control sites).

Table 2.1. List of experimental reefs and control sites included in this component of the study.

Zone	Station Type	Color Code in Fig. 1	Alphemeric Code in Fig. 1	Landscape Type	Lat (N34°)	Long (W76°)
1	Control	Red	MF(C)	Mud Flat	41.592	37.194
1	Control	Red	SM(C)	Salt Marsh	41.657	36.938
1	Control	Red	SG(C)	Seagrass	41.433	37.296
1	Reef	Red	MF	Mud Flat	41.621	37.185
1	Reef	Red	SM	Salt Marsh	41.638	37.184
1	Reef	Red	SG	Seagrass	41.471	37.241
2	Control	Blue	MF(C)	Mud Flat	41.57	37.225
2	Control	Blue	SM(C)	Salt Marsh	41.563	37.394
2	Control	Blue	SG(C)	Seagrass	41.644	37.232
2	Reef	Blue	MF	Mud Flat	41.569	37.267
2	Reef	Blue	SM	Salt Marsh	41.643	37.259
2	Reef	Blue	SG	Seagrass	41.569	37.356
3	Control	Green	MF(C)	Mud Flat	41.299	36.933
3	Control	Green	SM(C)	Salt Marsh	41.338	36.971
3	Control	Green	SG(C)	Seagrass	41.309	36.853
3	Reef	Green	MF	Mud Flat	41.307	36.925
3	Reef	Green	SM	Salt Marsh	41.309	37.002
3	Reef	Green	SG	Seagrass	41.358	36.922
4	Control	Yellow	MF(C)	Mud Flat	41.115	36.694
4	Control	Yellow	SM(C)	Salt Marsh	40.972	36.647
4	Control	Yellow	SG(C)	Seagrass	41.283	36.49
4	Reef	Yellow	MF	Mud Flat	41.098	36.745
4	Reef	Yellow	SM	Salt Marsh	40.941	36.651
4	Reef	Yellow	SG	Seagrass	41.324	36.504

Table 2.2. List of invertebrate species caught with core, trap or gillnet sampling.

Taxon	Method	Taxon	Method
Abra lioica	Core	*Limaria pellucida*	Core
Acteocina canaliculata	Core	*Lithophaga aristata*	Core
Acteocina candei	Core	*Lithophaga bisulcata*	Core
Amygdalum papyrium	Core	*Lyonsia hyalina*	Core
Anachis floridana	Core	*Macoma tenta*	Core
Anachis lafresnayi	Core	*Macrocallista nimbosa*	Core
Anemone Spp.	Core	*Mactra fragilis*	Core
Anomia squamula	Core	*Martesia cuneiformis*	Core
Arca imbricata	Core	*Mellita quinquiesperforata*	Core
Arcopsis adamsi	Core	Menippe mercenaria	Gillnet, Trap
Arenicolidae	Core	*Mercenaria mercenaria*	Core
Argopecten irradians	Core	*Mya arenana*	Core
Balanus Spp.	Core	*Nassarius Obsoletus*	Core
Barbatia candida	Core	*Nassarius vibex*	Core
Barnea truncata	Core	*Nereididae*	Core
Boonea impressa	Core	*Niso hendersoni*	Core
Busycotypus canaliculatus	Core, Gillnet	*Nucula acuta*	Core
Callianassa atlantica	Core	*Nucula proxima*	Core
Callianassa biformis	Core	*Ophioderma brevispina*	Core
Callinectes sapidus	Gillnet, Trap	*Ostreidae*	Core
Cerithium atratum	Core	Paguroidea	Gillnet, Trap
Chione cancellata	Core	*Panopeidae*	Core
Chione grus	Core	*Panopeus herbstii*	Core
Clibanarius vittatus	Core	*Parvilucina multilineata*	Core
Crassostrea virginica	Core	*Phyllodoce fragilis*	Core
Cyclinella tenuis	Core	*Pinnixa Spp.*	Core
Cyrtopleura costata	Core	*Pinnotheres ostreum*	Core
Diodora cayenensis	Core	*Pitar morrhuanus*	Core
Donax variabilis	Core	*Polynoidae*	Core
Encrusting Sponge Spp.	Core	Portunus spinimanus	Trap
Eupleura caudata	Core	*Seila adamsi*	Core
Eurypanopeus depressus	Core	*Semele purpurascens*	Core
Farfantepenaeus Spp.	Trap	*Solemya velum*	Core
Fasciolaria hunteria	Core	*Styela plicata*	Core
Fasciolaria tulipa	Core	*Tagelus divisus*	Core
Gammaridae	Core	*Tectonatica pusilla*	Core
Gastropoda	Core	*Tellina agilis*	Core
Gelidium Spp.	Core	*Terebra dislocata*	Core
Geukensia demissa	Core	*Tricho branchidae*	Core
Libinia ferreirae	Gillnet	*Urosalpinx cinerea*	Core

Table 2.3. List of fish species caught with core, trap, gillnet or hook-and-line sampling.

Taxon	Method	Taxon	Method
Anchoa Spp.	Trap	*Menticirrhus Spp.*	Gillnet, Line
Archosargus probatocephalus	Gillnet	*Micropogonias undulatus*	Gillnet
Brevoortia patronus	Gillnet	*Mugil cephalus*	Gillnet
Caranx crysos	Gillnet	*Mycteroperca microlepis*	Line
Caranx hippos	Gillnet	*Opsanus tau*	Core, Trap
Carcharhinus limbatus	Gillnet	*Orthopritis chrysoptera*	Gillnet, Trap, Line
Chaetodipterus faber	Gillnet	*Paralichthys Spp.*	Gillnet, Trap, Line
Chaetodon ocellatus	Trap	*Pogonias cromis*	Gillnet
Cynoscion nebulosus	Gillnet, Line	*Pomatomus saltatrix*	Gillnet, Line
Diplodus holbrooki	Trap	*Rhizoprionodon terraenovae*	Gillnet, Line
Dasyatis americana	Gillnet, Line	*Sciaenops ocellatus*	Gillnet, Line
Dasyatis sabina	Line	*Sphoeroides Spp.*	Trap
Elops saurus	Gillnet	*Stephanolepis hispidus*	Trap
Lagodon rhomboides	Gillnet, Trap, Line	*Synodus foetens*	Gillnet, Line
Leiostomus xanthurus	Gillnet, Trap, Line	*Trachinotus carolinus*	Gillnet

Table 2.4. ANOVA tables for invertebrate densities recorded during core sampling.

ANOVA Table: Density of Live Oysters

	DF	SS	MS	F-Value	P-Value
hab	2	3179488	1589744	36.286	<.0001
restor	1	3110256	3110256	70.991	<.0001
hab * restc	2	3179488	1589744	36.286	<.0001
Residual	90	3943088	43812		

ANOVA Table: Mass of Live Oysters

	DF	SS	MS	F-Value	P-Value
hab	2	2196073651	1098036825	28.067	<.0001
restor	1	10517038756	10517038756	268.823	<.0001
hab * restc	2	2196073651	1098036825	28.067	<.0001
Residual	90	3521024846	39122498		

ANOVA Table: Density of Bivalves (Excluding Oysters)

	DF	SS	MS	F-Value	P-Value
hab	2	1141436	570718	14.532	<.0001
restor	1	542613	542613	13.817	0.0003
hab * restc	2	1081244	540622	13.766	<.0001
Residual	90	3534510	39272		

ANOVA Table: Density of Arthropods (Excluding Decapods)

	DF	SS	MS	F-Value	P-Value
hab	2	4108	2054	2.353	0.1009
restor	1	3953	3953	4.528	0.0361
hab * restc	2	699	349	0.4	0.6714
Residual	90	78561	873		

ANOVA Table: Density of Decapods

	DF	SS	MS	F-Value	P-Value
hab	2	39987	19994	18.214	<.0001
restor	1	60612	60612	55.218	<.0001
hab * restc	2	42899	21449	19.541	<.0001
Residual	90	98792	1098		

ANOVA Table: Density of Gastropods

	DF	SS	MS	F-Value	P-Value
hab	2	440	220	0.27	0.7642
restor	1	153	153	0.187	0.6664
hab * restc	2	1113	557	0.683	0.5077
Residual	90	73360	815		

ANOVA Table: Density of Soft-Bodied Infauna

	DF	SS	MS	F-Value	P-Value
hab	2	50139	25070	8.371	0.0005
restor	1	99099	99099	33.089	<.0001
hab * restc	2	49946	24973	8.338	0.0005
Residual	90	269544	2995		

Table 2.5. ANOVA tables for invertebrate and fish CPUEs in trap sampling.

ANOVA Table: Invertebrate CPUE in Trap Sampling

	DF	SS	MS	F-Value	P-Value
hab	2	0.203	0.101	0.57	0.5662
restor	1	0.196	0.196	1.103	0.2947
hab * restc	2	0.127	0.063	0.356	0.7008
Residual	234	41.578	0.178		

ANOVA Table: Fish CPUE in Trap Sampling

	DF	SS	MS	F-Value	P-Value
hab	2	11.946	5.973	0.675	0.5104
restor	1	1.355	1.355	0.153	0.6961
hab * restc	2	2.653	1.326	0.15	0.861
Residual	234	2072.23	8.856		

Table 2.6. ANOVA tables for invertebrate and piscivorous fish CPUEs in gillnet sampling.

ANOVA Table: Invertebrate CPUE in Gillnet Sampling

	DF	SS	MS	F-Value	P-Value
hab	2	24.084	12.042	5.79	0.004
restor	1	2.018	2.018	0.97	0.3267
hab * restc	2	12.083	6.042	2.905	0.0588
Residual	114	237.097	2.08		

ANOVA Table: Invertebrate CPUE in Gillnet Sampling

	DF	SS	MS	F-Value	P-Value
month	4	51.565	12.891	6.627	<.0001
Residual	115	223.718	1.945		

ANOVA Table: Piscivorous Fish CPUE in Gillnet Sampling

	DF	SS	MS	F-Value	P-Value
hab	2	5.837	2.918	4.415	0.0142
restor	1	1.413	1.413	2.137	0.1465
hab * restc	2	3.39	1.695	2.565	0.0814
Residual	114	75.351	0.661		

ANOVA Table: Piscivorous Fish CPUE in Gillnet Sampling

	DF	SS	MS	F-Value	P-Value
month	4	4.141	1.035	1.455	0.2206
Residual	115	81.849	0.712		

Table 2.7. List of hook-and-line sampling participants.

Name	# Fish Caught
Baillie, Chris	6
Braddy, Jeremy	14
Fear, John	9
Fodrie, Joel	14
Hall, Nate	12
Hawkins, Jess	10
Ipock, J	10
Jones, Craig	4
Kenworthy, Jud	4

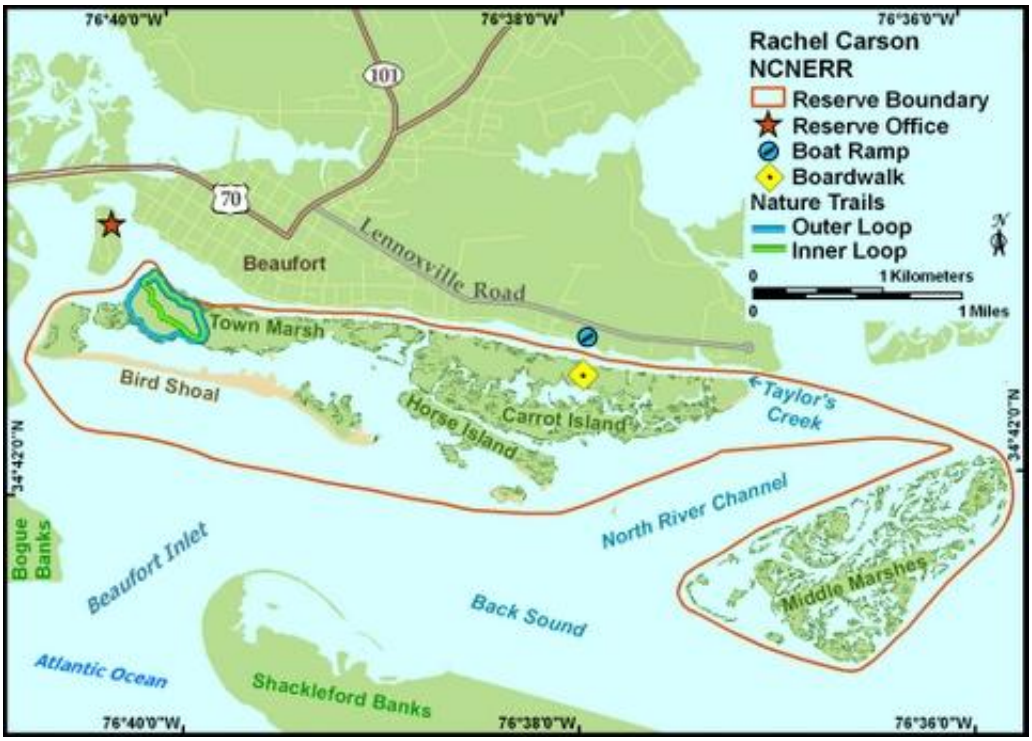
Table 2.8. ANOVA table for target fish CPUE in Hook-an-Line sampling.

ANOVA Table: CPUE of Targeted Hook-and-Line Fishes

	DF	SS	MS	F-Value	P-Value
hab	2	0.099	0.049	0.021	0.9791
restored	1	3.086	3.086	1.324	0.2504
hab * restc	2	0.434	0.217	0.093	0.9111
Residual	552	1286.74	2.331		

Figure 2.1. Map of: (A) Rachel Carson North Carolina-National Estuarine Research Reserve where field work was conducted; and (B) southwest Middle Marsh with restored reefs and control sites indicated.

A.



B.

Figure 2.2. Density of living oysters (#/0.25 m^2) versus landscape (μ + 1SE).

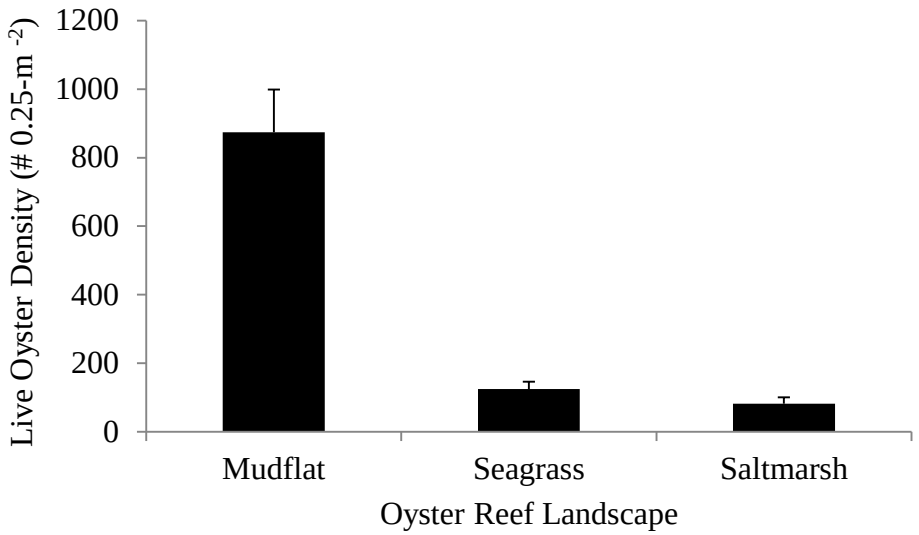


Figure 2.3. Legal oyster production (g/0.25 m^2) versus landscape (μ + 1SE).

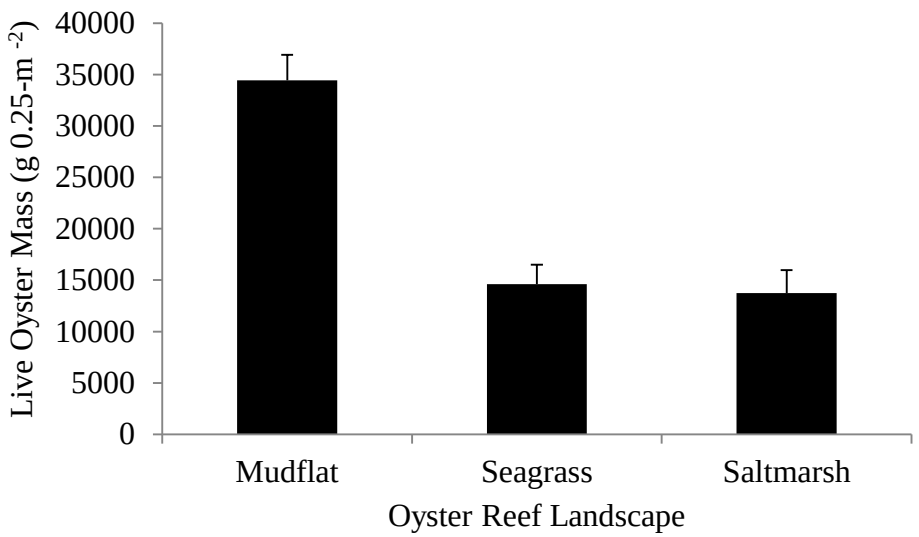


Figure 2.4. Size of living oysters (mm) versus landscape (μ + 1SE).

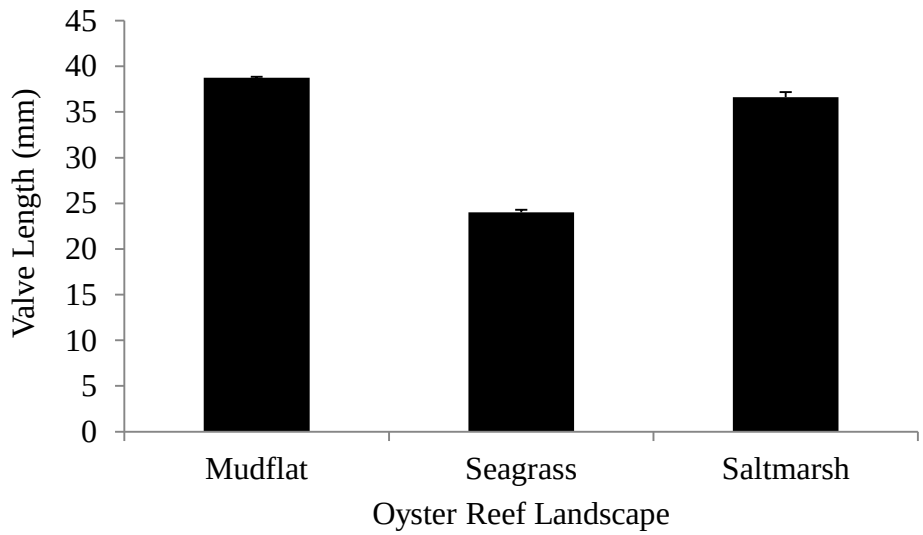


Figure 2.5. Density of living oysters (December 2010 only; #/0.25 m^2) versus sampling depth.

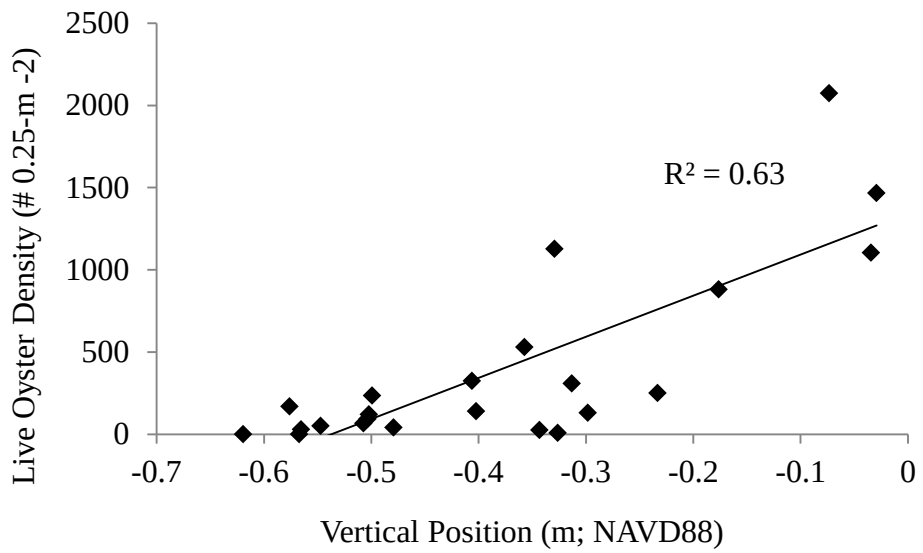


Figure 2.6. Density of all bivalves – excluding oysters (#/0.25 m^2): reef X landscape (μ + 1SE).

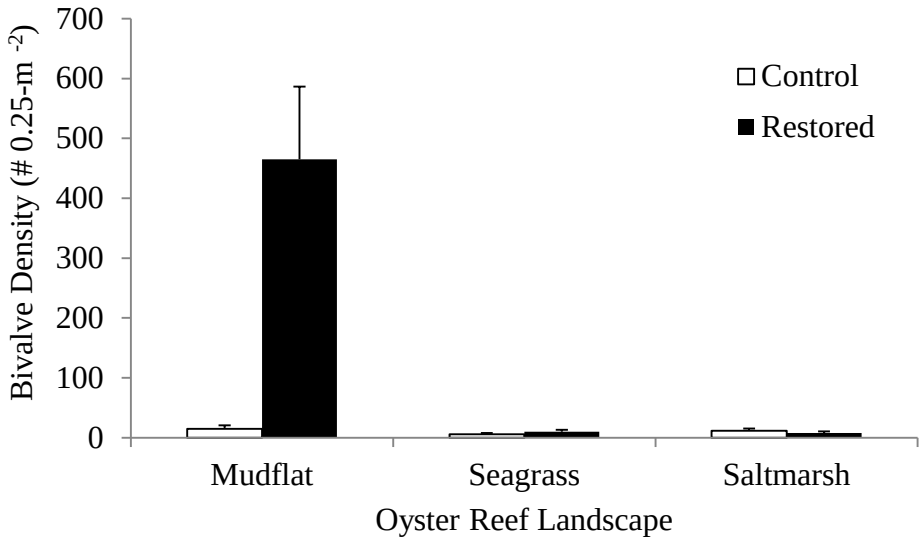


Figure 2.7. Density of all arthropods – excluding decapod crustaceans (#/0.25 m^2): reef X landscape (μ + 1SE).

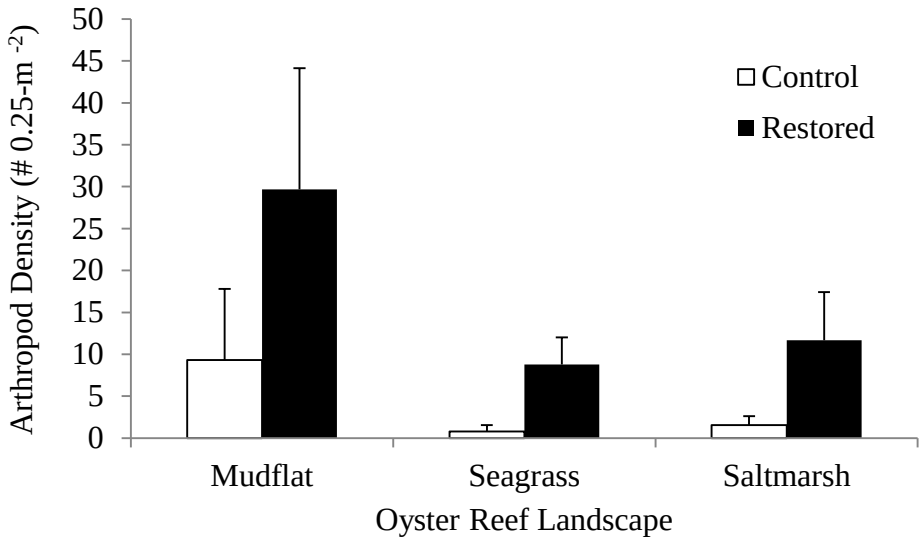


Figure 2.8. Density of decapod crustaceans (#/0.25 m^2): reef X landscape (μ + 1SE).

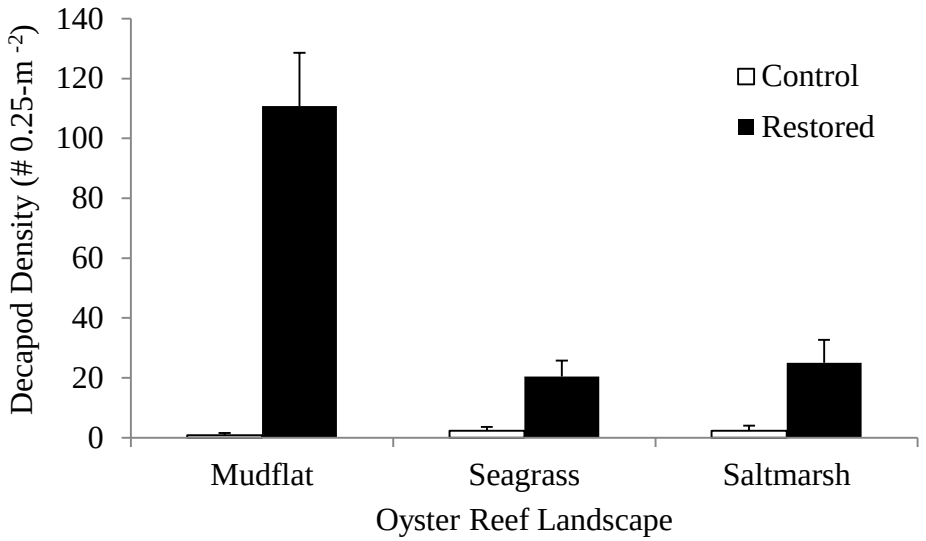


Figure 2.9. Density of all gastropods (#/0.25 m^2): reef X landscape (μ + 1SE).

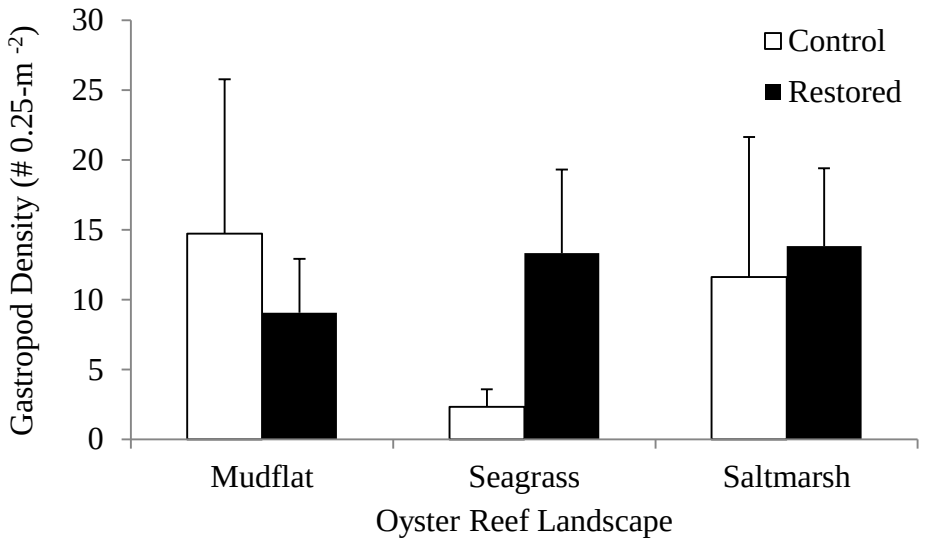


Figure 2.10. Density of all soft-bodied infauna/epifauna (#/0.25 m^2): reef X landscape (μ + 1SE).

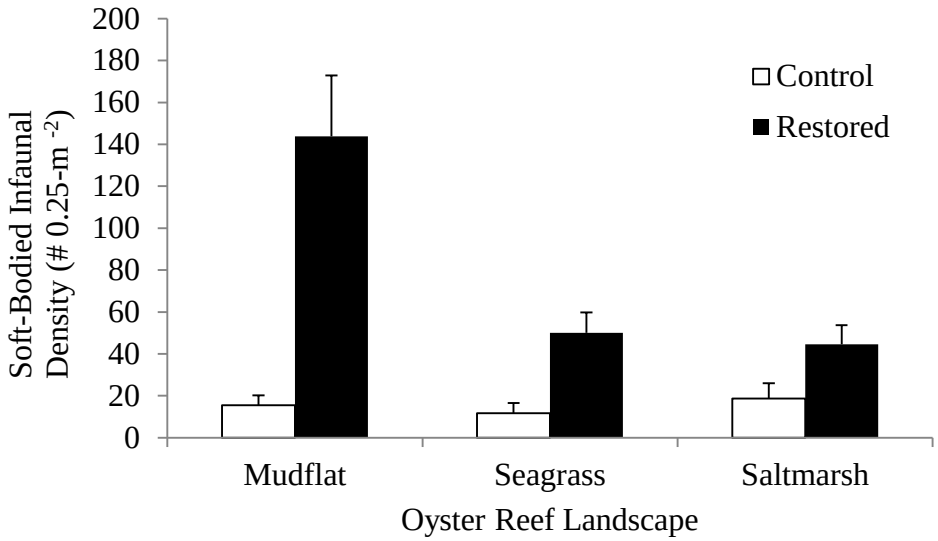
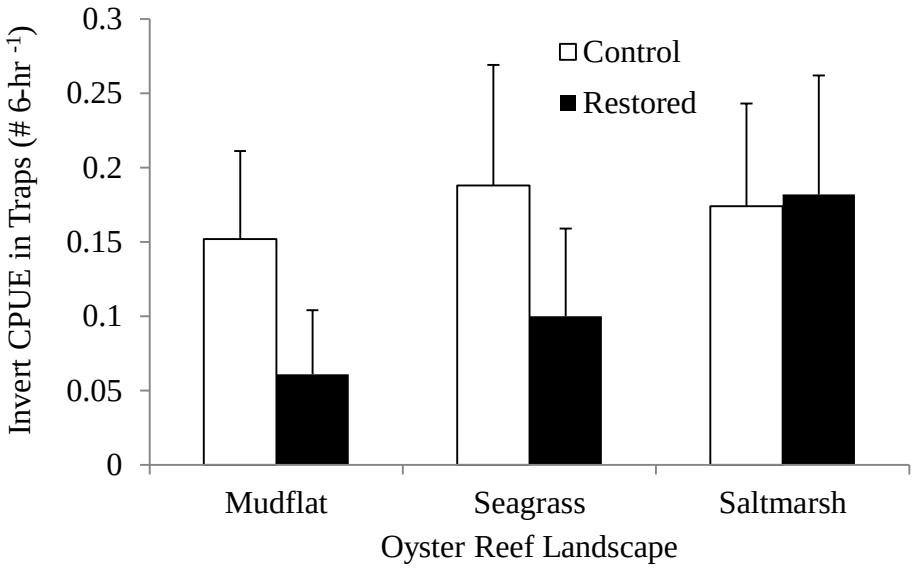


Figure 2.11. Total (A) invert and (B) fish abundance caught in traps (#/6 hr – minnow, Morton and crab traps combined): reef X landscape (μ + 1SE).

A.



B.

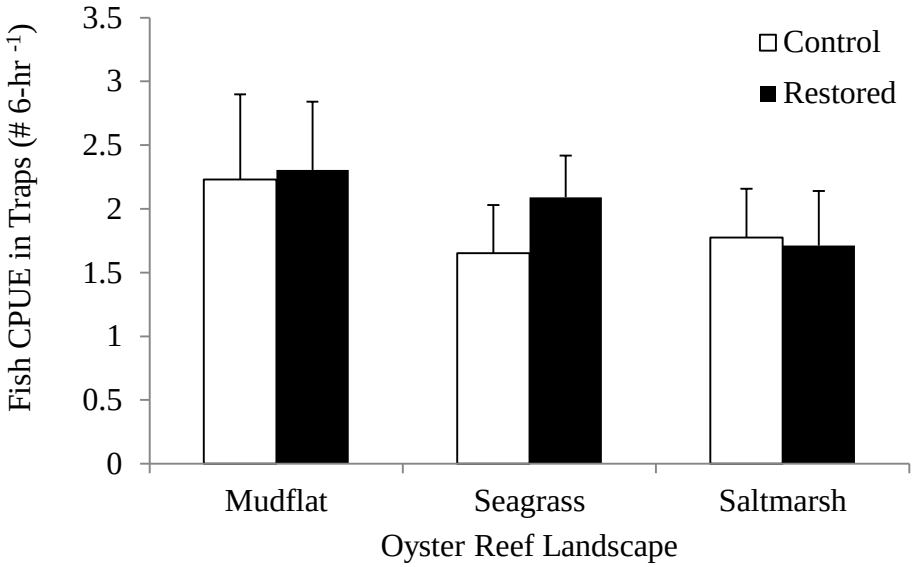


Figure 2.12. Total invert abundance caught in gillnets (#/6 hr): reef X landscape (μ + 1SE).

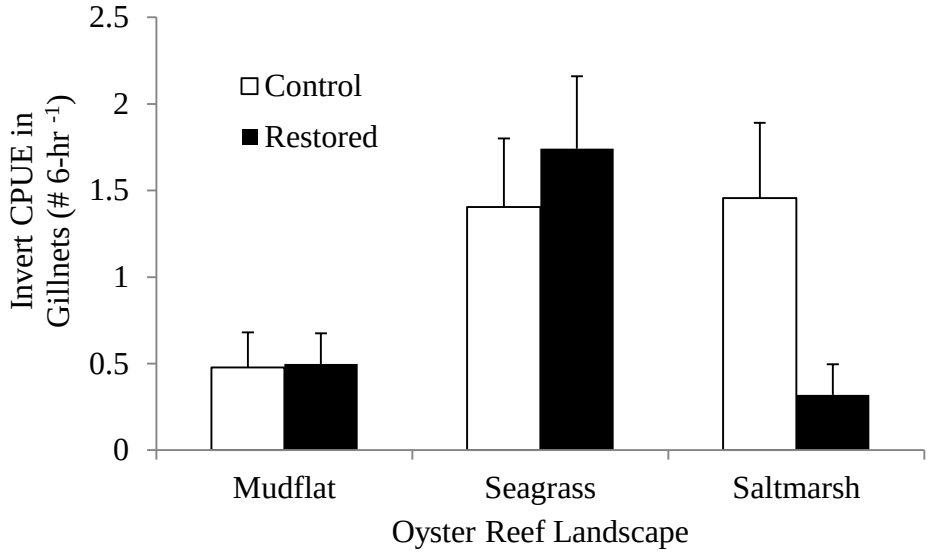


Figure 2.13. Total invert abundance caught in gillnets (#/6 hr): month (μ + 1SE).

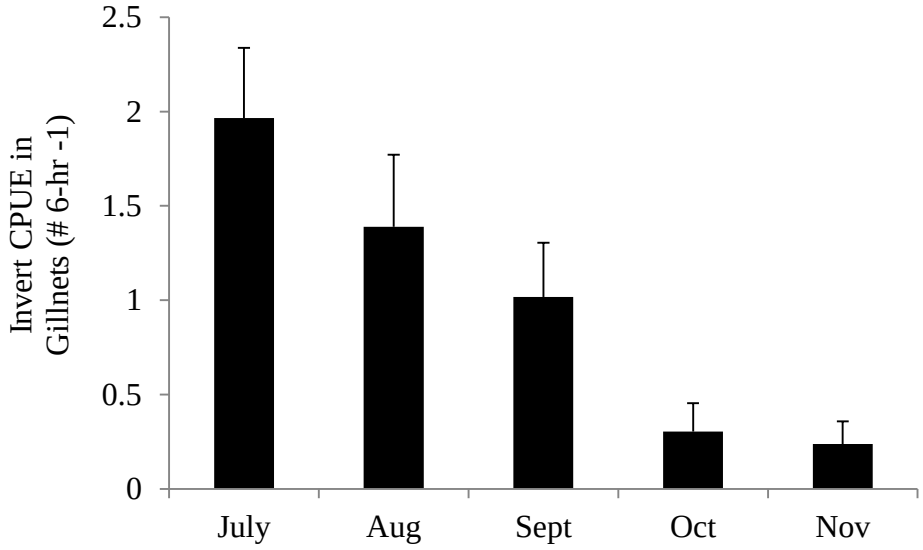


Figure 2.14. Piscivorous fish abundance caught in gillnets (#/6 hr): reef X landscape (μ + 1SE).

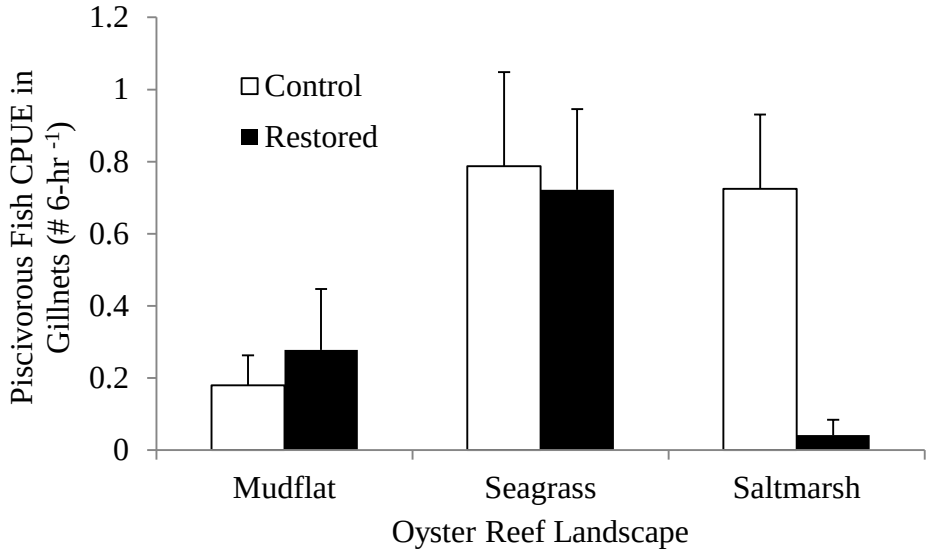


Figure 2.15. Piscivorous fish abundance caught in gillnets (#/6 hr): month (μ + 1SE).

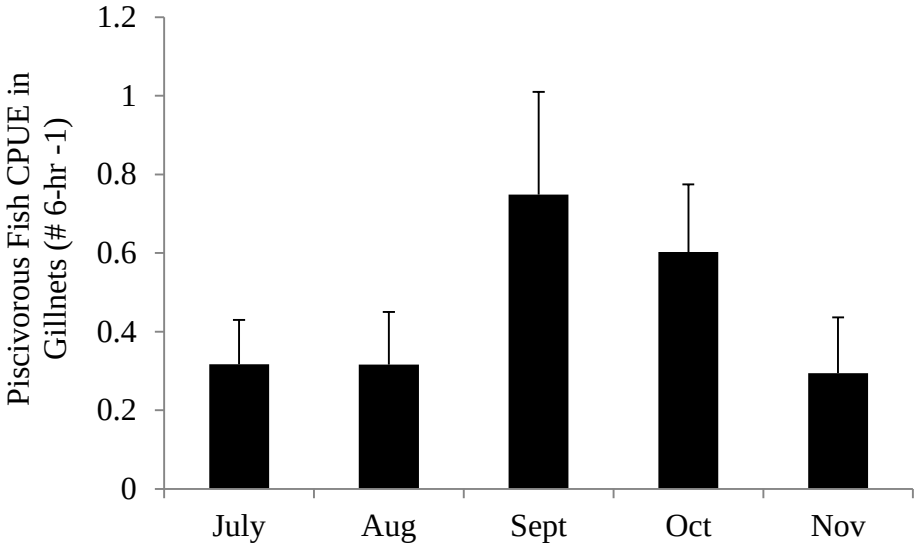
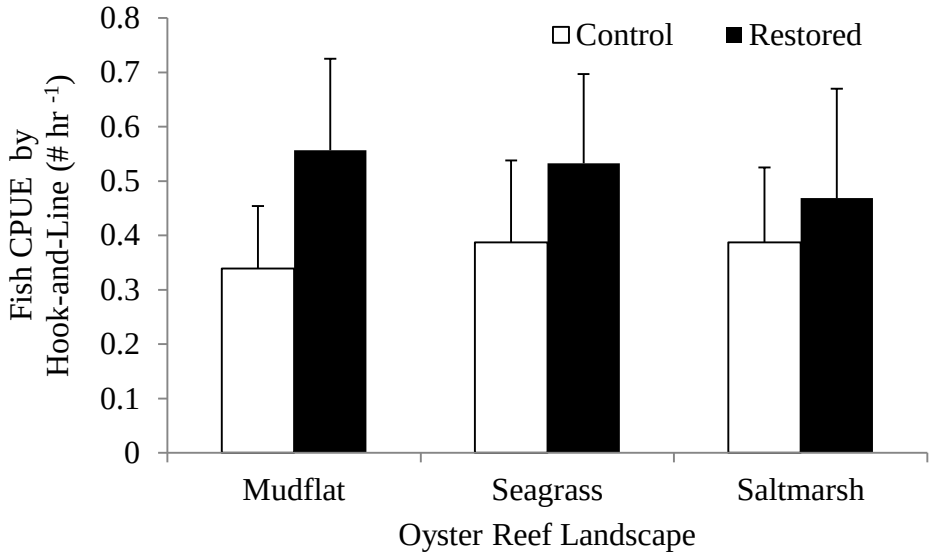


Figure 2.16. Total (targeted) fish abundance caught by hook & line (#/15 min): reef X landscape (μ + 1SE). Fishes included in analyses: *Cynoscion nebulosus*, *Leiostomus xanthurus*, *Menticirrhus spp*., *Mycteroperca microlepis*, *Paralichthys spp*., *Pomatomus saltatrix* and *Sciaenops ocellatus*.



Part 3: Fine-scale habitat utilization of red drum and sheepshead in a structurally complex intertidal ecosystem: and acoustic tagging study

Objectives (including some additional background)

Fishes are capable of daily, seasonal and ontogenetic migrations that affect our understanding of habitat value, stock concepts and mortality rates. For mobile species, recent advances in acoustic telemetry have allowed for improved analyses of the spatial and population ecology of estuarine fishes. Within North Carolina (NC), recreationally important red drum (*Sciaenops ocellatus*) and sheepshead (*Archosargus probatocephalus*) are model species for employing acoustic telemetry to rigorously investigate habitat use of mobile (juvenile) fishes over several spatial and temporal scales. While previous NCSU-based studies have acoustically tagged juvenile red drum to assess residency and mortality, our research is complementary by examining fine-scale habitat use within seagrass, saltmarsh and intertidal oyster reef landscape mosaics in a high-salinity environment.

Over the last few decades, acoustic tagging and tracking has become recognized as a reliable, direct method for charting the movements of highly-mobile marine species. The combination of ultrasonic transmitters implanted in fish and autonomous hydrophone listening stations allows for the continuous, remote monitoring of mesoscale (meters - many kilometers) movements by fishes in the coastal ocean. As such, it is now possible to resolve the movements of fishes over diel and seasonal scales without requiring researchers to be present at all times and at all sites. This approach is ideal for addressing the questions highlighted above related to: 1) habitat use over landscape (restoration) and estuary-wide scales; 2) the occurrence and implications of migratory versus resident stock contingents among estuarine species and 3) mortality.

Rigorous quantitative data on multi-scale habitat utilization by fishes will help stakeholders allocate limited financial and material resources towards the most valuable habitats for promoting healthy stocks. Thus, our primary objective with this component of our CRFL-funded research was to monitor acoustically tagged red drum (*Sciaenops ocellatus*) and sheepshead (*Archosargus probatocephalus*) at both broad (65 km^2) and fine (sub-meter) scales to track habitat preferences and movement behaviors in a natural, open system. To date, our data analyses have focused mostly on fine-scale behaviors within an intertidal marsh embayment defined by a mosaic of sandflat, seagrass, saltmarsh and intertidal oyster-reef habitats.

And although we recognized potential limitations related to the number of fish were able to implant with acoustic and external tags during 2011 (34 red drum, 7 sheepshead), a secondary objective for this component of our research was to consider what tag return rates suggest regarding local commercial and recreational fishing mortality.

Methods

In July, 2011, we set up an acoustic receiver array within the southwestern end of Middle Marsh (Back Sound), inside the Rachel Carson National Estuarine Research Reserve (Fig. 3.1). We utilized a Lotek brand Map 600 system (http://www.lotek.com/map_600.htm) to track both red drum and sheepshead in this estuarine landscape mosaic that included seagrass, saltmarsh,

intertidal oyster reef and mudflat habitats (Fig. 3.1B-C). The MAP 600 is a multi-port system of tethered acoustic hydrophones for wide area passage and multi-dimensional fish position determination. The combination of tethered hydrophones and individually coded and time-stamped fish detections allowed for the precise mapping of (multiple, simultaneous) fish locations within this region of Middle Marsh (Fig. 3.1D). Most notably, this acoustic array was capable of detecting the location of acoustically tagged fishes with sub-meter resolution. Within the Rachel Carson Reserve and immediately adjacent to our Map 600 array, a YSI 6600 V2-4 sonde (ysi.com) is permanently deployed and makes continuous measurements of temperature, salinity, dissolved oxygen, pH, Chl a concentration, light attenuation and turbidity.

In July, 2011, we also deployed 25 Vemco VR2W (http://www.vemco.com/products/receivers/vr2w.php; Figs. 3.2-3.5) acoustic omni-directional hydrophone receivers within the North River Estuary and Back Sound to track (date and time stamped) the movement and habitat use of adult red drum and sheepshead. These receivers were capable of detecting the presence of a tagged fish within a radius of up to 0.5 km, although exact detection ranges are a function of salinity, turbidity, ambient noise and line-of-sight. Detection ranges at individual receivers were assessed during periodic manual tracking cruises (described below). VEMCO receivers were strategically positioned throughout the study area to evaluate habitat use and fish movement within the entire estuary. All receivers were suspended ~1 m off the bottom using a sub-surface buoy tethered to a 50 lb concrete mooring

Both the Map 600 and VR2W receivers are capable of recording > one million tag encounters, and based on battery life can be deployed for over several days (Map 600) or months (VR2W) while requiring only periodic maintenance visits to download data and clear fouling organisms. For both our regional (VR2W) and fine-scale (Map 600) tracking, we mainted the hydrophones from July 15, 2011, until Dec, 15, 2011, to investigate the habitat use and movements of fishes throughout the summer and fall in the North River and Back Sound systems.

Sub-adult red drum and sheepshead were collected from the vicinity of Middle Marsh (e.g., North River Marsh, Carrot Island, Harkers Island Bridge) during July-Oct of 2011. All fishes were captured by working with local fishermen (Commercial gillnetter Adam Tyler), recreational fishing tournaments (Redfish Action Series; http://redfishaction.com/) and our own hook-and-line sampling. We targeted collections on red drum between 12-20 inches (TL) to explore the movements of sub-adult fish. For sheepshead, we collected fish 10-15 inches (TL). Following capture, red drum and sheepshead were transported to 500-gallon holding tanks at the Institute of Marine Sciences (IMS; UNC-CH). Fishes were held no more than 48 hours before tag implant surgeries were performed.

Prior to tag implant surgeries, red drum and sheepshead were sized and weighed, photographed (side and dorsally), and tagged with a 50 mm external dart tag (Hallprint Ltd., http://www.hallprint.com/) inserted in to the dorsal musculature. External tags were labeled with a unique ID number, contact information of the PI, and instructions for claiming a reporting reward. Acoustic tag implant surgeries were conducted in the running seawater laboratories at IMS. Surgeries were conducted on all fishes following a method described previously by NCSU-based researchers working with red drum. We did not administer a paralytic agent during tag implanting, as fishes were returned to Middle Marsh shortly (24 hours) after surgeries, whereas

FDA-approved anesthetics (MS222) cannot be administered within 21 days prior to re-entry of animals in to the human food chain. Rather, stress of study fish was minimized by cooling fish in a 50ºF bath for 1 hour before and 1 hour after surgeries (Graham Sherwood, personal communication). During surgeries, fishes were placed dorsal side down on a wooden V-board and covered with wet, clean cloths and seran wrap. The V-board was lined with foam to prevent injury to the fish. Five to six scales were removed from a small area on the ventral wall of the fishes parallel to the ventral midline about 3-4 cm anterior of the anus. A 1.5 cm incision was made parallel to the ventral midline and a coded acoustic transmitter with a 150 day estimated battery life was inserted into the peritoneal cavity. Since this tracking study was using both Lotek and VEMCO hydrophones, we employed a Lotek Wireless Inc. Dual-Mode transmitter (MM-MR-11-28, 60mm L, 12mm D, 11 g in air). This tag was capable of transmitting an R-type code detectable by VR2W receivers at distances > 500 m as well as a MAP code detectable by the Lotek receivers at distances of > 200 m (J. Fodrie, personal observations). These tags transmited a 'positioning' signal from each fish (using a combination of chirps unique to each individual fish) once every 5 seconds (Map code) or 1 minute (R code) throughout the life of the tag. Once the transmitter was implanted the incision was closed with 3 absorbable Monocryl sutures (Ethicon 2-0 with Taper CT-2 cutting needle, Ethicon, Somerville, NJ) in a simple interrupted suture pattern. The sealed incision was then covered with Batadine topical antiseptics (Purdue Pharma L.P.). Surgeries typically lasted between 4-5 minutes, and throughout the surgery we irrigated the gills of the fishes with a stream of 50ºF water. All surgical instruments and tags were sterilized using autoclaving and a weak bleach solution before coming in contact with our study fishes. Following surgeries, fishes were monitored for 24 hours for signs of stress including swimming abnormalities and buoyancy problems (only 1 fish was deemed unsuitable for re-release).

Tagged fishes were released approximately 24 hours after surgery. Regardless of collection location, all fishes were released within the southwestern corner of Middle Marsh in the Map 600 hydrophone array. Following release, fishes were at complete liberty to move through the system without further manipulation (i.e., there was no guarantee that fishes would return to the Map 600 detection area following the first low tide that forced most fishes to exit the embayment). We anticipated that some fraction of our tagged fishes would be recaptured by recreational or commercial fishermen during the course of our study. Therefore, we offered small incentives (Tee shirts) for fishermen to report recapture information.

During each month from Aug-Nov, 2011, we also conducted manual tracking cruises to explore the positions and residency status of red drum and sheepshead in and around Middle Marsh (where line of sight issues would not allow us to detect fishes in many instances with stationary hydrophone receivers). Manual tracking utilized a VEMCO VR100 ultrasonic telemetry and tracking receiver (http://www.vemco.com/products/receivers/vr100.php) mounted at the bow of an IMS vessel. We used a combination of omni- and uni-directional hydrophone receivers with the VR100 unit in order to find and locate acoustically tagged fishes. During each monthly cruise, we followed pre-set course through Middle Marsh to search for the presence and location of fishes. During these cruises, we entered all navigable creeks. The presence of adult red drum and sheepshead within the detection range of the manual tracker was stored in the unit and downloaded in the lab to supplement data collected from the 25 autonomous VR2W receivers. At the same time, dummy tags were deployed from the rear of the boat (on weighted line). By

cruising through Middle Marsh and in the vicinity of the Map 600 receivers on GPS programmed tracks, we made thorough checks of detection ranges of receivers throughout our study system.

Transmissions from all tagged fishes were processed to confirm fish identities, and individual fish tracks were analyzed in ArcMap (with 'spatial analyst' and 'animal movement' extensions) to quantify habitat utilization patterns, estuary-scale movements, residency patterns, and, as feasible, fish recovery/mortality rates. Additionally, position data from fishes are being combined with water quality data collected by the Rachel Carson NERRs and analyzed in standard multivariate statistical packages (e.g., Primer software) to more completely evaluate the environmental drivers of fish movement behavior [UNDERWAY].

Results

Throughout the summer and fall of 2011, 32 of the 34 red drum we tagged were detected at least once within the VR2W array, while 30 of the red drum were detected at some point within the MAP 600 array (we designated a 1-day lag between release dates and when detections were allowed to be recorded in our database). All seven of the sheepshead we tagged were detected at least once by the VR2W receivers, while 5 of the 7 sheepshead were detected in the MAP 600 array (although detections in the MAP 600 arena were dominated by hits from 1 sheepshead). Overall, our VR2W array collected 58,178 usable fish detections (52,331 for red drum, 5,847 for sheepshead), and the MAP 600 array made 149,169 interrogations of the fine-scale location of red drum (147,694) and sheepshead (1,475) within the landscape habitat mosaic (seagrass, saltmarsh, oyster reef and mudflat) inside Middle Marsh.

During July-Dec, 2011, 6 of the red drum we tagged were recaptured and returned by commercial gillnetters or recreational fishermen. Three more red drum were recaptured during the spring of 2012. For sheepshead, 1 individual was recaptured near the Radio Island jetty during the fall of 2011. For red drum, fish were recaptured at a 27% rate, while 14% of sheepshead were recaptured and reported to us. All reported fishes were recaptured within 30 km of Middle Marsh (ranging from Middle Marsh to the Bogue Inlet Pier), although we have not yet analyzed relationships between time-at-liberty and dispersal from Middle Marsh.

To date, data analyses have focused on fine-scale information available from the MAP 600 array, as these data more closely align with the projects central focus on landscape-level habitat utilization. Briefly, the VR2W data suggest that the number of individual detections of fishes, as well as the number of unique fish encountered at each receiver station, decreased rapidly with distance from our release point (Middle Marsh; Fig. 3.2-3.3). Ultimately, these data will be used to calculate individual and species-averaged home-range sizes as well as residency periods at a number of spatial scales. Interestingly, sheepshead appear to be more disperse than red drum, as the number of detections (and number of individual fish encountered at each receiver) within our array was much more evenly across the entire array (Figs. 3.4-3.5).

Here, we report a summary of our results based on the detections recorded from the MAP 600 array between July 15, 2011, and September 9, 2011. Our approach was to divide the data in to three segments: before September 9, then September 10 through October 15, finally October 16 on. This allowed us account for seasonal changes in the cover and extent of eelgrass meadows

within the array (accounting for the seasonal senescence of eelgrass throughout the fall). Data processing remains underway for all detections following September 9th. In the first 1 ½ months of our observations, 10 tagged drum entered the MAP 600 array (average length 466 ± 31 mm SL).

These 10 individuals provided 56,275 data points regarding position. Among the fish, the number of days in which we detected that individual ranged from 1 to 33, while the number of individual detections ranged from 38 to 26,084. Online video samples of the tracks made by these fishes (recorded every 5 seconds) can be found at: http://www.unc.edu/ims/fodrie/media.htm.

Among these 10 fish, we noted the degree to which individualized strategies may be important. For instance, 4 fish spent 50% of their time in seagrass habitat without significant time in mudflat habitat also. Two other red drum divided their time nearly evenly between seagrass and mudflat habitat. The remaining 4 red drum were more often associated with oyster reef habitat , or in areas fringing saltmarsh habitat (Fig. 3.6).

While acknowledging the importance of individual behavior, several broad patterns do emerge regarding the selectivity of habitats by red drum. Our basic premise is that if 50% of available habitat is type A, and the remaining 50% is type B, a fish should allocate its time and position evenly among those two alternatives if there is no preference for either habitat. Similarly, if 10% of available habitat is type A, and the remaining 90% is type B, a fish should allocate its time and position 10:90 among those two alternatives, respectively, if there is no preference for either habitat. Thus, our analyses are based on the ratio between proportional habitat availability and proportion of detections from each fish within each habitat type (Fig. 3.7). Ratios of 1 indicated fish used a habitat in direct proportion to its availability (no preference), ratios less than 1 indicated the avoidance of a habitat, and ratios greater than 1 indicated a preference for a habitat.

We identified 9 unique habitat types within Middle Marsh (taking in to account landscape context; Fig. 3.1C). Among these alternatives, red drum typically avoided unstructured habitats such as sand flats and channels (relative to habitat availability), and showed little preference/avoidance either way for seagrass or flooded marsh habitat. Overwhelmingly, red drum disproportionately selected oyster reef habitat, or the strip of unvegetated habitat that typically separates a seagrass meadow from a fringing reef environment (Fig. 3.7). Moreover, regardless of habitat type, red drum demonstrated a marked preference for occupying the border (i.e., “edge”, defined as a 0.5 m band – selected as the average standard body length of fish - around the perimeter of all habitat patches) between habitat alternatives. This might support the often-held view that red drum are “edge predators”.

The influence of landscape context was particularly evident among oyster reef environments (Fig. 3.8) Although “sand flat reefs” support higher oyster and infaunal densities (Figs. 2.2-2.3, 2.6-2.10), thus indicating higher prey availability, drum showed a slight bias against oyster reefs in this landscape setting. Rather, drum selected seagrass and saltmarsh-fringing reefs with strong positive biases.

Early Interpretations

Our data suggest that habitat utilization by fish is highly context dependent, meaning that use of any particular habitat is affected by proximity of other habitat types, time of day and tidal level. For instance, oyster reefs adjacent to saltmarsh or seagrass meadows were utilized proportionally more than equally productive oyster reefs on isolated sand flats. The results from this study provide a more elaborate and fine-scale understanding of the functionality of various habitats within a dynamic estuarine ecosystem.

Over the next several months, data analyses will continue so that the effects of season (i.e., September 10 through December 15 data), tidal level, diel pattern, context-dependency of habitat use, and individuality can be more thoroughly explored. Also, presently, our data can only be used to rigorously document the distribution of red drum among habitat alternative – they do not explain WHY fish select the habitats they do. Potential explanations include gradients among foraging, refuge use or reproductive activity. We are currently underway with tether experiments to examine if prey mortality among habitats and landscapes follows the distribution data resulting from our fish tracks.

Figure 3.1. Map of study area for fine-scale acoustic tagging to evaluate fine-scale habitat utilization of red drum and sheepshead. (A) Location of study site within the Rachel Carson Reserve. (B) Areal image of habitat mosaic, Lotek receiver locations and overall detection range within study site. (C) Habitat classifications within study site. (D) All detections of red drum (N = 10) during July and August of 2011.

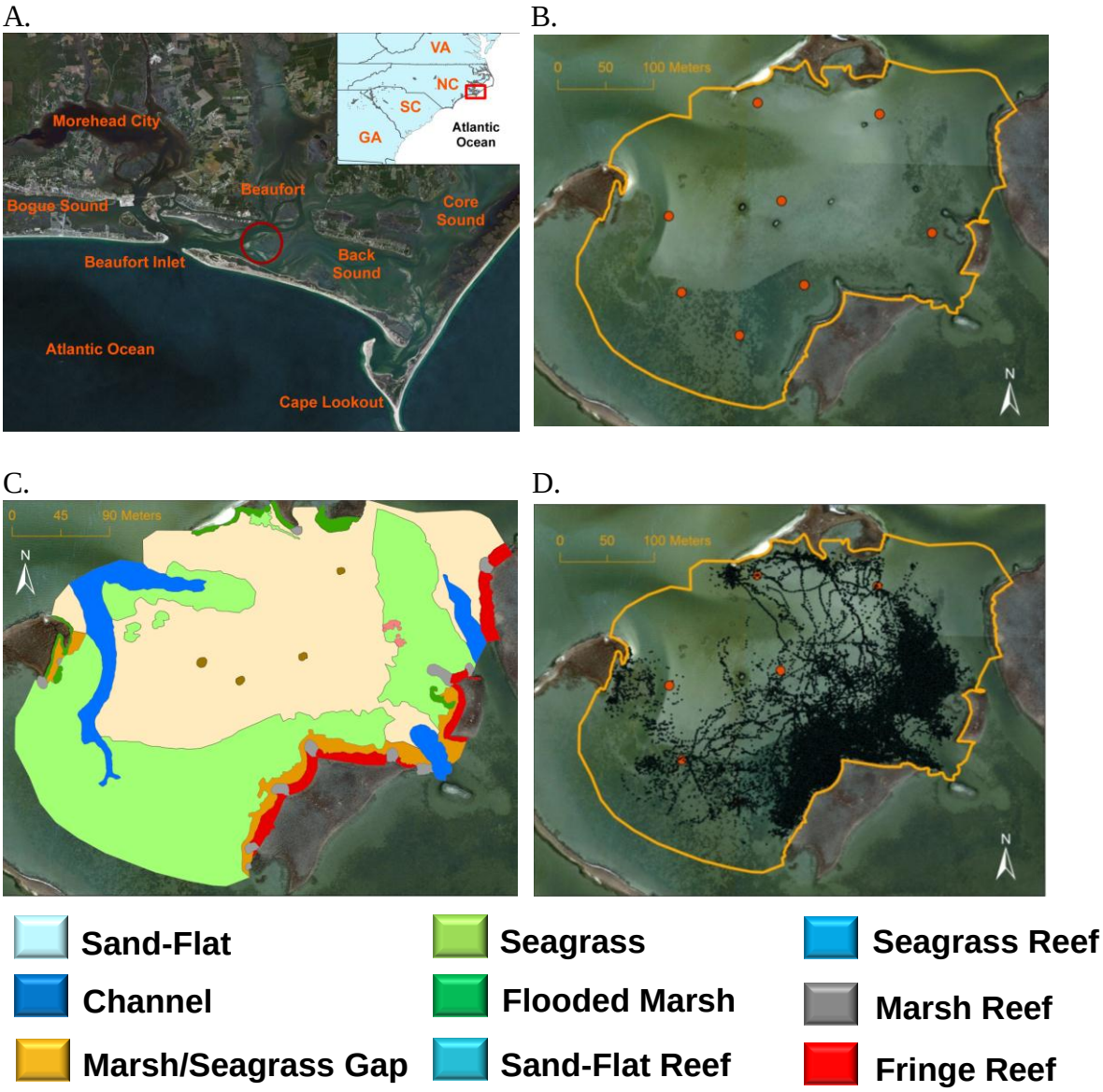


Figure. 3.2. Number of red drum detections recorded at each of 25 Vemco receivers deployed in the Back Sound and North River estuarine systems during July-December of 2011. All fish were released near receiver #14.

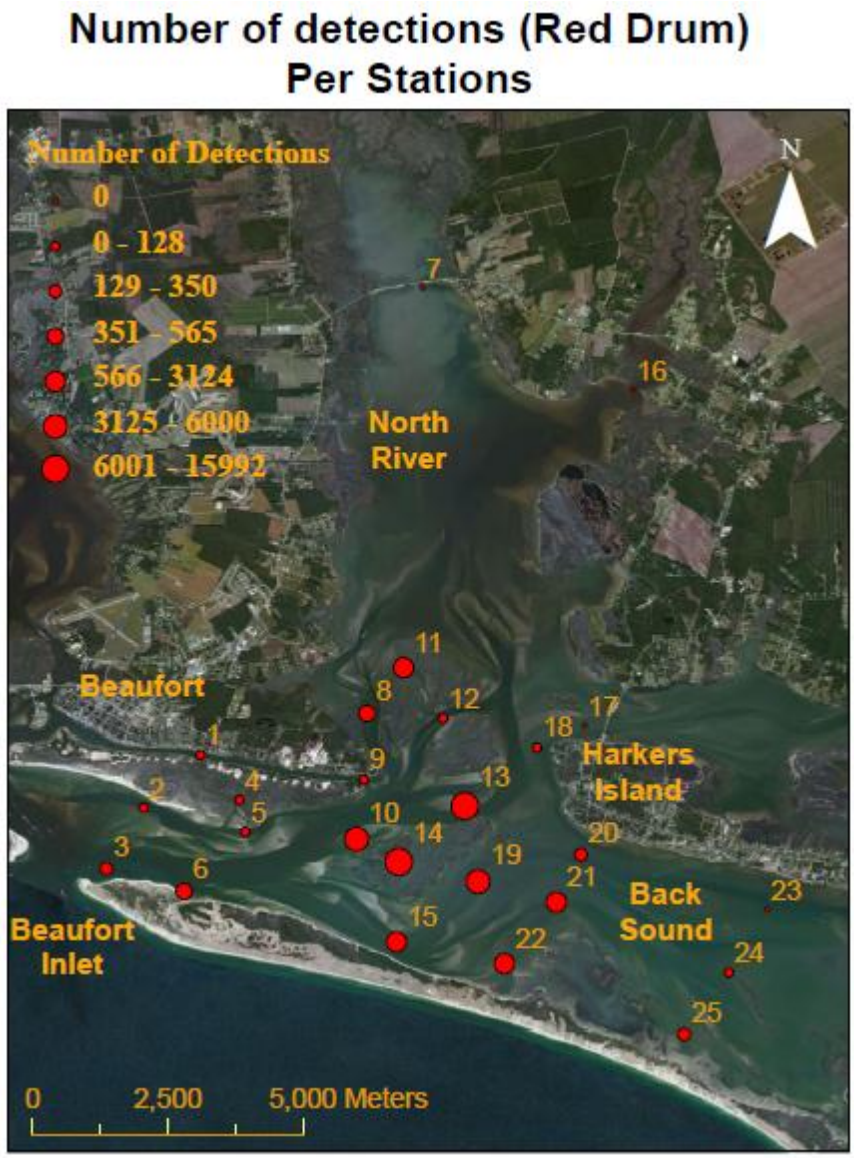


Fig. 3.3. Number of individual red drum detected at least once at each of 25 Vemco receivers deployed in the Back Sound and North River estuarine systems during July-December of 2011. All fish were released near receiver #14.

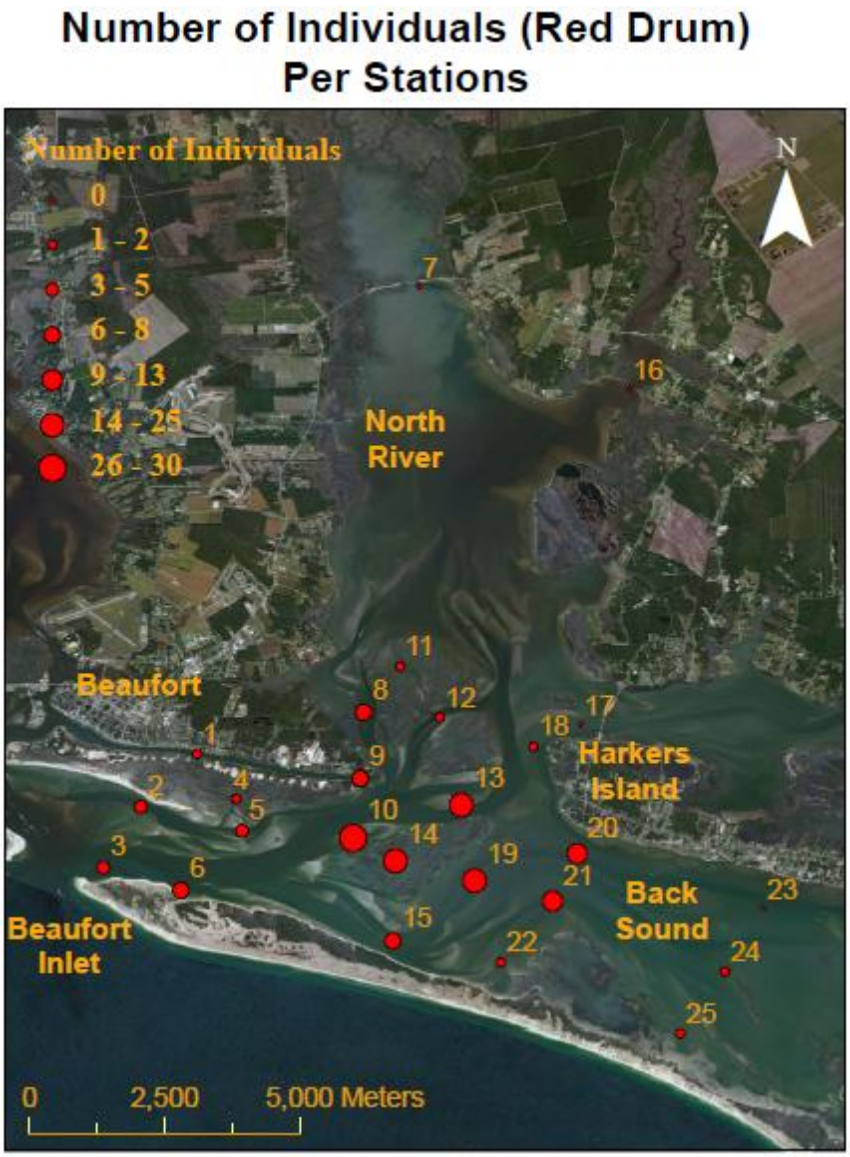


Figure 3.4. Number of sheepshead detections recorded at each of 25 Vemco receivers deployed in the Back Sound and North River estuarine systems during July-December of 2011. All fish were released near receiver #14.

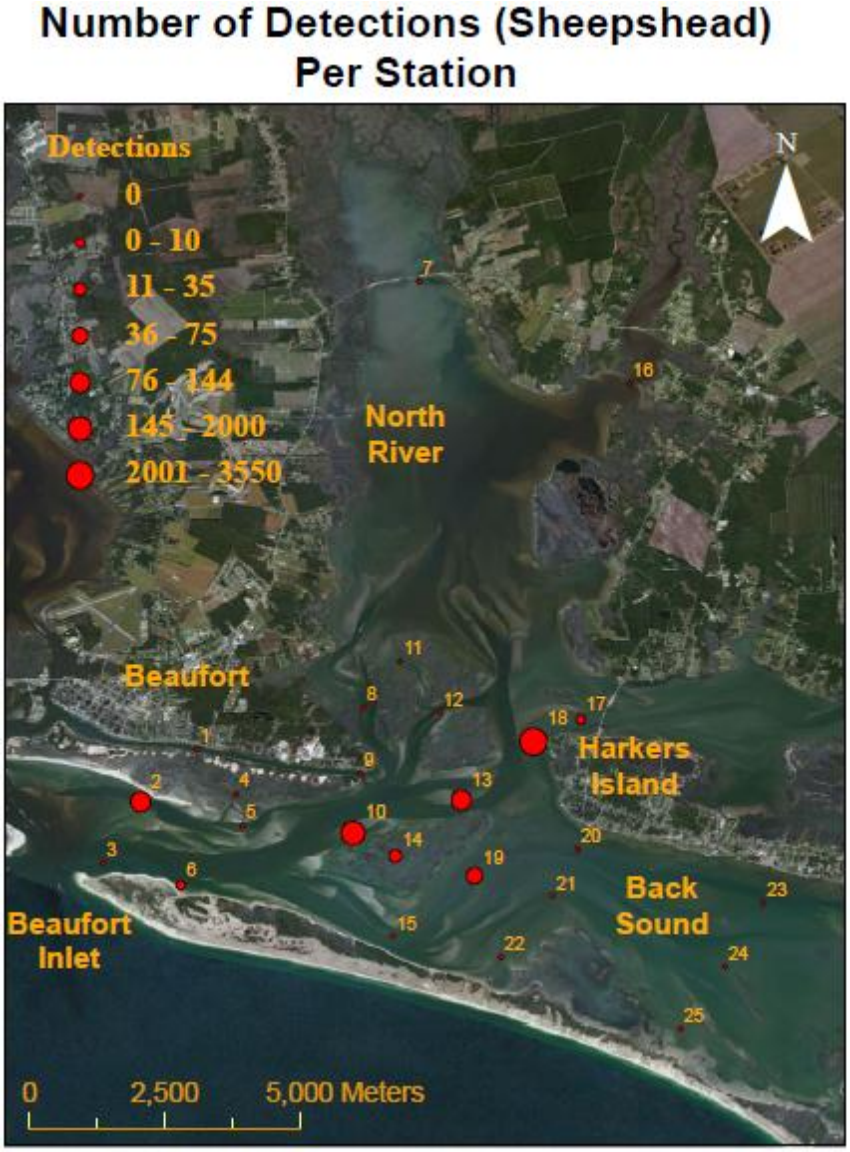


Figure. 3.5. Number of individual sheepshead detected at least once at each of 25 Vemco receivers deployed in the Back Sound and North River estuarine systems during July-December of 2011. All fish were released near receiver #14.

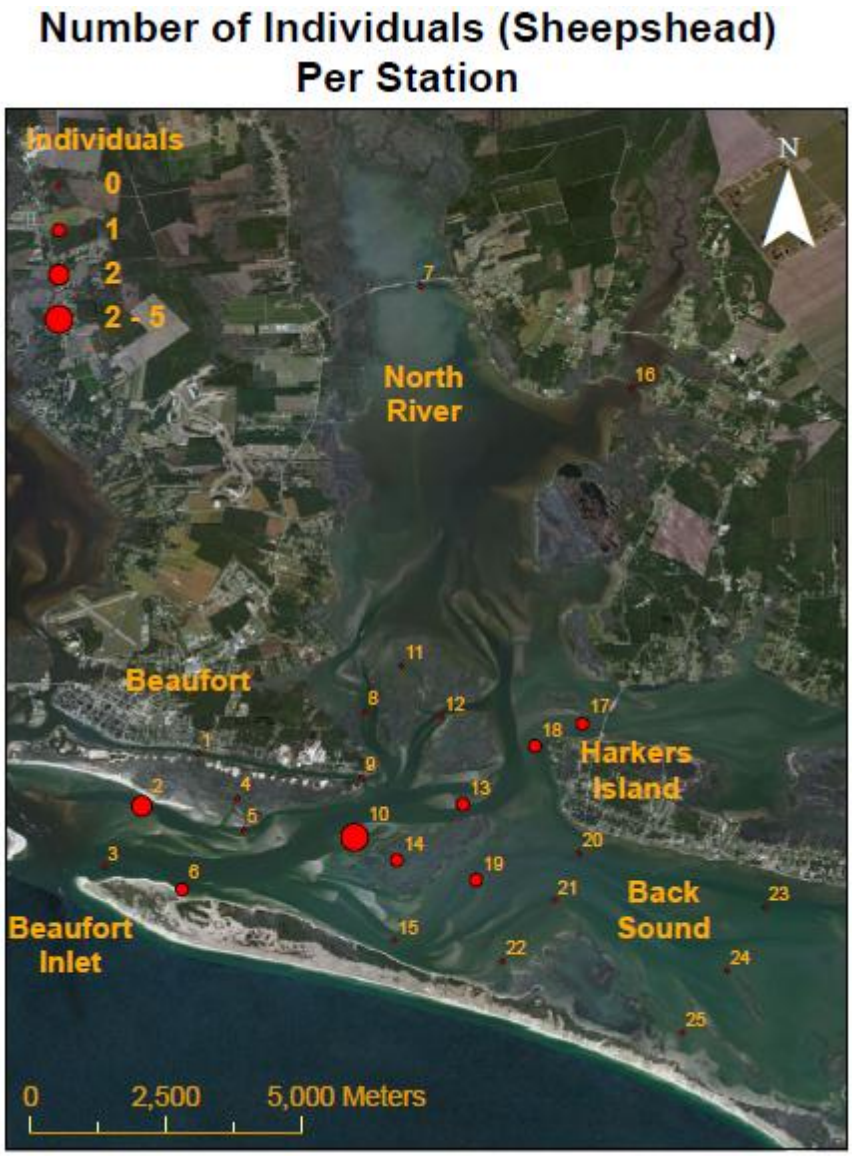


Figure 3.6. Percentage of habitat use by 10 individual red drum during July and August of 2011 within the Rachel Carson study system.

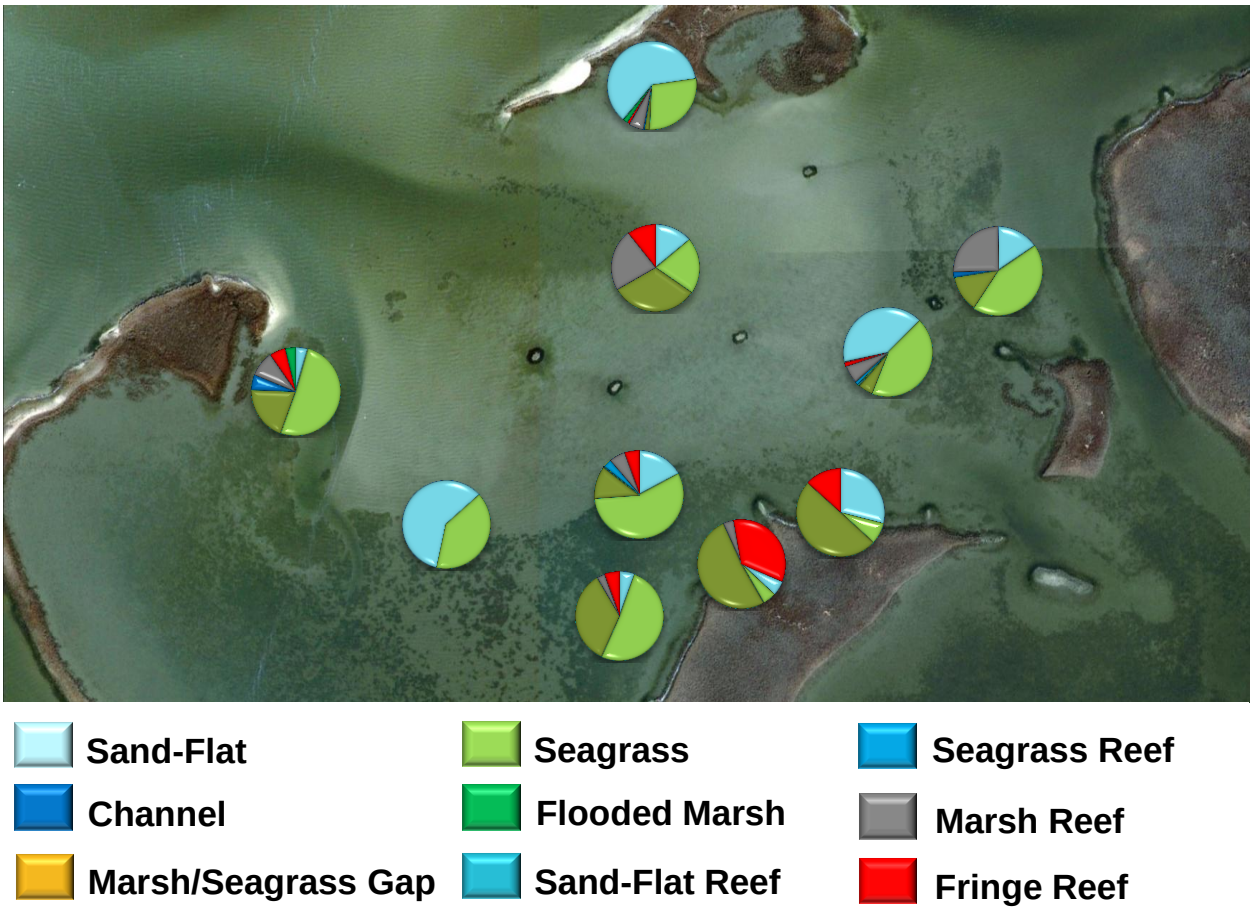


Figure. 3.7. Overall habitat selectivity by red drum (N = 10) during July and August of 2011 within the Rachel Carson study system. Values greater than 1 indicate that fish differentially preferred those habitats relative to habitat availability, values less than 1 indicate that fish avoided habitats relative to habitat availability, and values equal to one indicate that fish utilized habitat directly in proportion with habitat availability. Also shown are the relative utilization of "edge" (defined as the outermost 1 m of any given habitat type) versus "core" habitat.

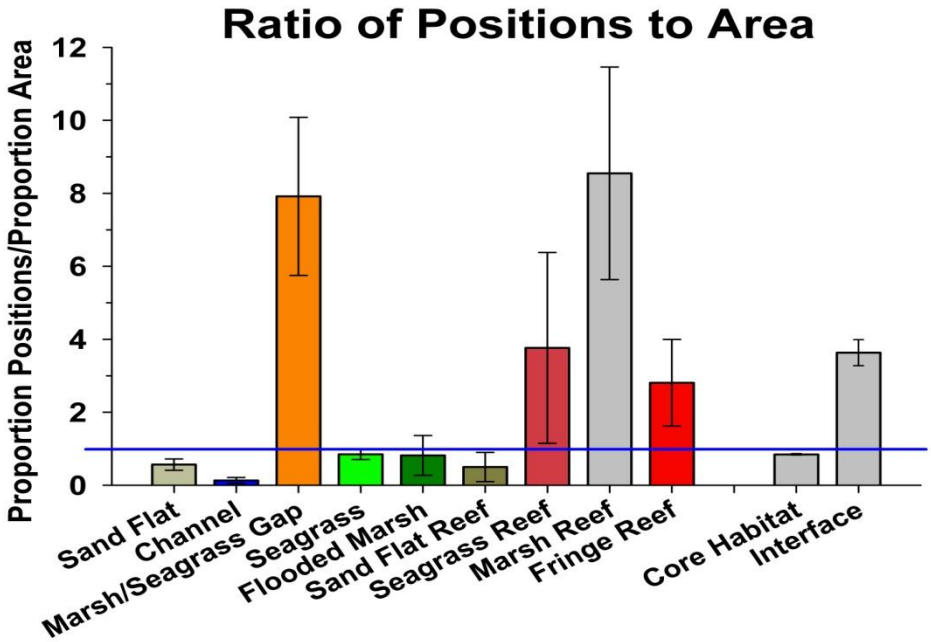
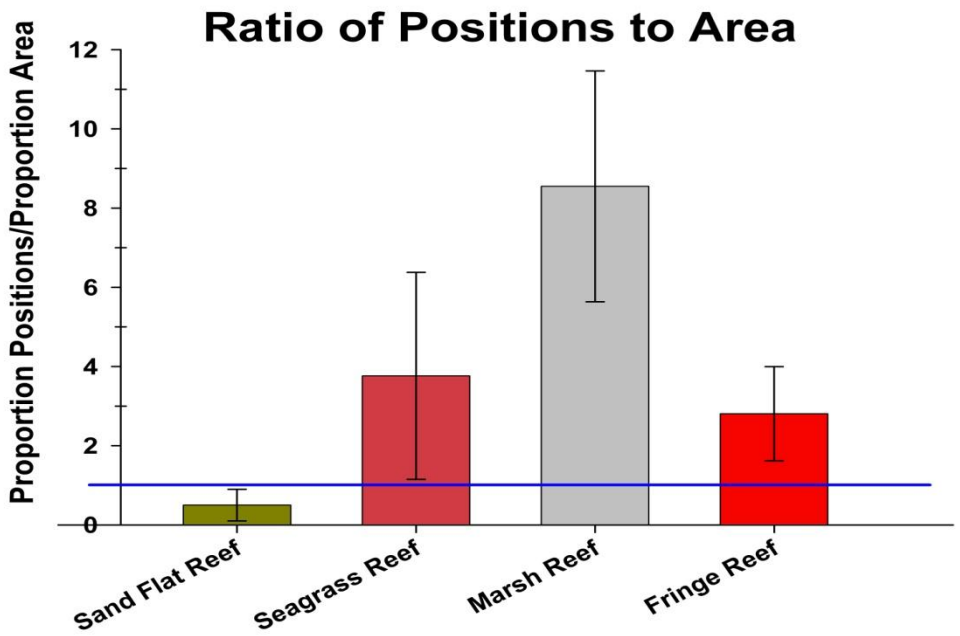


Figure 3.8. Oyster reef habitat selectivity by red drum (N = 10) during July and August of 2011 within the Rachel Carson study system. Values greater than 1 indicate that fish differentially preferred those habitats relative to habitat availability, values less than 1 indicate that fish avoided habitats relative to habitat availability, and values equal to one indicate that fish utilized habitat directly in proportion with habitat availability.



Amendments and deviations to proposal

We made several notable alterations to our proposed research plan, and we are confident these changes resulted in more complete, robust analyses of the nursery-role of estuarine habitats. Below, we include a list of notable changes to our work plan, and provide and rationale for those changes.

1) Our original survey design specified that in addition to trawl sampling we would also conduct seine and trap surveys in each landscape considered in Part 1 of our report. While we did initially conduct these trap and seine collections, it quickly became apparent that unbaited trap sampling was not efficient (most collections resulted in the capture of or 2 pinfish), while seining was largely redundant (i.e., catch composition, especially for fishes, although seining tended to capture more small invertebrates) with trawl sampling. Therefore, we did not continue trap or seine sampling past the fall of 2010.

2) Although we originally intended to avoid sampling oyster reefs, we ultimately decided that it was critical to include all common estuarine habitat types to fully investigate the landscape effect of habitat utilization by juvenile fishes and decapod crustaceans. Notably, the eventual inclusion of intertidal oyster reef habitat (the dominant form of reef habitat in high salinity waters) allowed us to also consider the role of landscape setting in determining the ecosystem services provided by restored habitats. Finally, we also recognize that the incorporation of acoustic tagging technology allowed us a way to sample habitat utilization of fishes in a manner that was compatible across habitat types.

3) In our proposal, we planned to test habitat preference (selectivity) using a series of pair-wise choice experiments in which fishes were able to select between habitat alternatives within mesocosms. While potentially informative, these mesocosm tests could suffer from a series of caging artifacts related to difficulties in matching realistic prey and predator densities among habitat alternatives, as well as issues related to the penning of mobile fishes. In year 1 of our study, we did perform our proposed mesocosm choice experiments with gag grouper, but became worried that experimental artifacts would make our results equivocal. Therefore, in year two of our study, we employed fine-scale acoustic tagging technology to ascertain the habitat preference of sub-adult red drum and sheepshead in the field under completely natural conditions (see Part 3 above).

4) We did conduct field-based environmental monitoring and laboratory thermal tolerance experiments to explore whether SAV and wetland landscapes differentially promote the overwintering success of juvenile fishes and invertebrates [See attached data files]. In all, we maintained 9 HOBO temperature loggers within seagrass, saltmarsh creek, seagrass-saltmarsh interface and mudflat habitats in both of our study areas, as well as saltmarsh creeks covered with seagrass landscapes in Core Sound. In the laboratory, we focused our thermal tolerance trials on gray snapper and stone crabs. We selected these species for several reasons, such as: gray snapper are abundant to our south and may reach their lower thermal tolerances in NC. Therefore, it is unclear if NC is able to contribute to the offshore, adult stock along the southeastern US coastline. Furthermore, gray snapper are

commonly caught in trawl sampling starting in Sept. As this is fairly late in the year, gray snapper to do not have much time to grow and exit estuarine landscapes prior to seasonal cooling. Stone crabs are also historically more abundant to our south , but recent trends suggest stone crabs may be extending their range and becoming more common in NC in response to regional warming. However, during Dec, 2010, we observed dozens of stone crabs within our Middle Marsh study site that appeared to be cold stunned, lethargic and subject to predation by various birds. We did learn during the course of our gray snapper trials that similar work was being conducted at Rutgers University to determine the thermal tolerances of that species, and we are therefore working with those researchers to determine if our results can be combined to examine the abiotic controls of snapper regionally. Our stone crab trials are complete [See attached data files], although we have not yet had the opportunity to analyze those data and do not report on them further here.

Applicability of study results to CRFL Strategic Plan and priorities

This research directly addressed *Strategy H.2.5* (identify linkages between coastal fish habitat and fish production, and identify key aspects of habitat function and effects of human activities) under **Objective 2** (identify, designate and conserve fish habitat and SHAs) of the **Habitat Management Goal**. This research will also explored the biotic and abiotic controls of juvenile fish distributions within marine SAVs, coastal saltmarshes and intertidal oyster reefs thereby addressing a specific priority need listed in the RFP: account for environmental variation in population projections. Furthermore, the proposed research will be valuable for coastal managers relative to *Strategy H.3.1.* (identify degraded fish habitat and implement restoration measures) under **Objective 3** (enhance and protect habitat) of the **Habitat Management Goal**. This work was completed in close cooperation with other DENR agencies (e.g., National Estuarine Research Reserve) so that standard measures of estuarine habitat condition were generated (*Strategy H.1.1*). Lastly, juvenile vital-rate data are being generated (e.g., growth rates) for several estuarine-dependent species (e.g., pigfish, gag grouper, gray snapper, speckled trout) that occupy SAV, wetland, oyster reef and mudflat habitats. These data could eventually be incorporated in to current stock assessment models (*Strategy F.1.3.*).

Recommendations

Many exploited marine and estuarine populations have experienced significant reductions in spawning stock biomass and recruitment. Concurrently, essential habitats such as nursery and foraging grounds have been degraded or lost in many areas such that these critical habitats are no longer adequate to fulfill nursery, feeding or reproductive functions.

However, despite a general appreciation for the importance of high quality habitat in promoting healthy fisheries, as well as a vast literature on habitat-specific growth and mortality rates, there is a general lack of understanding for how habitat quality, habitat loss or habitat restoration contribute QUANTITATIVELY toward population-level dynamics and health of fishery species. Unfortunately, this has limited the formal and more meaningful inclusion of habitat in to fishery management plans.

Perhaps two reasons that the linkages between habitat and fishery dynamics have been difficult to evaluate are because: A) Within-habitat variability has been insufficiently explored. Thus, loss of a habitat in one place/context may not have the same effects on fishery species as loss of the same habitat in another place/context; and B) Many fish and invertebrate species are able to select among a diverse portfolio of habitat alternatives for reproduction, foraging or evading predators. Variability in habitat choice among individuals or over time within a species, as well as movements among habitats by individuals add significant complexity for quantifying the functional value of purported essential fish habitats.

Thus, there is considerable need to consider the landscape effects of habitat function in order to better preserve and enhance essential fisheries habitat. In particular:

1) Our 2-year trawl and acoustic tagging surveys unequivocally demonstrate that the utilization of seagrass meadows, saltmarsh creeks and intertidal oyster reefs are highly landscape dependent. We recommend *that NC-DMF initiates a seagrass/saltmarsh trawl survey that accounts for landscape-level variability in seagrass type, meadow size and connectivity with other habitats*, or supports the continuation of university-based seagrass/saltmarsh trawl surveys. These data are needed to complement the ongoing Pamlico Sound survey and fill a gap in spatial coverage to include one of the major habitats listed in the CHPP. Over time, these data would also contribute significantly to demographic models of fishery species, as well as syntheses regarding the effects of regional climate change on habitat forming species (e.g., eelgrass) or fishery species (e.g., snappers).

2) In future restoration or conservation efforts, *NC-DMF should consider the value of strategically including MULTIPLE habitats in the design and placement of SHAs or enhancement projects in order to promote overall fishery benefits for North Carolina's estuaries.* For instance, seagrass meadows isolated from (preferred by lane snapper, larger sheepshead) and connected to (preferred by gag grouper, gray snapper, red drum, speckled seatrout) saltmarshes may provide species-species benefits. Likewise, the function of saltmarsh creeks as fish and decapod crustacean habitat may be enhanced by promoting conditions that ensure the health of shoalgrass. Also, the placement of oyster reefs within the estuarine landscape (see below) likely has significant effects on the fishery benefits that can be accrued.

3) Our findings reinforce that oyster reefs provide a multitude of ecosystem services within estuaries (filtration capacity - mudflat reefs appear best, fish and invertebrate habitat utilization – saltmarsh fringing "beds" appear best based on acoustic tagging results, shoreline stabilization –saltmarsh reefs appear best); however, where they are restored, whether it be on a mudflat or adjacent to a seagrass meadow or a saltmarsh, or in the intertidal zone vs. in the subtidal zone, will all influence the type and degree of benefits provided by reefs. At the core of this study - provision of nursery/feeding habitat that traditionally is attributed more to seagrasses and saltmarshes - oyster reefs could extend the range of fish by redistributing them more evenly across estuarine landscapes, which could increase the secondary productivity of the entire estuary. The extensive reduction in North Carolina of oyster reef habitat from overharvesting could have penalized fish

that historically foraged on reefs by increasing the amount of time a fish must spend searching for a reef. As a consequence, fish might switch to foraging in what was previously a less optimal habitat, which could result in a decline in fish abundance if other habitats do not provide enough food, thereby biasing habitat evaluations against spatially diminished habitats such as oyster reefs as foraging grounds for mobile species. The management implications of this finding are clear when one considers the importance of nursery habitat for North Carolina's commercial fisheries and how resilient oyster reefs are to natural environmental disturbance when left undisturbed by humans. In conclusion, the "concern" status of oyster stocks coupled with an emerging understanding of the services provided by oyster habitat makes it imperative to assess the ecosystem benefits of various restoration programs and implement findings into policy decision making. Our project results should provide NC-DMF and the public with enhanced understanding of the long-term (>1 decade) fishery benefits that can be accrued through both "primary" (oysters) and secondary production (associated fauna, especially recreationally/commercially important species) on restored oyster reefs. *We pose two alternative strategies for managing oyster restoration activities: 1) balance restoration efforts between landscapes and tidal zones to ensure provision of the entire array of benefits provided by reefs; or 2) prioritize the benefits provided by oyster reefs and restore reef habitat in different landscapes and tidal zones relative to their ability to provide the desired benefits in order to optimize returns on reef restoration efforts.*

4) *Fishery managers should more directly take in to account the individual variability that fishes demonstrate regarding movement patterns or habitat use*. To date, stock assessments are not able to constrain the diversity of foraging and movement strategies of most fisheries species, and as a result the role of contingents in buffering or exacerbating the effects of harvest are poorly understood. Furthermore, a dearth of information regarding diversity in how individuals within a species select habitats makes it nearly impossible to relate habitat availibity/quality with fishery population models in any meaningful way. NC-DMF could use their current tagging studies, or consider new approaches that allow fine-scale examination of habitat use, to investigate these dynamics further.

Anticipated publications acknowledging CRFL support (submitted or in preparation)

Brodeur, M.C., F.J. Fodrie and M.F.Piehler (2012) Consumer pressure dampens effects of heat stress and nutrient enrichment at the southern limit of eelgrass meadows (*Zostera marina* L.). Target Journal: *Marine Ecology Progress Series*

Baillie, C.J. and F.J. Fodrie (2012) Landscape effects on the nursery role of SAV and wetland habitats for recreationally important fishes in a mid-Atlantic estuary. Target Journal: *Estuarine, Coastal and Shelf Science*

Fodrie, F.J., and J. H. Grabowski (2012) Restoration revisited: assessing the shellfish and finfish production value of decade-old, man-made oyster reefs. Target journal: *Conservation Biology*.

Fodrie, F.J., M.D. Kenworthy, J.H. Grabowski, C.A. Layman, G.D. Sherwood, S.P. Powers, C.H. Peterson, C.J. Baillie, J.M. Fear and A.B. Rodriguez (2012) Fine-scale habitat use of predatory finfish in estuarine landscape mosaics. Target journal: *Ecological Applications*

Fodrie, F.J., M.D. Kenworthy, J.H. Grabowski, C.A. Layman, and G.D. Sherwood (2012) Estuarine-wide habitat use, movement patterns and mortality of red drum and sheepshead Target journal: *Fishery Bulletin*

Gittman, R.K. and F.J. Fodrie (2013) A community-based approach for examining the use of restored and natural oyster reefs by fishes and crustaceans within a complex *Spartina* marsh landscape. Target journal: TBD