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The effect of an inshore artificial reef on the community structure and feeding ecology of estuarine fishes in Barataria Bay, Louisiana

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THE EFFECT OF AN INSHORE ARTIFICIAL REEF ON THE COMMUNITY STRUCTURE
AND FEEDING ECOLOGY OF ESTUARINE FISHES IN BARATARIA BAY, LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Masters of Science

in

The Department of Oceanography and Coastal Sciences

by
Kirsten A. Simonsen
B.S., Roger Williams University, 2001
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DEDICATION

To my grandparents, Stella and Joe, who taught me how to dream, and to Melissa, who never had the chance.

And to all the Posdas, who help me to remember that I like fish, but that's ok.

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ABSTRACT

Recently we have begun to understand the importance of inshore hard-bottom substrate, including oyster reefs, to estuarine fish communities in the Gulf of Mexico, especially in the context of identifying Essential Fish Habitat (EFH). However, problems such as habitat loss, disease, overharvest, and failure to replace shell have severely decreased the amount of high-relief oyster reef habitat available to finfish. The purpose of this project was to establish an artificial high-relief mimic-oyster reef in Barataria Bay, Louisiana, and monitor its use by economically and ecologically important finfish, including spotted seatrout (*Cynoscion nebulosus*) and Atlantic croaker (*Micropogonias undulatus*). The finfish and invertebrate communities over the artificial reef site were compared to a mud bottom reference site, using two different gear types to sample the entire water column. I also examined site-specific trophic linkages by enumerating gut contents and performing stable isotope analyses of spotted seatrout, Atlantic croaker and bay anchovy (*Anchoa mitchilli*). There was no overall difference in the community structure between sites, though there was a seasonal difference in the numbers of individuals found at both sites. Species richness also varied by season, with highest number of species present in summer months. Results of the gut-content analysis showed that diets of spotted seatrout do not differ significantly between sites. Spotted seatrout consumed mostly fish and anchovies by number, and penaeid shrimp by weight. Stable isotope analysis indicated that while there were no overall differences in mean stable isotope values, the dietary breadth of spotted seatrout was greater over the artificial reef. In contrast, results indicated that there were significant differences in the diets of Atlantic croaker between sites. Atlantic croaker diets consisted of mud crabs (Xanthidae) and other, unidentifiable crabs over the reef, and bivalves and fish over the reference site. Stable isotope analysis of Atlantic croaker indicates that overall

dietary breadth was similar between sites, though $\delta^{15}\text{N}$ values were significantly higher over the artificial reef. Results of the stable isotope analysis for bay anchovy indicate that there was a greater dietary breadth over the artificial reef.

GENERAL INTRODUCTION

Estuarine habitat loss is a growing problem throughout the country, but nowhere is it as prevalent as in coastal Louisiana, where over 80% of the nation's wetland losses have occurred (Turner, 1997). This is particularly disturbing when considering that many fish species utilize estuarine habitats for growth and development through larval and juvenile stages. Some have hypothesized that loss of habitat will directly affect fish populations in the future (Coen et al. 1999; Minello, 1999; Jones et al., 2002; Cowan et al., in press). In response, The Magnuson Steven Fishery Conservation and Management Act, and its 1996 reauthorization as the Sustainable Fisheries Act (SFA), called for the conservation and protection of marine habitats. The SFA describes the loss of marine, estuarine and aquatic habitats as "one of the greatest long-term threats to the viability of commercial and recreational fisheries" (16 USC 1801). The act therefore called for the identification and protection of essential fish habitat (EFH), defined as those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity (16 USC 1801). Additionally, all commercially and recreationally important finfish and shellfish are required to have a management plan, which requires identification and protection of EFH for each species.

In the Gulf of Mexico, and throughout the east coast of the United States, a majority of past work to identify EFH has focused on salt-marsh edge habitat (Rakocinski et al., 1992; Baltz et al., 1993; Minello, 1999; Jones et al., 2002) as well as offshore natural reefs (Wells, 2007) and oil and gas platforms (Patterson, et al. (eds.), 2007). However, more recently hard-bottom substrate, including oyster reefs, is speculated to constitute EFH for a number of commercially and recreationally important species, especially in estuarine ecosystems (Breitburg, 1999; Coen et al., 1999; Harding and Mann, 2001; Luckenbach, et al., 2005; Coen and Grizzle, 2007). It is

well documented that oyster larvae recruit and settle in the presence of mature oysters, and therefore oyster reefs have long been recognized as EFH for oysters themselves (Coen et al. 1999; Plunket, 2003). We have also begun to realize the importance of oyster reefs, particularly the eastern oyster, *Crassostrea virginica*, to estuarine fish communities (Coen et al., 1999). Reefs provide substrate for growth and attachment of benthic algae and sessile organisms that can provide food for many species, while the interstitial space within a reef acts as refugia for smaller benthic fish species and early life history stages of larger species (Coen and Grizzle, 2007). There is also evidence that high relief oyster reefs can provide benthic organisms with a means of escaping hypoxia in areas of the Chesapeake Bay and Gulf of Mexico (Breitburg, 1994; Breitburg et al., 1994; Lenihan et al., 2001). Zones of hypoxia can be several centimeters thick above the sea floor. Oyster reefs can reach heights of over a meter above the substrate, providing benthic organisms with access to more oxygen rich water higher in the water column. Breitburg et al. (1995) showed that the vertical relief provided by reefs can also decrease the velocity of water flow, which will allow larval fish to more easily maintain their position over the reef. In turn, predators of small and larval fishes congregate over the reef to take advantage of the feeding opportunities they present (Breitburg et al., 1995).

Oyster reefs were once extremely numerous throughout the Gulf of Mexico (Gulf) and Atlantic coasts of the United States. In recent years, a combination of factors, including disease, degrading water quality, overharvest, habitat loss, and the failure to replace oyster shell, has led to drastic declines of oyster populations. Rothschild et al. (1994) estimated current oyster habitat in Chesapeake Bay to be less than 50% of historic area, and today may be as low as 2% of historic area (CBF, 2007). In addition to being smaller in size, existing oyster reefs are also much lower in relief than historic reefs, providing less surface area for the settling of new oysters

and less refuge for resident fish species (Lenihan et al., 2001). Despite the problems, oyster production is still high, especially in the Gulf, where over 4.5 million kilograms of meat are still harvested annually (Plunket, 2003), due in part to the methods used to grow and harvest oysters. The industry today is mostly a “put-and-take” industry, where reefs are seeded with oyster spat, and then harvested when oysters reach a marketable size. Effective management plans, such as spatial and temporal fisheries restrictions, stock enhancement and addition of oyster shell substrate, have also helped to maintain high yields (LDWF, 2005). However, these harvest methods do not maintain the complex reef structure of natural oyster reefs, and as such the amount of habitat available to finfish is limited.

Oyster reef restoration has expanded in both size and number of projects over recent decades as we have begun to realize the importance of reefs to fish communities and overall estuarine health (Coen and Grizzle, 2007). A majority of this work has been conducted on the U.S. Atlantic coast in the Chesapeake Bay and in North and South Carolina. The goal of this project was to establish an artificial high relief oyster reef in Barataria Bay, Louisiana, and monitor its affects on the estuarine fish community, particularly those of commercial or recreational importance such as spotted seatrout (*Cynoscion nebulosus*). Chapter 1 examines the community structure of the artificial reef, as compared to an unaltered mud-bottom reference site. My goal was to determine if presence of added structure significantly changed the fish community, or increased abundance of certain species at the reef site. Chapter 2 examines the site-specific trophic linkages through the use of both gut-content and stable isotope analyses. Dietary analysis was conducted for key species, including spotted seatrout, Atlantic croaker (*Micropogonias undulatus*), and bay anchovy (*Anchoa mitchilli*), to determine if there is a difference in the feeding ecology between the artificial reef and the mud-bottom reference site.

LITERATURE CITED

- Baltz, D. M., C. F. Rakocinski, et al. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. *Environmental Biology of Fish* **36**: 109 - 126.
- Breitburg, D. L. 1994. Behavioral response of fish larvae to low dissolved oxygen concentrations in a stratified water column. *Marine Biology* **120**: 615-625.
- Breitburg, D. 1999. Are three dimensional structure and healthy oyster populations the keys to an ecologically interesting and important fish community. In M.W. Luckenbach, R. Mann and J.A. Wesson, editors. *Oyster reef habitat restoration. A synopsis and synthesis of approaches*. Gloucester Point, Virginia: Virginia Institute of Marine Science Press. pp 239 – 250.
- Breitburg, D. L., N. Steinburg, S. DuBeau, C. Cooksey, and E.D. Houde. 1994. Effects of low dissolved oxygen on predation on estuarine fish larvae. *Marine Ecology Progress Series* **104**: 235-246.
- Breitburg, D. L., M. A. Palmer, and T. Loher. 1995. Larval distributions and the spatial patterns of settlement of an oyster reef fish: response to flow and structure. *Marine Ecology Progress Series* **125**: 45-60.
- Breitburg, D. L., L. D. Coen, M.W. Luckenbach, R. Mann, M. Posey, and J. Wesson. 2000. Oyster reef restoration: convergence of harvest and conservation strategy. *Journal of Shellfish Research* **19**(1): 371 - 377.
- Chesapeake Bay Foundation (CBF). 2007. Oyster Restoration. www.cbf.org.
- Coen, L. D., M. W. Luckenbach, D.L. Breitburg. 1999. The role of oyster reefs as Essential Fish Habitat: a review of current knowledge and some new perspectives. *AFS Symposium* **22**: 438 - 454.
- Coen, L. D. and R. E. Grizzle. 2007. The importance of habitat created by molluscan shellfish to managed species along the Atlantic coast of the United States. *ASMFC Management Series* #8. 109pp.
- Cowan, J.H. Jr., C.B. Grimes, and R. F. Shaw. In press. Life history, history, hysteresis, and habitat changes in Louisiana's coastal ecosystem. *Bulletin of Marine Science*.
- Harding, J. M. and R. Mann. 1999. Fish species richness in relation to restored oyster reefs, Piankatank River, Virginia. *Bulletin of Marine Science* **61**: 289 – 300.
- Harding, J. M. and R. Mann 2001a. Oyster reefs as fish habitat: opportunistic use of the restored reefs by transient fishes. *Journal of Shellfish Research* **20**(3): 951 - 959.

- Harding, J. M. and R. Mann 2001b. "Diet and habitat use by bluefish, *Pomatomus saltatrix*, in a Chesapeake Bay estuary." *Environmental Biology of Fish* **60**: 401 - 409.
- Harding, J. M. and R. Mann (2003). Influence of habitat on diet and distribution of striped bass (*Morone saxatilis*) in a temperate estuary. *Bulletin of Marine Science* **72**(3): 841 – 845.
- Jones, R. F., D. M. Baltz, and R.L. Allen. 2002. Patterns of resource use by fishes and macroinvertebrates in Barataria Bay, Louisiana. *Marine Ecology Progress Series* **237**: 271 - 289.
- Lenihan, H. S., C. H. Peterson, J.E. Byers, J. Grabowski, G.W. Thayer, and D.R. Colby. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. *Ecological Applications* **11**(3): 764 - 782.
- Luckenbach, M. W., L. D. Coen, P.G. Ross, J.A. Stephen. 2005. Oyster reef habitat restoration: Relationships between oyster abundance and community development based on two studies in Virginia and South Carolina. *Journal of Coastal Research* **SI-40**: 64 - 78.
- Louisiana Department of Wildlife and Fisheries (LDWF). 2005. Louisiana Department of Wildlife and Fisheries 2004 – 2005 Annual Report. <http://www.wlf.state.la.us>. 60 pp.
- Minello, T. J. 1999. "Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of Essential Fish Habitat." *AFS Symposium* **22**: 43 - 75.
- Patterson, W.F.III, J.H. Cowan Jr., G.R. Fitzhugh, and D.L. Nieland, editors. 2007. Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society Symposium 60, Bethesda, Maryland. 396 pp.
- Plunket, J.T. 2003. A comparison of finfish assemblages on subtidal oyster shell (clutched oyster lease) and mud bottom in Barataria Bay, Louisiana. Louisiana State University Thesis, Department of Oceanography and Coastal Sciences. 84 pp.
- Rakocinski, C. F., D. M. Baltz, and J.W. Fleeger. 1992. Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. *Marine Ecology Progress Series* **80**: 135 - 148.
- Rothschild, B. J., J. S. Ault, P. Gouletquer, and M. Heral. 1994. Decline of the Chesapeake Bay oyster populations: a century of habitat destruction and overfishing *Marine Ecology Progress Series* **111**: 29 - 39.
- Turner, R.E. 1997. Wetland loss in the northern Gulf of Mexico: multiple working hypotheses. *Estuaries* **21**(1): 1 – 13.
- Wells, R.J.D. 2007. The effects of trawling and habitat use on red snapper and the associated community. Louisiana State University Dissertation, Department of Oceanography and Coastal Sciences. 179 pp.

CHAPTER1: ESTUARINE FISH COMMUNITY STRUCTURE OVER AN INSHORE ARTIFICIAL OYSTER REEF IN BARATARIA BAY, LOUISIANA

INTRODUCTION

The loss of coastal marine habitats has been described as one of the greatest threats to the viability of commercial and recreational fisheries (Caddy, 2007). For this reason, the Magnuson Steven Fishery Conservation and Management Act, and its 1996 reauthorization as the Sustainable Fisheries Act (SFA), called for the identification and protection of those habitats deemed “essential” to the spawning, breeding, feeding or growth to maturity of marine fish species (NMFS, 1997). The concept of essential fish habitat (EFH) has therefore governed a great deal of the focus of fisheries research and management over the past decade.

Louisiana’s oligohaline estuaries are dominated by three types of habitat including marshes, shallow non-vegetated or soft bottom habitats, and oyster reefs. A majority of the past work to identify EFH along the Gulf of Mexico (Gulf) coast documented the role of salt marsh edge as nursery habitat for juveniles of ecologically and economically important fish species (Rakocinski et al., 1992; Baltz et al., 1993; Minello, 1999; Jones et al., 2002). Numerous larval and juvenile fishes aggregate along the marsh edge to take advantage of available prey items, as well as utilizing flooded marsh surfaces at high tide to avoid predation (Kneib, 1987; Rakocinski et al., 1992; Baltz et al., 1993). The role of oyster reefs in the life history of estuarine fishes is not as well-defined.

Oyster reefs, composed primarily of the eastern oyster (*Crassostrea virginica*), have always been considered important to estuarine health, primarily in the context of maintaining water quality. In the Chesapeake Bay, the decline of the oyster population is directly correlated with decreasing water quality (Rothschild et al., 1994). Rothschild et al. (1994) estimated that the oyster population in Chesapeake Bay was less than 50% of its historic area as of the early

1990s, and today it may be as low as two percent of historic levels (CBF, 2007). In addition to being less extensive, existing oyster reefs in the Chesapeake Bay, as well as those along the Gulf coast, are also lower in relief due to consistent mechanical harvest of oysters using dredges (Lenihan et al., 2001). Oyster reefs have always been considered “essential” to oysters themselves by providing critical habitat and increasing the recruitment of oyster spat (Coen et al., 1999; Plunket, 2003). More recently, we have begun to realize the importance of oyster reefs as critical habitat for fish species as well (Coen and Grizzle, 2007).

Coen et al. (1999) hypothesized that three different groups of fishes use oyster reefs, including resident species, facultative residents, and transient species. Resident species are typically small benthic fishes that spend most of their lives utilizing reef habitat for foraging opportunities, protection from predators, and substrate for attachment of benthic eggs (Breitburg, 1999; Coen et al., 1999). Facultative residents are attracted to the structure of reefs, but may also opportunistically use other structured habitats such as submerged aquatic vegetation (SAV). The majority of estuarine fishes are transient species. These include schooling planktivores such as bay anchovy (*Anchoa mitchilli*) and gulf menhaden (*Brevoortia patronus*). Transient species also include top predators such as striped bass (*Morone saxatilis*) on the Atlantic coast and spotted seatrout (*Cynoscion nebulosus*) on the Gulf coast, a highly prized recreational species in Louisiana. Many transient species opportunistically use different types of habitats based upon availability and their needs for prey, predator avoidance, or spawning. For these species, the most important function of oyster reefs may be to aggregate prey species. Breitburg et al. (1995) showed that the vertical structure of reefs in Chesapeake Bay has the ability to decrease the velocity of water flow, making it easier for small, larval fishes to maintain position in space. Several studies have illustrated that habitat selection may be linked to prey availability and that

habitat complexity may increase the amount of available prey (Connell and Jones, 1991; Burke, 1995; Eklov, 1997; Wells, 2007).

The perceived value of oyster reefs as fish habitat has led to an increase in the number of habitat restoration projects in areas of historically high oyster populations, including the U.S. southeast Atlantic and Gulf coasts (Coen and Grizzle, 2007). However, with a decrease in the amount of oyster shell available for habitat enhancement, alternative materials have been utilized to provide substrate for larval oysters and other benthic invertebrates normally associated with oysters. One such material that has been found to be cost-efficient and effective as a reef material is limestone cobble (Haywood et al., 1999). The purpose of this project was to monitor an artificial high-relief oyster-like reef constructed of limestone cobble in Barataria Bay, Louisiana and evaluate its effects on the estuarine fish community, particularly those species of commercial or recreational importance. The focus of this chapter is to examine overall community structure and fish abundance at the artificial reef site, as compared to an unaltered mud-bottom reference site. Special focus is given to species of particular economical or ecological importance, such as spotted seatrout, Atlantic croaker (*Micropogonias undulatus*), and bay anchovy.

METHODS AND MATERIALS

Study Site

The artificial reef site (reef) is located in Bay Ronquille, Plaquemines Parish, Louisiana. Bay Ronquille is located in southeastern Barataria Bay, east of Grande Isle, and to the north of Quatre Bayou Pass leading to the Gulf of Mexico (Figure 1.1).

The reference site is located approximately 1km to the northwest of the artificial reef site (Figure 1.1). The reference site, characterized by a mud-bottom, with no hard substrate, was

chosen due to its location with respect to the reef. The proximity of the reference site to the reef allows for water conditions, including temperature, salinity, tidal movement and depth to be consistent between sites. The sites were therefore hypothesized to have a similar fish species composition before the addition of reef material. However, the reference site is far enough away from the reef that it is not likely to be included in the feeding halo around the reef.

Reef Construction

The artificial reef was constructed on 18 June, 2004 by the Recreational Fisheries Research Institute, Inc. (RFRI) in association with the Louisiana Department of Wildlife and Fisheries. Construction was supported through a National Fish and Wildlife Foundation Habitat Restoration Grant and public fund-raising events. The artificial reef site encompasses approximately 4050m² of estuary bottom that was previously an oyster lease, but now contains only relic oyster shell and no living oysters. Breitburg et al. (2000) commented on the necessity to determine an appropriate site for reef construction. Characteristics such as availability of nutrient rich water, high phytoplankton biomass, and proximity to other favorable habitat structures (natural oyster reefs, salt marsh edge, etc.) can help ensure the survival of oyster reef communities (Breitburg et al., 2000). Appropriate substrate must also be considered when constructing oyster reefs, as soft sediments can lead to the rapid burial of reef material. Therefore, historic oyster reefs make suitable sites for restored reefs. The site in Bay Ronquille satisfies all the criteria established by Breitburg et al. (2000) as necessary for a successful restoration project. Reef material used here consists of limestone cobble number 57 averaging 3.8cm in diameter. Limestone cobble acts as an effective cultch material by providing a suitable substrate for oyster larvae to settle and is considered to be an effective alternative to oyster shell in creating artificial oyster reefs (Haywood, 1992; Coen and Luckenbach, 2000). Additionally,

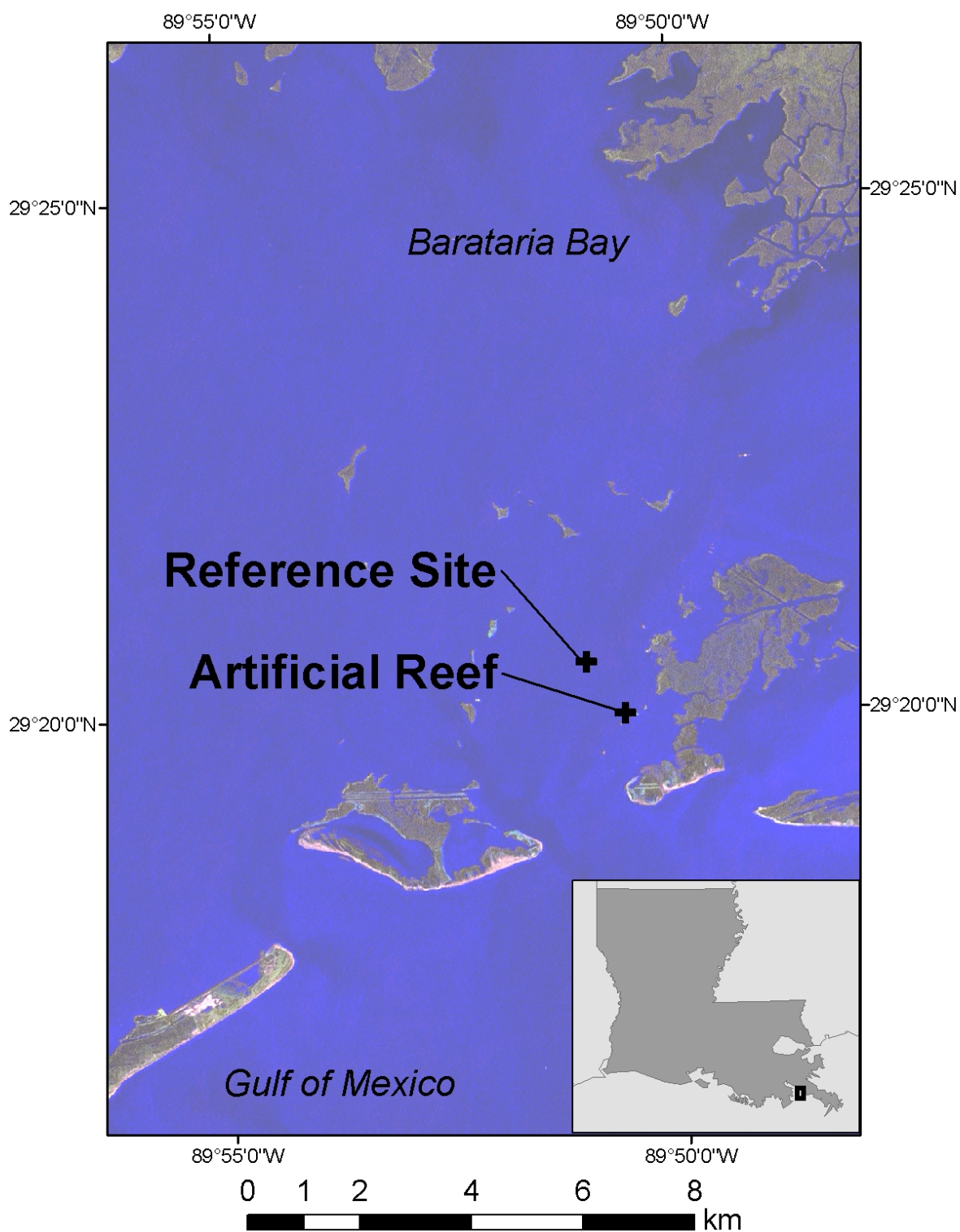


Figure 1.1: Location of Barataria Bay sampling sites.

limestone cobble is presumed to maintain the interstitial space that is necessary for the survival of larval oysters and benthic macroinvertebrates (Coen and Luckenbach, 2000).

Water Quality and Meteorological Data

Water quality was measured at each site at the start of each sampling trip. Temperature, salinity, and dissolved oxygen (DO) were measured and recorded using an YSI model 85. Turbidity was also measured using a Secchi disk. Finally tidal stage, defined as incoming, outgoing, slack high or slack low, and bay conditions, defined as calm, light chop, moderate chop or rough were recorded. Meteorological data including air temperature, wind speed and wind direction were also recorded using an anemometer. To determine if water quality, including temperature, salinity and dissolved oxygen, was consistent between sites a two-way analysis of variance (ANOVA) was run to analyze differences between sites and seasons (SAS Institute, 2002). A Tukey HSD post-ANOVA test was used applied for all results significant at the $\alpha = 0.05$ level.

Sampling Methods

Fish collection occurred from March 2005 – February 2007, with samples collected twice per quarter, or season. Seasons were defined as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August) and fall (September, October, and November). Two types of gear were used to collect finfish over the two sites, including gillnets and a purse seine. Due to the inherent selectivity of all gear types, I chose to utilize gear that would effectively sample the larger adult estuarine species (gillnets), as well as smaller prey species and post-larval and juvenile fishes higher in the water column (purse seine). The gillnets are 45.7m long and 1.8m deep, consisting of five 9.1m panels. Panels are randomly arranged with mesh sizes of 1.27, 1.91, 2.54, 3.18, and 3.81cm square. The purse seine measures 20m in

length by 2m deep, with a mesh size of 2 x 2mm square. Gillnets were set for one hour at each site. After one hour, the gillnets were pulled, cleaned and reset in the same location to obtain replicate samples in time. The purse seine was set twice as well, to obtain replicate samples. The first purse seine was set before the first gillnet set, and the second after the final gillnet set. Fish were bagged by gear type, net panel (for the gillnets), location (reef or reference) and set (first or second), and placed on ice. All fishes remained on ice until return to the laboratory for analysis. Those fish that were not analyzed immediately were frozen and stored at -80°C to ensure no degradation of muscle tissue. All fish collected were identified to species, and measured for total length (TL) and standard length (SL) to 1.0mm, and wet weight to 0.1g.

Supplementary sampling was conducted in June and July of 2007 in an attempt to collect benthic organisms from the artificial reef surface for analysis. Several different techniques were tested to collect benthos, including ponar grabs, habitat trays, SCUBA and snorkeling sampling, suction pump and trawling, all of which met with relatively little success. Finally, a 45.72 cm wide oyster dredge equipped with 1.27cm mesh was used to collect samples of small organisms associated with the cobble. The dredge was heavy enough to sink into the reef and collect cryptic animals living in interstitial spaces. Three dredge tows were made at each of the two sites. Dredge tows on the reference site were five minutes long, while dredge tows over the reef were five, four and three minutes in tow length. Tows over the reef were decreased in time due to the large amount of reef material collected in the dredge. After a few minutes of towing the dredge became saturated with cobble, decreasing catch efficiency. Due to the short tow lengths, disturbance to the reef was minimal, and all reef material was returned after collection to maintain reef size and structure. Samples collected were kept on ice until returned to the laboratory, where they were frozen at -80°C to prevent degradation of tissue material. All mud

crabs collected were identified to genus, and later grouped together as xanthid crabs for analyses. Mud crabs were weighed to the nearest 0.1g wet weight, and measured for carapace width to the nearest 1.0mm. All other invertebrates were identified to species and measured for wet weight to 0.1g, carapace length for hermit crabs to 1.0mm, and shell length for gastropods to 1.0mm.

Data Analysis

Overall community composition was assessed using PRIMER (Plymouth Routine in Multivariate Ecological Research; Warwick, 1990), using each one hour gillnet sample set and each purse seine set as a replicate. Every species collected was considered a variable, and data were entered as a percentage of the total catch for each sample replicate. Data were $\log(x+1)$ transformed to normalize the data and reduce the importance of the most abundant species. A Bray-Curtis similarity index was constructed from the transformed data, and an analysis of similarity (ANOSIM) was run using this matrix to compare each sample to every other sample. A two-way ANOSIM was used to compare community structure between site and season, and their interaction. Following ANOSIM, the original $\log(x+1)$ transformed data were analyzed using the similarity percentages (SIMPER) option, which examines the within group (site or season) similarity as well as the between group (site and season) dissimilarity. This method allows identification of fish species that contribute to differences in community structure between sites or season. Separate analyses were run for each gear type because I believe that the catches from these gears represent independent samples. Levels of significance are set to $p = 0.10$ for all PRIMER analyses.

Species richness for each site was calculated as the total number of species collected over each site during the study period. Mean species richness was calculated as the mean number of species present at each site during each season, and was the sum of all species collected in both

gear types. Therefore, mean species richness was only determined for sampling months in which both gear types were utilized. A two-way ANOVA was used to determine if there was a difference in mean species richness between sites and seasons. Due to small samples sizes, level of significance were set as $p = 0.10$ for this analysis. All results significant at the $p = 0.10$ level were further tested using a Tukey HSD post-ANOVA exam to determine which variables contributed to the differences.

The average raw (nominal) catch-per-unit-effort (CPUE) for all species was compared between sites and seasons using a two-way ANOVA. Effort was defined as a 1-hour soak for gillnets and as one net set for the purse seine. A separate analysis was conducted for CPUE for all species excluding gulf menhaden, which dominated all catch totals. Each gear type (gillnet and purse seine) was analyzed independently as described above. Catch totals for ecologically and economically important species were assessed separately to determine their distribution over space and time. These included CPUEs for spotted seatrout, Atlantic croaker, and bay anchovy. Catch per unit effort was also assessed separately for the most abundant species, including gulf menhaden, rough silversides (*Membras martinica*), penaeid shrimp (white shrimp, *Litopenaeus setiferus* and brown shrimp, *Farfantepenaeus aztecus*), hardhead catfish (*Ariopsis felis*), southern kingfish (*Menticirrhus americanus*), sand seatrout (*Cynoscion arenarius*), spot (*Leiostomus xanthurus*), and silver perch (*Bairdiella chrysoura*). Data for the total number of fishes collected were analyzed without transformation. However due to the high number of zeros for individual species, these data were $\log(x+1)$ transformed to reduce heteroscedasticity. All results significant at the $p = 0.10$ level were further tested using Tukey HSD post-ANOVA tests to determine which variables contributed to the difference. The level of significance was set as $p = 0.10$ for all analysis due to small sample sizes.

Abundances of economically and ecologically important species, including spotted seatrout, Atlantic croaker, and bay anchovy, were further tested using a logistic regression to determine if presence of each species over a certain habitat was influenced by environmental factors such as water temperature, salinity or dissolved oxygen (SAS Institute, 2002). The Proc Genmod procedure in SAS was used with a negative binomial link for this analysis, as this provided the best overall model fit to the data. The model was run using the variables habitat, temperature, salinity, and the interaction of habitat and temperature, but excluding dissolved oxygen, as this provided the best overall model fit. A comparison of the size of spotted seatrout, Atlantic croaker, and bay anchovy was also conducted to determine if there was a difference in the mean size of each species between sites. A one-way ANOVA was run comparing standard length and mass of these three species by site, with the level of significance set as $p = 0.05$ due to larger sample size for individuals. All analyses that produced significant results at the $p = 0.05$ level were further compared with a Tukey HSD post-hoc test.

RESULTS

A total of fourteen sampling trips were completed, including four spring, summer, and winter samples, and two fall samples. Field research was suspended in the fall of 2005 due to Hurricane Katrina, which passed near to the study site and resulted in the loss of all fishing gear. Sampling resumed with gillnets in January of 2006 and with the purse seine in March of 2006 after the gear was replaced.

Mean water temperature, salinity and dissolved oxygen did not differ between sites ($p > 0.05$, ANOVA) (Table 1.1). Temperature ranged from 11.8 to 32.1°C over the reef and from 10.8 to 32.1°C over the reference site (Figure 1.2). Salinity ranged from 8.1 to 32.7ppt over the reef and from 14.9 to 32.7ppt over the reference site (Figure 1.2). Dissolved oxygen ranged from

2.05 to 9.75mg/l over the reef and 2.12 to 10.12mg/l over the reference site (Figure 1.2). Only temperature was found to be significantly different between seasons, with higher temperatures found in summer months from June through August (Table 1.1). No seasonal differences were found for salinity and dissolved oxygen ($p > 0.05$).

A total of 4149 fishes were collected, with the eleven most commonly caught species making up 95% of the total catch (Table 1.2). The two most common species were gulf menhaden and bay anchovy, which made up 40% and 22% of the total catch, respectively. Eighty-nine spotted seatrout, 410 Atlantic croaker, and 900 bay anchovy were collected. A total of forty-six species were collected, including forty-three finfish and three shrimp species (Table 1.3). Thirty-eight species were collected over the artificial reef, and thirty-four species collected over the reference site (Table 1.3). Twelve were found exclusively over the reef, and eight were collected exclusively over the reference site. These twenty species were all collected infrequently and made up only 1.1% of the total catch combined. No difference was found in mean species richness between sites ($p > 0.1$, ANOVA) (Table 1.4). Species richness was generally higher in the summer ($p = 0.079$), but Tukey post-ANOVA testing revealed no significant differences in species richness were observed between seasons (Table 1.4). The mean number of species collected per sample ranged from 1 to 18 over the reef and from 3 to 14 over the reference site (Figure 1.3).

The PRIMER analysis showed no significant differences between sites in community structure. Average dissimilarity between sites was 79%, with gulf menhaden, bay anchovy, Atlantic croaker and hardhead catfish contributing most to the dissimilarity between sites (over 50% cumulative dissimilarity).

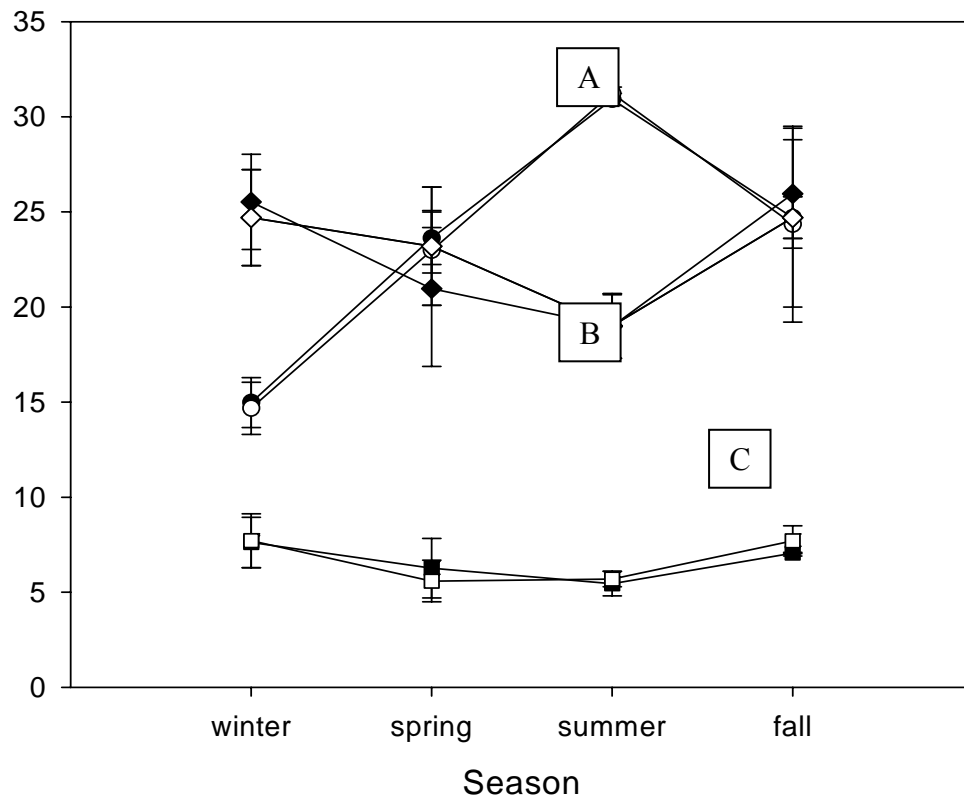


Figure 1.2: Mean values of A. water temperature, B. salinity and C. dissolved oxygen over seasons. Dark symbols represent artificial reef samples and light symbols represent reference site samples. Circles represent water temperature, diamonds represent salinity, and squares represent dissolved oxygen. Bars represent standard error.

Table 1.1: Results of the analysis of variance comparing the environmental variables temperature, salinity and dissolved oxygen between sites and seasons. Asterisk indicates significance at the $p = 0.10$ level.

		df	F	MS	p-value
Temperature	Site	1	0.41	4.08	0.52
	Season	3	39.78	391.52	< 0.0001 *
	Site x season	3	0.18	1.79	0.91
Salinity	Site	1	0.06	2.47	0.82
	Season	3	1.04	46.46	0.39
	Site x season	3	0.48	21.66	0.69
Dissolved oxygen	Site	1	0.01	0.037	0.93
	Season	3	1.26	7.59	0.31
	Site x season	3	0.10	0.63	0.95

Table 1.2: Total numbers and percentage of total catch for the eleven most commonly collected species. Total number collected over each site is also shown. Two species of shrimp, white shrimp, *Litopenaeus setiferus* and brown shrimp, *Farfantepenaeus aztecus*, were grouped as Penaeid shrimp for all analyses.

Species	Total Number Caught	Percentage of Catch	Total number over artificial reef	Total number over reference site
<i>Brevoortia patronus</i>	1657	39.9	1060	597
<i>Anchoa mitchilli</i>	900	21.7	431	469
<i>Micropogonias undulatus</i>	410	9.9	135	275
<i>Membras martinica</i>	236	5.7	145	91
<i>Ariopsis felis</i>	227	5.5	73	153
Penaeid shrimp	162	5.0	66	96
<i>Menticirrhus americanus</i>	91	2.2	37	54
<i>Cynoscion nebulosus</i>	89	2.1	57	32
<i>Leiostomus xanthurus</i>	82	2.0	37	45
<i>Cynoscion arenarius</i>	52	1.3	27	25
<i>Bairdiella chrysoura</i>	51	1.2	43	8
TOTAL	3957	94.5	2111	1845

Table 1.3: Total number of species and total number of individuals collected at each site during study period.

Species Collected	Common Name	Artificial Reef	Reference Site	Total
		Total Number of Species		
		38	34	46
		Total Number of Individuals		
<i>B. patronus</i>	Gulf menhaden	1060	597	1657
<i>A. mitchilli</i>	Bay anchovy	431	469	900
<i>M. undulatus</i>	Atlantic croaker	135	275	410
<i>M. martinica</i>	Rough silverside	145	91	236
<i>A. felis</i>	Hardhead catfish	73	153	226
<i>Litopenaeus setiferus</i>	White shrimp	36	88	124
<i>M. americanus</i>	Southern kingfish	37	54	91
<i>C. nebulosus</i>	Spotted seatrout	57	32	89
<i>L. xanthurus</i>	Spot	37	45	82
<i>C. arenarius</i>	Sand seatrout	27	25	52
<i>B. chrysoura</i>	White perch	43	8	51
<i>Farfantepenaeus aztecus</i>	Brown shrimp	30	8	38
<i>A. hepsetus</i>	Striped anchovy	14	19	33
<i>Scomberomorus maculatus</i>	Spanish mackerel	12	21	33
<i>Harengula jaguana</i>	Scaled sardine	14	2	16
<i>Dorosoma petenense</i>	Threadfin shad	10	4	14
<i>Opisthonema oglinum</i>	Atlantic thread herring	0	11	11
<i>Bagre marinus</i>	Gafftopsail catfish	7	3	10
<i>Elops saurus</i>	Ladyfish	5	4	9
<i>Chloroscombrus chrysurus</i>	Atlantic bumper	2	4	6

Table 1.3: Continued

<i>Gobionellus oceanicus</i>	Highfin goby	5	0	5
<i>Pogonias chromis</i>	Black drum	3	2	5
<i>Sphoeroides parvus</i>	Least puffer	2	3	5
<i>Symphurus plagiusa</i>	Blackcheek tonguefish	1	4	5
<i>Gobiesox strumosus</i>	Skilletfish	0	5	5
<i>Citharichthys spilopterus</i>	Bay whiff	4	0	4
<i>Loligo</i> sp.	Squid	3	1	4
<i>Peprilus burti</i>	Gulf butterfish	1	2	3
<i>Caranx hippos</i>	Crevale jack	2	0	2
<i>Lagodon rhomboides</i>	Pinfish	2	0	2
<i>Etropus crossotus</i>	Fringed flounder	2	0	2
<i>Menidia beryllina</i>	Inland silverside	2	0	2
<i>Alosa chrysochloris</i>	Skipjack herring	1	1	2
<i>Oligoplites saurus</i>	Leatherjack	1	1	2
<i>Trichiurus lepturus</i>	Cutlassfish	0	2	2
<i>Chaetodipterus faber</i>	Atlantic spadefish	1	0	1
<i>Lutjanus griseus</i>	Gray snapper	1	0	1
<i>E. argenteus</i>	Spotfin mojarra	1	0	1
<i>Gobionellus boleosoma</i>	Darter goby	1	0	1
<i>Rachycentron canadum</i>	Cobia	1	0	1
<i>Strongylura marina</i>	Atlantic needlefish	1	0	1
<i>Mugil cephalus</i>	Striped mullet	0	1	1
<i>Squilla</i> sp.	Mantis Shrimp	0	1	1
<i>Trachinotus carolinus</i>	Florida pompano	0	1	1
<i>Peprilus alepidotus</i>	Harvestfish	0	1	1
<i>Prionotus</i> sp.	Searobin	0	1	1

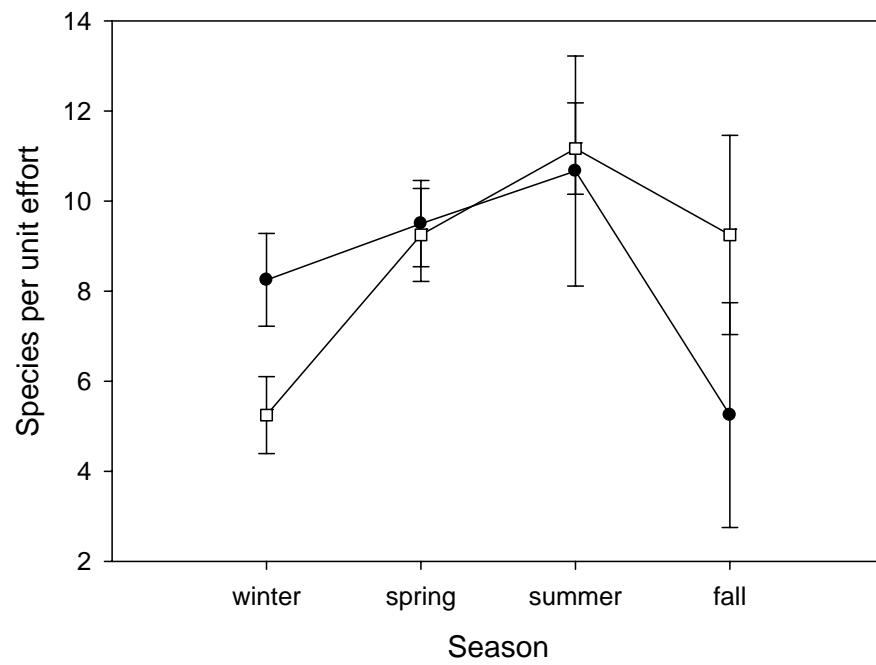


Figure 1.3: Mean species richness by season. Black circles represent artificial reef samples. White squares represent reference site samples. Standard error bars are shown.

There was a significant seasonal difference in community structure ($p < 0.1$) based on ANOSIM results. All seasonal comparisons resulted in greater than 80% dissimilarity between groups. Gulf menhaden was the most abundant species during sampling pooled over all seasons and months, and were therefore present in high abundances all year. Spring samples were characterized by high abundances of gulf menhaden, bay anchovy, and Atlantic croaker. Summer samples resulted in high abundances of rough silversides and hardhead catfish, as well as gulf menhaden. Fall and winter samples both showed high abundances of gulf menhaden, rough silversides, and bay anchovy, as well as hardhead catfish. Abundances of spotted seatrout were similar in the spring and summer and low in the fall and winter, while Atlantic croaker had highest abundances in spring.

There were no statistical differences between sites for the mean overall CPUE, mean CPUE excluding menhaden, or the mean CPUE for the purse seine ($p > 0.10$, ANOVA) (Table 1.4). However, there were significant seasonal differences for comparisons ($p < 0.10$, ANOVA) (Table 1.4). Mean CPUE for fall samples was significantly higher than winter (Tukey test; Figure 1.4). Tukey HSD post-ANOVA testing for the CPUE excluding menhaden revealed that summer samples were significantly higher than winter samples (Figure 1.4). Post-hoc tests for the purse seine CPUE revealed that winter samples were significantly higher than all other seasons (Figure 1.4). The interaction between site and season was not significant for CPUE of all species combine, but was significant for CPUE excluding menhaden and CPUE for the purse seine (Table 1.4).

Overall abundance of spotted seatrout was 1.8 times higher over the artificial reef (Table 1.2), though this difference was not significant ($p = 0.11$, ANOVA) (Table 1.5). There were seasonal differences in abundance of spotted seatrout ($p < 0.1$) with Tukey HSD post-ANOVA

tests revealing that summer catches were significantly higher than winter and fall totals (Figure 1.5). The interaction between site and season was not significant ($p > 0.1$, ANOVA) (Table 1.5). Results of the logistic regression revealed no effect of site on the presence of spotted seatrout ($p = 0.14$), but that there was a significant effect of water temperature ($p < 0.01$) and salinity ($p < 0.05$) (Table 1.6).

Overall abundance of Atlantic croaker was 2.0 times higher over the reference site (Table 1.2), though this difference was not significant ($p > 0.1$, ANOVA) (Table 1.5). There were seasonal differences in the abundance of Atlantic croaker ($p = 0.027$) with Tukey HSD post-ANOVA tests revealing that spring and summer catch totals were significantly higher than winter catch totals (Figure 1.6). The interaction between site and season was not significant for Atlantic croaker (Table 1.5). Results of the logistic regression showed no significant effect for habitat, water temperature or salinity ($p > 0.05$) (Table 1.7).

Abundance of bay anchovy was similar between sites (Table 1.2), both literally and statistically ($p > 0.1$, ANOVA) (Table 1.5). There was a significant seasonal difference in bay anchovy abundance ($p < 0.01$), with Tukey HSD post-ANOVA testing revealing that winter catch totals were significantly higher than all other seasons (Figure 1.7).

There was a significant interaction between site and season for bay anchovy ($p = 0.07$). Results of the logistic regression showed no significant effect for habitat, water temperature or salinity ($p > 0.05$) (Table 1.8).

Gulf menhaden, rough silversides and silver perch all were found in higher abundance over the artificial reef, though of these, only silver perch were found in significantly higher abundance ($p = 0.013$, ANOVA). Penaeid shrimp, southern kingfish, and hardhead catfish all were found in higher abundance over the reference site, though only hardhead catfish were found

Table 1.4: Results of the analysis of variance comparing species richness and CPUE between sites and seasons. Asterisk indicates significance at the $p = 0.10$ level.

		df	F	MS	p-value
Species Richness	Site	1	0.07	1.0	0.79
	Season	3	2.52	36.40	0.079 *
	Site x Season	3	1.15	16.63	0.35
CPUE	Site	1	0.51	3749.14	0.48
	Season	3	3.53	25741.70	0.041 *
	Site x season	3	3.07	322403.24	0.060 *
CPUE – non-menhaden	Site	1	0.84	690.04	0.37
	Season	3	2.93	2339.49	0.068 *
	Site x season	3	0.13	105.49	0.94
CPUE – Purse Seine	Site	1	0.19	1.56	0.68
	Season	3	22.91	18946.84	0.0011 *
	Site x season	3	3.67	3032.73	0.082 *

Table 1.5: Results of the analysis of variance comparing abundance of key species between sites and seasons. Asterisk indicates significance at the $p = 0.10$ level.

		df	F	MS	p-value
Spotted seatrout	Site	1	2.94	2.38	0.11
	Season	3	3.04	2.46	0.062 *
	Site x season	3	0.55	0.44	0.66
Atlantic croaker	Site	1	0.04	0.048	0.84
	Season	3	4.04	4.73	0.027 *
	Site x season	3	0.65	0.77	0.59
Bay anchovy	Site	1	0.08	80.22	0.79
	Season	3	14.23	14391.50	0.0039 *
	Site x season	3	3.94	3981.31	0.072 *

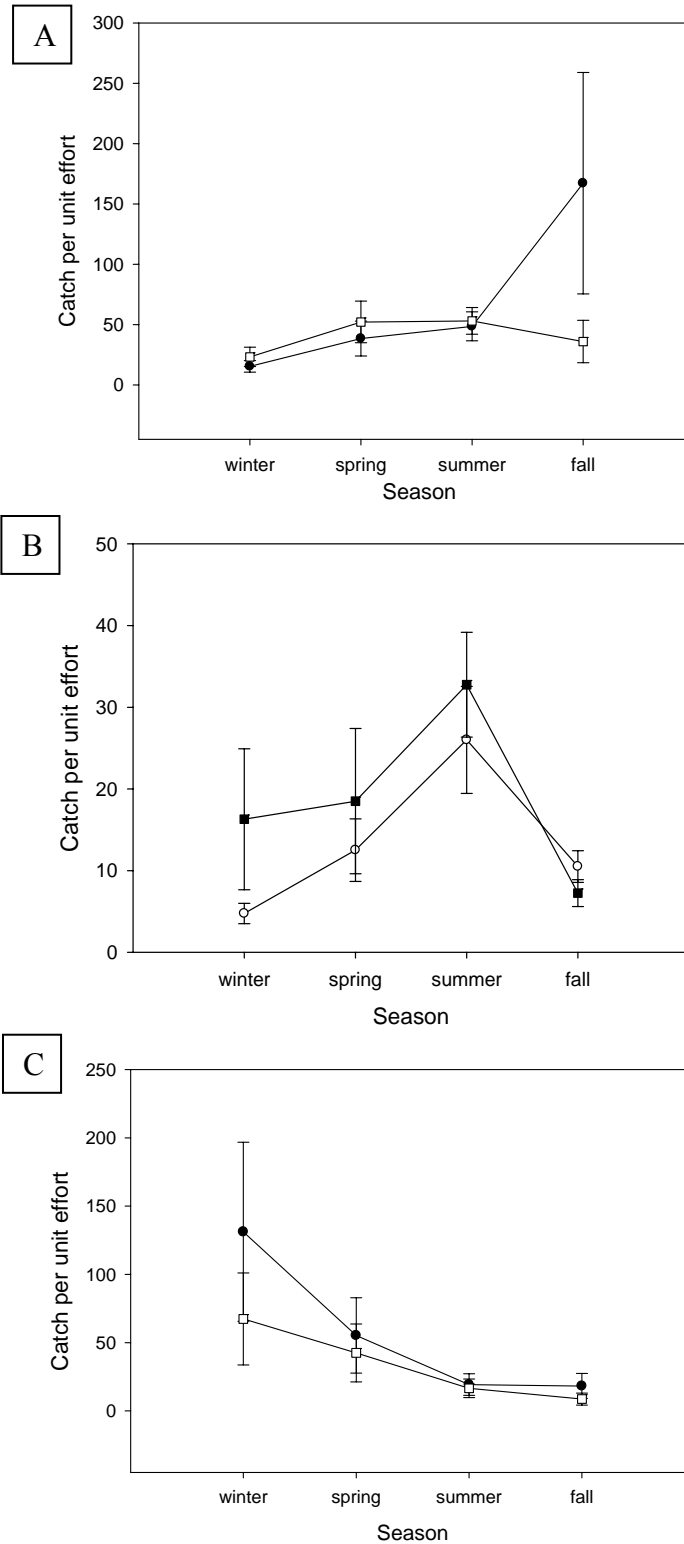


Figure 1.4: Mean CPUE of A. gillnets, B. gills nets without menhaden and C. purse seine samples over seasons. Black circles represent reef samples and white squares represent reference site samples. Bars represent standard error.

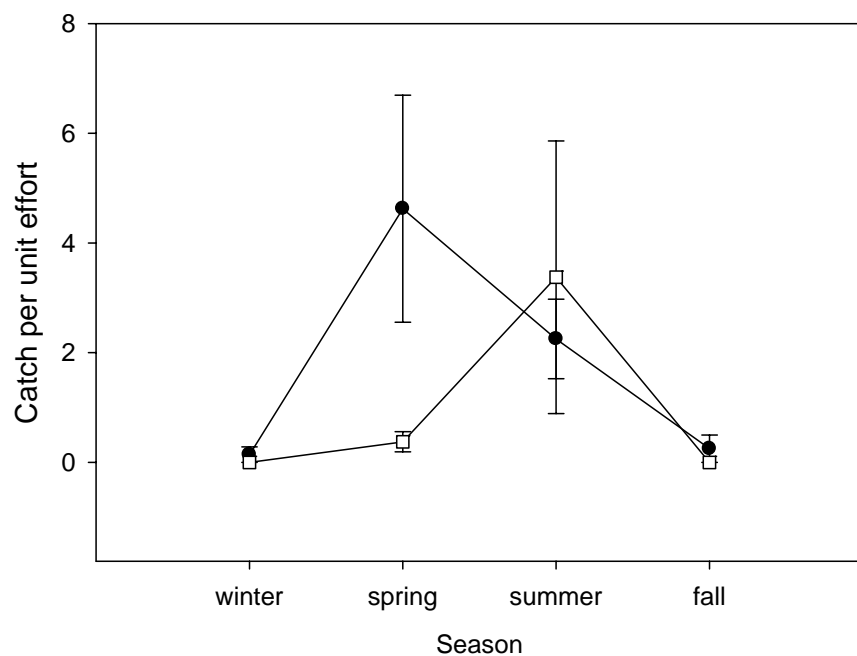


Figure 1.5: Mean CPUE of spotted seatrout over seasons. Black circles represent reef samples and white squares represent reference site samples. Bars represent standard error.

Table 1.6: Results of logistic regression for spotted seatrout for all variables analyzed. Results significant at the $p = 0.05$ level are indicated with an asterisk.

	df	value	value/df	
	23	21.57	0.94	
Deviance				
	df	Estimate	Chi Square	p-value
Habitat	1	5.64	2.18	0.14
Temperature	1	0.29	6.76	0.0093 *
Salinity	1	-0.13	3.92	0.048 *
Habitat x Temp	1	-0.19	1.90	0.17

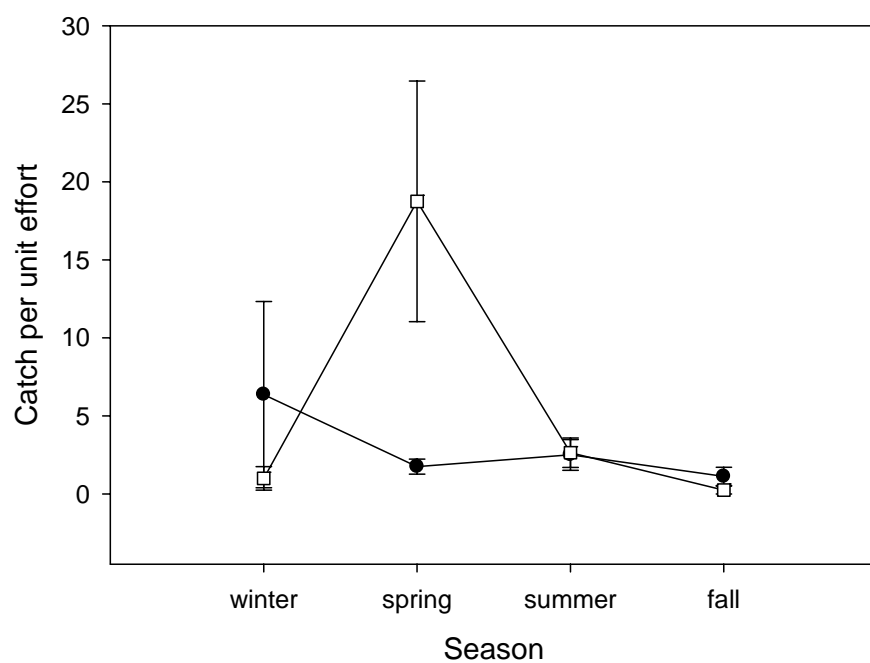


Figure 1.6: Mean CPUE of Atlantic croaker over seasons. Black circles represent reef samples and white squares represent reference site samples. Bars represent standard error.

Table 1.7: Results of logistic regression for Atlantic croaker for all variables analyzed. Results significant at the $p = 0.05$ level are indicated with an asterisk.

	df	value	value/df	
Deviance	39	43.14	1.11	
	df	Estimate	Chi Square	p-value
Habitat	1	-1.89	0.35	0.55
Temperature	1	-0.10	0.95	0.33
Salinity	1	-0.10	0.41	0.52
Habitat x Temp	1	0.043	0.12	0.73

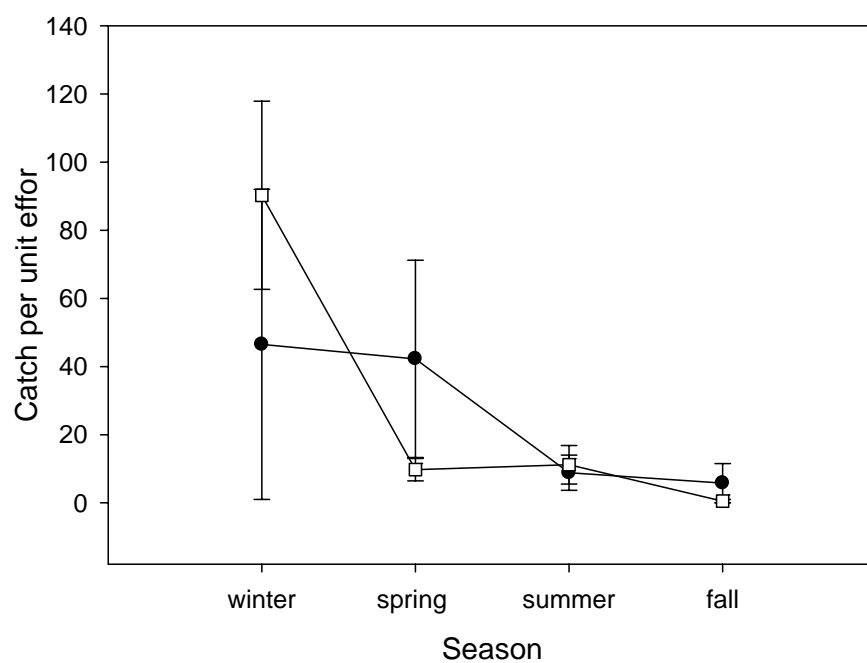


Figure 1.7: Mean CPUE of bay anchovy over seasons. Black circles represent reef samples and white squares represent reference site samples. Bars represent standard error.

Table 1.8: Results of logistic regression for bay anchovy for all variables analyzed. Results significant at the $p = 0.05$ level are indicated with an asterisk.

	df	value	value/df	
Deviance	13	20.66	1.58	
	df	Estimate	Chi Square	p-value
Habitat	1	-0.56	0.03	0.14
Temperature	1	-0.11	1.89	0.17
Salinity	1	0.069	0.44	0.51
Habitat x Temp	1	0.026	0.04	0.84

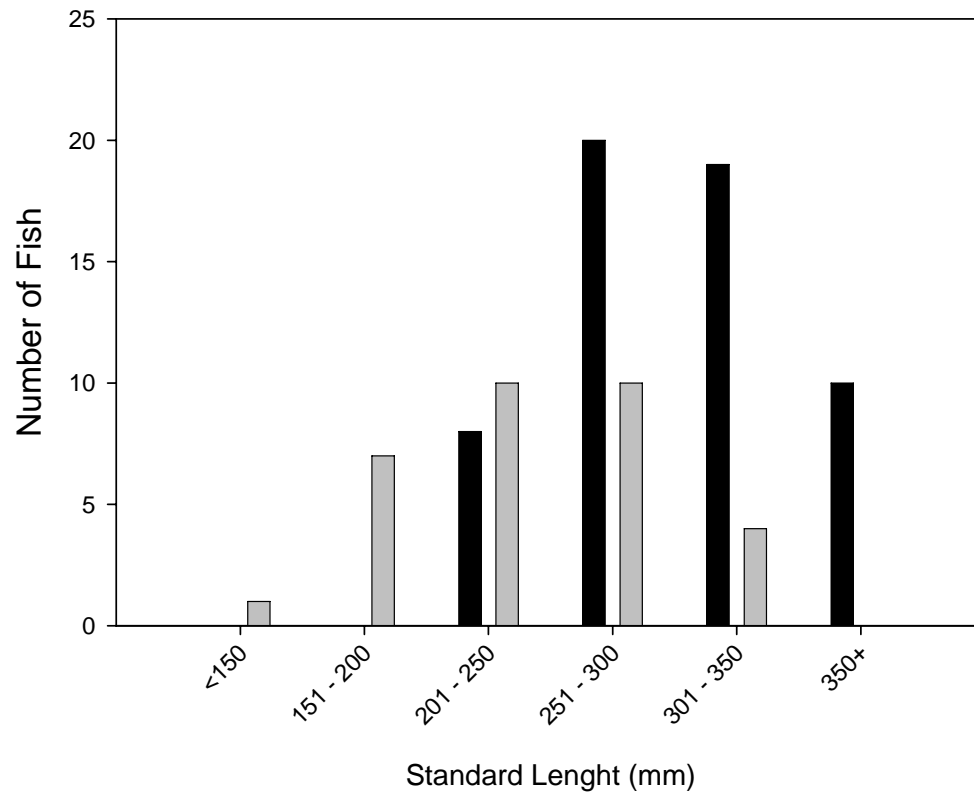


Figure 1.8: Size frequency distribution of spotted seatrout at each site. Black bars represent artificial reef samples. Grey bars represent reference site samples.

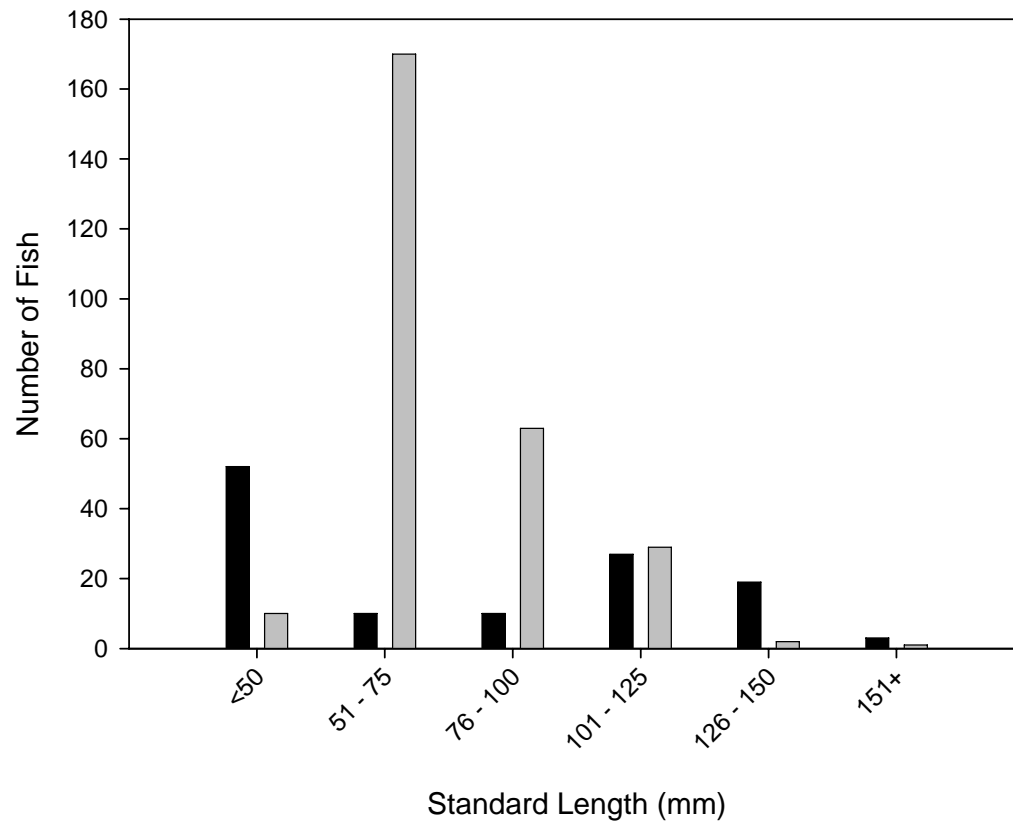


Figure 1.9: Size frequency distribution of Atlantic croaker at each site. Black bars represent artificial reef samples. Grey bars represent reference site samples.

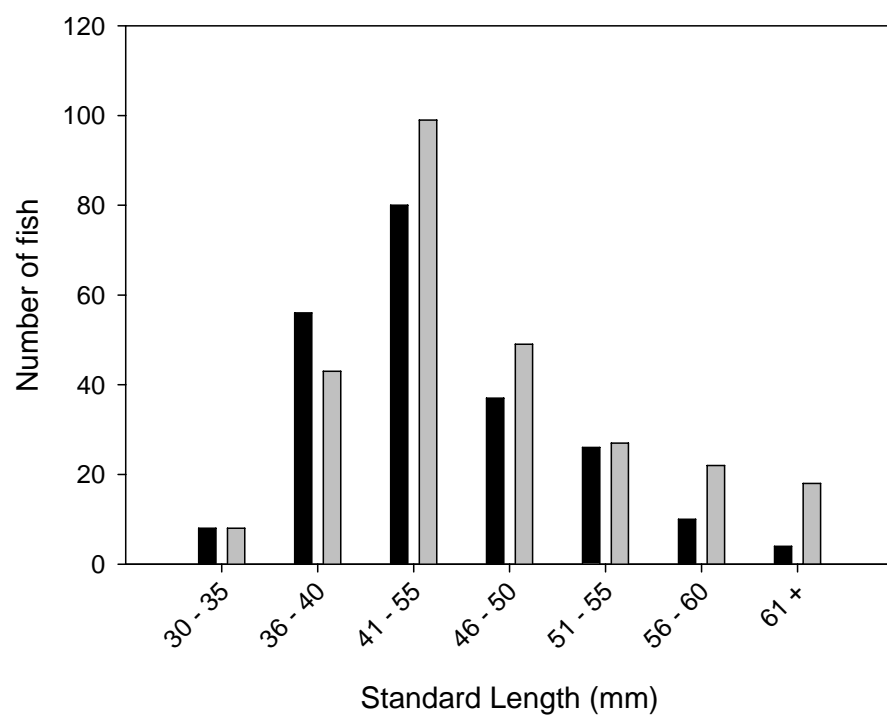


Figure 1.10: Size frequency distribution of bay anchovy at each site. Black bars represent artificial reef samples. Grey bars represent reference site samples.

in significantly higher abundances ($p = 0.051$, ANOVA). The other commonly caught species, including sand seatrout and spot, were found in similar abundance at both sites ($p > 0.1$, ANOVA).

Results of the size analysis showed significant differences in size of spotted seatrout, Atlantic croaker and bay anchovy between sites. Spotted seatrout had significantly higher standard length and weight over the reef site ($p < 0.0001$, ANOVA), with a mean standard length of 305 ± 6.7 mm over the reef, and 243 ± 10.1 mm over the reference site (Figure 1.8). The mean biomass of spotted seatrout was also significantly different, with a mean of 435.3 ± 28.5 g over the reef as compared with 233.5 ± 24.4 g over the reference site ($p < 0.0001$). Atlantic croaker also were significantly larger over the artificial reef ($p < 0.0001$, ANOVA), with a mean standard length of 83 ± 3.7 mm over the reef and 77 ± 0.9 mm over the reference site (Figure 1.9). The mean biomass of croaker was significantly different, with a mean of 19.8 ± 2.1 g over the reef as compared to 9.9 ± 0.5 g over the reference site ($p < 0.0001$). Bay anchovy were significantly larger over the reference site ($p < 0.001$, ANOVA), with a mean standard length of 45 ± 0.4 mm over the reef as compared to 47 ± 0.5 mm over the reference site (Figure 1.10). The mean mass of bay anchovy was also significantly different between sites, with a mean of 1.2 ± 0.04 g over the reef as compared to 1.4 ± 0.05 g over the reference site ($p < 0.001$, ANOVA). Tukey HSD post-ANOVA comparisons confirm all differences in size between sites for the three species examined.

DISCUSSION

While the artificial reef examined in this study shares many characteristics with natural high-relief oyster reefs, it is important to note that many ecological functions will differ from that of a natural oyster reef. Oyster growth gives natural oyster reefs a very complex structure that is

likely absent in a limestone cobble artificial reef. Natural oyster reefs also grow in size as oysters grow and as new oysters are recruited, resulting in much larger reefs than those constructed for habitat enhancement projects. As such, it is likely that community complexity over the artificial reef examined in this study is less than that of natural oyster reefs. Coen et al. (1999) found approximately 80 species of fishes associated with natural oyster reefs, while the current study identified 43 species of finfish associated with the artificial reef. The lower number of species found at the Barataria Bay reef may be due to the type of reef, the size of the reef, or the location. Sampling large natural reefs in multiple locations was beyond the scope of this project, and therefore no conclusive results can be drawn about comparisons to natural reefs in this estuary. It is possible that because of the lack of high-relief oyster reefs in Barataria Bay, this artificial reef may be acting as an ecological surrogate for oyster reefs as fish habitat. This can be determined by analyzing the number of reef-dependent residents that are associated with the oyster reef. Coen et al. (1999) described numerous species that can be considered “residents” of oyster reefs, and would therefore be found in higher abundance on reefs compared to off reef. However, these are mostly small cryptic fishes, and due to the limitations of my sampling gear, were not collected effectively in this study. While I was able to collect a large number of mud crabs (Xanthidae), which are known to be reef-dependent and found in high abundance on oyster reefs (Minello, 1999; Luckenbach et al. 2005), future sampling should include provisions for the collection of cryptic fish species. The presence of benthic, reef-associated fishes in high abundances would be a better indicator of overall reef function. However, due to the consistently high catches of finfish over the artificial reef, I believe that in the absence of natural oyster reef habitat, artificial reefs can act as an effective alternate fish habitat.

The estuarine fish community in Barataria Bay showed no distinct differences in species richness between the artificial reef site and the reference site. The dominant species collected were found in high abundances over both sites, and those species that were collected solely at one site were found too infrequently (3 times or fewer) to influence comparison of community structure using PRIMER. There was also no difference in abundance of fishes between sites, with similar CPUE observed over both sites. These results are consistent with other studies in Barataria Bay by MacRae (2006) and Plunket and LaPeyre (2005), who also found no difference in species richness or abundance between oyster reef habitat and mud-bottom habitat. A similar study by Harding and Mann (2001b) on transient fish species in Chesapeake Bay found no site-specific linkages based on habitat, and equated this to the generalist nature of many of the fish species examined in the study. Other studies have concluded that a large and diverse fish community can regularly be observed in the vicinity of oyster reefs (Coen et al., 1999). These studies demonstrate the generalist nature of most estuarine fishes, and provide evidence that many species will opportunistically use different habitat types for foraging, spawning, or predator avoidance.

Spotted seatrout were found in higher numbers over the artificial reef, though the difference was not significant. Similar studies by Harding and Mann found higher abundance of bluefish (*Pomatomus saltatrix*) (2001a) and striped bass (2003) over oyster reefs in the Chesapeake Bay. These three species occupy a similar niche in their respective environments and therefore are hypothesized to utilize habitats in a similar manner. However, the Harding and Mann (2001a, 2003) studies collected finfish samples only from the months May through September, when the species of interest are known to utilize the estuaries, and therefore did not analyze seasonal effects on distribution. Spotted seatrout are known move into deeper water in

winter months (Music, 1981; Lassuy, 1983). The results of this project indicate that this seasonal pattern of movement has a greater influence on the distribution of spotted seatrout than the presence of reef structure. In addition, spotted seatrout are known to feed opportunistically and have relatively low site fidelity, with average movements within an estuary in the range of 9 km (Music, 1981; J. Callihan, Louisiana State University, personal communication). Therefore, the most important aspect of a habitat for such a species may be the availability of prey. Harding and Mann (2001a, 2003) concluded that the increased abundance of bluefish and striped bass over oyster reefs was likely due to the increased availability of teleost prey. The authors regularly observed approximately thirty fish species in the vicinity of the reef structure, making oyster reefs an attractive foraging ground for piscivorous fishes. In this study, spotted seatrout found over the reef site were also significantly larger than those found over the mud. This is also consistent with a study of transient fish species on oyster reefs in the Chesapeake Bay (Harding and Mann 2001b), as well as previously mentioned studies of bluefish and striped bass. The authors found that as habitat complexity increased, the size of some transient species, including Atlantic menhaden (*Brevoortia tyrannus*), Atlantic croaker and striped bass, increased.

Abundance of Atlantic croaker did not differ significantly between sites, though higher numbers were collected over the reference site. Previous studies on the abundance of Atlantic croaker between different habitats have had conflicting results. Harding and Mann (2001a) collected Atlantic croaker consistently over all habitat types, but found higher overall abundances of Atlantic croaker over a restored oyster reef in the Chesapeake Bay estuary. A review by Coen and Grizzle (2007) indicated that croaker utilize oyster reef habitat frequently as a foraging ground. However, Petrik et al. (1999) found no effect of habitat on newly recruited Atlantic croaker in a Texas estuary. Atlantic croaker are known to be one of the most numerous

species found throughout the Gulf of Mexico, especially in estuaries during early life stages, and are found consistently over various habitats, though are best adapted for foraging on soft-bottom substrate (Overstreet and Heard, 1978). The results of this study are consistent with previous studies of croaker abundance and also reflect the generalist foraging characteristics of croaker. I found no difference in the abundance of Atlantic croaker between sites, but did find a difference in the size of fish between sites. Atlantic croaker were found to be larger over the reef, which is consistent with the previously mentioned study of transient fish species over an oyster reef in Chesapeake Bay (Harding and Mann 2001b). The authors hypothesized that the increased structural complexity led to enhanced productivity at restored oyster reef sites.

Previous studies indicate that bay anchovy are a transient schooling species, and therefore do not associate with any one type of habitat. Minello (1999) found high abundances of bay anchovy over shallow non-vegetated habitat and along marsh edge habitat, and relatively few individuals over oyster reefs in Texas and Louisiana. Alternately, Coen et al. (1999) found bay anchovy associated with oyster reefs in Virginia, South Carolina, and Texas, and Harding and Mann (2001a) found bay anchovy in the stomachs of bluefish collected over oyster reefs in Chesapeake Bay. Coen and Grizzle (2007) reported that bay anchovy associated with oyster reefs in Virginia, South Carolina, and Texas. Results of my study indicate there is a similar abundance of bay anchovy between the artificial reef and the reference site. Bay anchovy are one of the most abundant fish species in the northern Gulf of Mexico and are known to be distributed ubiquitously throughout Louisiana's estuaries. As such, it is likely that the presence of reef habitat did not affect the abundance of bay anchovy. However, higher numbers of bay anchovy were found in the stomachs of spotted seatrout over the reef in this study, which is consistent with the study by Harding and Mann on bluefish (2001a) (See Chapter 2). Therefore,

the artificial reef may act as a means of aggregating schools. Brietburg et al. (1995) found that the presence of high-relief reefs decreased the water velocity, which enabled larval fishes to more easily maintain their position in space. The artificial reef may perform a similar function for small schooling fishes like bay anchovy. Hydrological sampling was beyond the scope of this project and therefore it is difficult to say whether or not the reef affected water velocity over the artificial reef.

The presence of the artificial reef did not seem to increase the overall abundance of most species examined in this study. While a few species were found in higher numbers over the reef, overall community structure and species richness did not vary between sites, and observed differences may be attributable to seasonal variations in estuarine community structure. Due to limitations of the sampling gear used in this study, no reef-dependent fishes were collected, which are typically small benthic species. Thus analysis of the fish community is limited to larger species, and not small benthic species. It is also important to note that the Bay Ronquille artificial reef has only been in existence since 2004. Many of the reefs examined by Coen et al. (1999) and Harding and Mann (2001b) were constructed over four years before sampling began, as opposed to less than one year for my project. Artificial reefs follow a pattern of succession, with initial rapid colonization of transient species, followed by establishment of reef-associated species, and finally colonization of reef-dependent fish, invertebrate, and algal species (Bohnsack, 1989; Cummings, 1994). A reef is considered “established” when it reaches the equilibrium phase of a stable community structure. It is possible that the artificial reef examined here has not had enough time to become established and as such does not support a “stable” reef community. This may be the reason for the lower total number of reef-associated species found in this study as compared to the review by Coen et al. (1999). Additionally, storm events have

been shown to reset artificial reef systems by scouring the reef material and causing dispersal of reef-associated species (Cummings, 1994). Shortly after sampling began for this study, Hurricane Katrina, a category 4 storm, and Hurricane Rita, a category 3 storm passed very close to the study area in a one month period. The passage of these two storms could have easily scoured the reef surface to remove any reef-dependent fish and invertebrates. In addition to tropical storm systems, the area is regularly subjected to strong winter storms that can have similar, though less severe effects. The dynamic environment in which this artificial reef was constructed may prevent the system from ever reaching an equilibrium state. Additional, long-term sampling would be necessary to determine if the artificial reef reaches a stable equilibrium state.

LITERATURE CITED

- Baltz, D. M., C. F. Rakocinski, et al. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. *Environmental Biology of Fish* **36**: 109 - 126.
- Breitburg, D. L., M. A. Palmer, et al. 1995. Larval distributions and the spatial patterns of settlement of an oyster reef fish: response to flow and structure. *Marine Ecology Progress Series* **125**: 45-60.
- Breitburg, D. 1999. Are three dimensional structure and healthy oyster populations the keys to an ecologically interesting and important fish community. In M.W. Luckenbach, R. Mann and J.A. Wesson, editors. *Oyster reef habitat restoration. A synopsis and synthesis of approaches*. Virginia Institute of Marine Science Press, Gloucester Point, Virginia. pp 239 – 250.
- Breitburg, D. L., L. D. Coen, M.W. Luckenbach, R. Mann, M. Posey, and J. Wesson. 2000. Oyster reef restoration: convergence of harvest and conservation strategy. *Journal of Shellfish Research* **19**(1): 371 - 377.
- Burke, J. S. 1995. Role of feeding and prey distribution of summer and southern flounder in selection of estuarine nursery habitats. *Journal of Fish Biology* **47**: 355-366.
- Caddy, J.F. 2007. *Marine habitat and cover. Their importance for productive coastal fishery resources*. Paris, France: UNESCO Publishing. 253 pp.

- Chao, L.N., and J.A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York River estuary, Virginia. *Fishery Bulletin* **75**(4): 657 – 700.
- Chesapeake Bay Foundation (CBF). 2007. Oyster Restoration. www.cbf.org.
- Coen, L. D., M. W. Luckenbach, D.L. Breitburg. 1999. The role of oyster reefs as Essential Fish Habitat: a review of current knowledge and some new perspectives. *AFS Symposium* **22**: 438 - 454.
- Coen, L. D. and M. W. Luckenbach 2000. Developing success criteria and goals for evaluating oyster reef restoration: Ecological function or resource exploitation? *Ecological Engineering* **15**: 323 - 343.
- Coen, L. D. and R. E. Grizzle. 2007. The importance of habitat created by molluscan shellfish to managed species along the Atlantic coast of the United States. *ASMFC Management Series #8*. 109pp.
- Connell, S. D. and J. P. Jones. 1991. The influence of habitat complexity on postrecruitment processes in a temperate reef fish population. *Journal of Experimental Marine Biology and Ecology*. **151**: 271-294.
- Eklov, P. 1997. Effects of habitat complexity and prey abundance on the spatial and temporal distributions of perch (*Perca fluviatilis*) and pike (*Esox lucius*). *Canadian Journal of Fisheries and Aquatic Sciences* **54**: 1520-1531.
- Hartman, K.J., J. Howell, and J.A. Sweka. 2004. Diet and daily ration of bay anchovy in the Hudson River, New York. *Transactions of the American Fisheries Society* **133**: 762 – 771.
- Harding, J. M. and R. Mann. 1999. Fish species richness in relation to restored oyster reefs, Piankatank River, Virginia. *Bulletin of Marine Science* **61**: 289 – 300.
- Harding, J. M. and R. Mann 2001a. Oyster reefs as fish habitat: opportunistic use of the restored reefs by transient fishes. *Journal of Shellfish Research* **20**(3): 951 - 959.
- Harding, J. M. and R. Mann 2001b. Diet and habitat use by bluefish, *Pomatomus saltatrix*, in a Chesapeake Bay estuary. *Environmental Biology of Fish* **60**: 401 - 409.
- Harding, J. M. and R. Mann (2003). Influence of habitat on diet and distribution of striped bass (*Morone saxatilis*) in a temperate estuary. *Bulletin of Marine Science* **72**(3): 841 – 845.
- Haywood, E.L., and T.M. Soniat. 1992. The use of cement stabilized gypsum as cultch for the American oyster, *Crassostrea virginica*, and its effectiveness as compared to clamshell and limestone. *Journal of Shellfish Research*. **11**(1): 197.

- Haywood, E.L. III, T.M. Soniat, and R.C. Broadhurst, III. 1999. Alternatives to clam and oyster shell as cultch for eastern oysters. In M.W. Luckenbach, R. Mann and J.A. Wesson, editors. Oyster reef habitat restoration. A synopsis and synthesis of approaches. Virginia Institute of Marine Science Press, Gloucester Point, Virginia.
- Jones, R. F., D. M. Baltz, et al. 2002. Patterns of resource use by fishes and macroinvertebrates in Barataria Bay, Louisiana. *Marine Ecology Progress Series* **237**: 271 - 289.
- Jung, S., and E.D. Houde. 2004. Production of bay anchovy *Anchoa mitchilli* in Chesapeake Bay: application of size-based theory. *Marine Ecology Progress Series* **281**: 217 – 232.
- Kneib, R.T. 1987. Predation risk and the use of intertidal habitats by young fishes and shrimp. *Ecology* **68**: 379 – 386.
- Lassuy, D.R. 1983. Species profiles: life histories and environmental requirements (Gulf of Mexico) – spotted seatrout. U.S. Fish and Wildlife Service, Division of Biological Services. FWS/OBS-82/11.4. U.S. Army Corps of engineers, TR EL-82-4. 14 pp.
- Lenihan, H. S., C. H. Peterson, et al. (2001). Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. *Ecological Applications* **11**(3): 764 - 782.
- Luckenbach, M. W., L. D. Coen, P.G. Ross, J.A. Stephen. 2005. Oyster reef habitat restoration: Relationships between oyster abundance and community development based on two studies in Virginia and South Carolina. *Journal of Coastal Research* **SI-40**: 64 - 78.
- MacRae, P.S.D. 2006. A community approach to indentifying essential fish habitat of spotted seatrout, *Cynoscion nebulosus*, in Barataria Bay, Louisiana. Louisiana State University Dissertation, Department of Oceanography and Coastal Sciences. 161 pp.
- Minello, T. J. 1999. "Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of Essential Fish Habitat." *AFS Symposium* **22**: 43 - 75.
- Music, J.L. 1981. Seasonal movement and migration of potted seatrout (*Cynoscion nebulosus*). *Estuaries*. **4**(3): pp280.
- Overstreet, R.M., and R.W. Heard. 1978. Food of the Atlantic croaker, *Micropogonias undulatus*, from Mississippi Sound and the Gulf of Mexico. *Gulf Research Reports* **6**(2): 145 – 152.
- Plunket, J.T. 2003. A comparison of finfish assemblages on subtidal oyster shell (clutched oyster lease) and mud bottom in Barataria Bay, Louisiana. Louisiana State University Thesis, Department of Oceanography and Coastal Sciences. 84 pp.
- Plunket, J.T. and M.K. LaPeyre. 2005. Oyster beds as fish and macroinvertebrate habitat in Barataria Bay, Louisiana. *Bulletin of Marine Science*. **77**(1): 155-164.

- Rakocinski, C. F., D. M. Baltz, et al. 1992. Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. *Marine Ecology Progress Series* **80**: 135 - 148.
- Rothschild, B. J., J. S. Ault, et al. 1994. Decline of the Chesapeake Bay oyster populations: a century of habitat destruction and overfishing *Marine Ecology Progress Series* **111**: 29 - 39.
- SAS Institute Inc., 2002. Version 9.1. Cary, North Carolina, USA.
- Wells, R.J.D. 2007. The effects of trawling and habitat use on red snapper and the associated community. Louisiana State University Dissertation, Department of Oceanography and Coastal Sciences. 179 pp.

CHAPTER 2: TROPHIC DYNAMICS OF THREE SPECIES OF ESTUARINE FISHES OVER AN INSHORE ARTIFICIAL REEF IN BARATARIA BAY, LOUISIANA

INTRODUCTION

Estuaries are considered to be among the most productive of marine ecosystems. This is due in part to the large variety of habitat types that are present in estuaries, and the resources they provide. Louisiana estuaries are dominated by three distinct habitat types, including marsh edge, shallow non-vegetated or soft-bottom habitats, and oyster reefs. In coastal Louisiana, a majority of past work has examined the role that marsh-edge plays in the life history of commercially, recreationally and ecologically important finfish species. It has been well documented that marsh-edge habitats are important as nursery grounds for some species (Kneib, 1987; Rakocinski et al., 1992; Baltz et al., 1993; Minello, 1999; Jones et al., 2002). Tidal movements over marsh surfaces flush nutrients back into the water column to be utilized for primary production (Minello, 1999). Larval and juvenile fishes aggregate along the marsh edge to take advantage of available prey items and escape into flooded marsh surfaces at high tide to avoid predation (Kneib, 1987; Rakocinski et al., 1992; Baltz et al., 1993; Minello, 1999; Jones et al., 2002). The role of oyster reefs in the life history of estuarine fishes is not as well-defined.

Coen et al (1999) reported that approximately 80 species associate with oyster reefs in the Chesapeake Bay, North and South Carolina, and Texas. They divided these species into three groups based upon their level of association with reefs, including resident species, facultative resident species and transient species. Resident species are typically cryptic small benthic fish species, including skillettfish (*Gobiesox strumosus*), naked gobies (*Gobiosoma bosc*), and several members of the blenny family (Blenniidae). These species spend most of their lives on reefs, utilizing the habitat for foraging opportunities, protection from predators, and substrate for

attachment of benthic eggs (Breitburg, 1999; Coen et al 1999). Facultative residents are attracted to the structure of reefs, but may also opportunistically use other structured habitats, such as submerged aquatic vegetation (SAV). Some facultative residents are thought to spend several months each year around oyster reefs (Coen et al 1999). The majority of estuarine fishes using oyster reefs are considered to be transients. These include top predators such as spotted seatrout (*Cynoscion nebulosus*) and striped bass (*Morone saxatilis*), and schooling planktivores such as bay anchovy (*Anchoa mitchilli*) and gulf menhaden (*Brevoortia patronus*), as well as numerous other species.

In the context of identifying essential fish habitat (EFH) as mandated in the Sustainable Fisheries Act of 1996 (and subsequent reauthorizations), it is important to determine species-specific patterns of habitat utilization, including oyster reef habitat. The SFA describes four habitat-specific levels of data required to identify EFH, including 1) presence/absence, 2) density or relative abundance, 3) feeding, growth and survival, and 4) differential production of new biomass. The extent to which commercially and recreationally important species utilize oyster reefs can have significant management implications.

For transient species that do not necessarily associate with one particular habitat type, the most important function of oyster reefs may be aggregation of prey species. Several studies have illustrated that habitat selection may be linked to prey availability, and habitat complexity may increase the amount of available prey (Connell and Jones, 1991, Burke, 1995; Eklov, 1997; Wells 2007). A study conducted in the Chesapeake Bay showed that the vertical structure of reefs has the ability to decrease water velocity, making it easier for small and larval fishes to maintain their positions in space (Breitburg et al 1995). Predators, in turn, associate with the reefs to take advantage of feeding opportunities presented by aggregation of prey. Harding and

Mann (2001b) described diets of bluefish (*Pomatomus saltatrix*) associated with oyster reefs and noted that bluefish stomachs contained a higher percentage of teleost prey by number over reefs than over adjacent soft-bottom habitats. They speculated that presence of nearly twenty-five different fish species at one oyster reef provided an attractive foraging ground for piscivores. Striped bass also were found to have higher percentages of teleost prey by number in their diets over oyster reefs than over soft-bottom sites (Harding and Mann 2003). Additionally, 100% of striped bass stomachs collected over the oyster reef contained prey items, compared to 87% and 90% at a shell bar and soft-bottom site, respectively (Harding and Mann 2003).

A reduction in the number of large, natural oyster reefs has resulted in a shift in the oyster industry to a “put-and-take” fishery (Coen and Luckenbach, 2000). This has led to a continually high harvest of oyster meat, while the amount of oyster reef habitat available to estuarine fishes has continued to decrease substantially. As a result, numerous restoration projects along the southeast and Gulf coasts of the U.S. are designed to increase the amount of available oyster reef and artificial oyster reef habitat (Coen and Grizzle, 2007). This begs the question of whether restored and artificial reefs are producing new fish biomass, or merely attracting and concentrating fishes from other parts of the estuary (Polovina, 1989; Bohnsack et al., 1997). The answer can have profound management implications. Peterson et al. (2003) developed a method to assess fish production over restored oyster reefs by developing an index of reef exclusivity (IRE) based on feeding habits of estuarine fishes. Versar (2008) expanded this index to include dietary information for each species to calculate the IRE. As such, a detailed analysis of fish diets is necessary to develop even a first-order estimate of the effects of artificial reefs on biomass production.

Fish diets are typically assessed by two different methods; gut content analysis and stable isotope analysis. Gut content analysis (GCA) is traditionally utilized to determine feeding habits of fishes because it provides an accurate description of recent feeding. Gut-content analysis is not as useful for determining changes in feeding behavior, or describing feeding behavior, over long time periods because of the relatively rapid depletion of stomach contents via digestion. Partially digested prey items are often hard to identify and may be underestimated when determining the overall contribution of prey to diet (Hyslop, 1980; Grey et al, 2002; MacRae, 2006). If large prey items are ingested, stomachs may contain only a limited number of items, which may falsely indicate that the animal is a specialized feeder (Araujo et al, 2007). Additionally, prey is often patchily distributed, and the source of prey can change over short intervals of time or space (Araujo et al, 2007). This, combined with opportunistic feeding strategies of many estuarine species can make gut content analysis an ineffective way to assess diets over long time periods, unless large sample sizes are collected. For these reasons, stable isotope analysis is often used in combination with GCA. Stable isotopes are used in ecological studies as indicators of feeding pathways over a longer time period, and have been used to determine feeding differences between habitats and age classes. Compared to gut contents, stable isotopes have a slow turnover rate, on the order of weeks to months for muscle tissue and yield integrated description of diet. The most common isotopes used in ecological studies are $\delta^{13}\text{C}$ Carbon (C), $\delta^{15}\text{N}$ Nitrogen (N), and $\delta^{34}\text{S}$ Sulfur (S). Carbon isotopes are most commonly used as an indication of the sources of primary production for the food web. Nitrogen isotopes are an indication of trophic level, with a fractionation of approximately 3.4‰ for each trophic level, though conflicting reports have given values ranging from 2‰ to 5‰ (Peterson and Fry, 1987; Deegan et al., 1990). Sulfur isotopes have been used to determine differences in feeding

between organisms in different salinities (Fry et al 1999; Fry, 2002; Wissel and Fry, 2005).

Stable isotopes are used increasingly more often in assessing marine food webs, though there are limitations to this technique as well. In healthy estuarine food webs, there often is considerable trophic redundancy, with many different organisms comprising the same trophic level. In such cases, diet variability can be underestimated based solely upon the $\delta^{15}\text{N}$ value of the predator and prey (Araujo et al, 2007). Conversely, some prey sources may be widely distributed within the estuary, and may themselves feed on a variety of habitat types. Isotopic analysis may show a greater variability in diet than actually exists in this case (Araujo et al, 2007). For these reasons, stable isotope analysis is used most effectively in combination with GCA (Grey et al, 2002; Guiguer et al, 2002; Cocheret de la Moriniere et al, 2003; Lugendo et al, 2006). Only a few studies in the Gulf of Mexico (Gulf) have used these two techniques in combination to assess fish diets over different habitat types (MacRae, 2006; Wells, 2007).

Traditionally, stable isotope analysis has focused on examining the mean values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ for particular species in relation to some independent variable (site, habitat type, age, season, etc.) (Peterson and Howarth, 1985; Deegan et al, 1990; Fry et al 1999; Herzka and Holt 2000; Grey et al 2002; Fry, 2002; Wissel and Fry, 2005). Recently, techniques have been developed that take into account the variability of stable isotope values within the community and individual organism (Bearhop et al. 2004; Layman et al. 2007a; Layman et al. 2007b). The theory is that greater variation in isotopic signatures for a population indicates a wider range of prey species, switching of diets, consumption of prey over a range of trophic levels, foraging over large spatial scales, or numerous sources of primary productivity in the food chain (Bearhop et al. 2004; Layman et al. 2007a; Layman et al. 2007b). Layman et al. (2007a) describe several different metrics for analyzing variation of niche space, as represented by a $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ biplot.

These include $\delta^{13}\text{C}$ range, $\delta^{15}\text{N}$ range, total area (TA) of niche space, mean centroid distance for each point (CD), mean nearest neighbor distance, and standard deviation of nearest neighbor distance. Such metrics then can be used to describe the variation in feeding ecology of a single species (Layman et al. 2007b) or of the entire community (Layman et al. 2007a) over time, or between different habitat types.

In this chapter, my effort is focused on the feeding ecology of commercially, recreationally and ecologically important fish species. The goal is to examine trophic dynamics on a community basis by examining a selection of fishes utilizing different foraging strategies. Spotted seatrout (*Cynoscion nebulosus*) were chosen because they are a top predator in Barataria Bay. Spotted seatrout consume mostly fish and shrimp, though they are inclined to be opportunistic feeders (Lassuy, 1983). They are also extremely important in the recreational fishery in Louisiana, with catch totals of over 9 million fish in 2002 (Russel, 2004). Atlantic croaker (*Micropogonias undulatus*) (hereafter croaker) are demersal feeders. They also are thought to exhibit higher site fidelity than spotted seatrout, and are hypothesized to have a diet that is more habitat-specific in nature. In addition, croaker were once a valuable commercial and recreational species in Louisiana (Overstreet and Heard, 1978; Petrik et al., 1999). The third species is the bay anchovy (*Anchoa mitchilli*), a key prey species for many piscivores in coastal estuaries along the U.S. Gulf and Atlantic coasts. Bay anchovies are schooling zooplanktivores, and represent a significant fraction of the fish biomass in Barataria Bay, making them ecologically important as a link between primary production, primary consumers, and higher trophic levels (Jung and Houde, 2004; Hartman et al. 2004). A selection of benthic invertebrates, including mud crabs (family Xanthidae), the oyster drill (*Urosalpinx cinera*), the striped hermit crab (*Clibinarius vittatus*), and brown shrimp (*Farfantepenaeus aztecus*), was also

analyzed to determine if there is a difference in the trophic ecology of organisms feeding directly on the habitat types I studied.

METHODS AND MATERIALS

Study Site

The artificial reef site was constructed to mimic an oyster reef, and is located in Bay Ronquille, Plaquemines Parish, Louisiana. Bay Ronquille is located in southeastern Barataria Bay, east of Grande Isle and to the north of Quatre Bayou Pass leading to the Gulf (Figure 1).

The reference site is located approximately 1km to the northwest of the artificial reef site (Figure 1), and is characterized by a mud-bottom, with no hard substrate. The reference site was chosen due to its location with respect to the artificial reef. Close proximity of the sites allowed for water conditions, including temperature, salinity, tidal movement and depth, to be consistent between sites. The sites were assumed to have similar fish species composition prior to the construction of the artificial reef. However, the reference site is far enough away from the artificial reef, so as to not be included in the feeding halo around the artificial reef.

Reef Construction

The artificial reef was constructed on 18 June, 2004 by the Recreational Fisheries Research Institute, Inc. (RFRI) in association with the Louisiana Department of Wildlife and Fisheries. Construction was supported through a National Fish and Wildlife Foundation Habitat Restoration Grant and public fund-raising events. The artificial reef site encompasses approximately 4050m² of estuary bottom that was previously an oyster lease, but contained only relic oyster shell and no living oysters at initiation of reef construction. Reef material consists of limestone cobble number 57 averaging 3.8cm in diameter. Limestone cobble acts as an effective

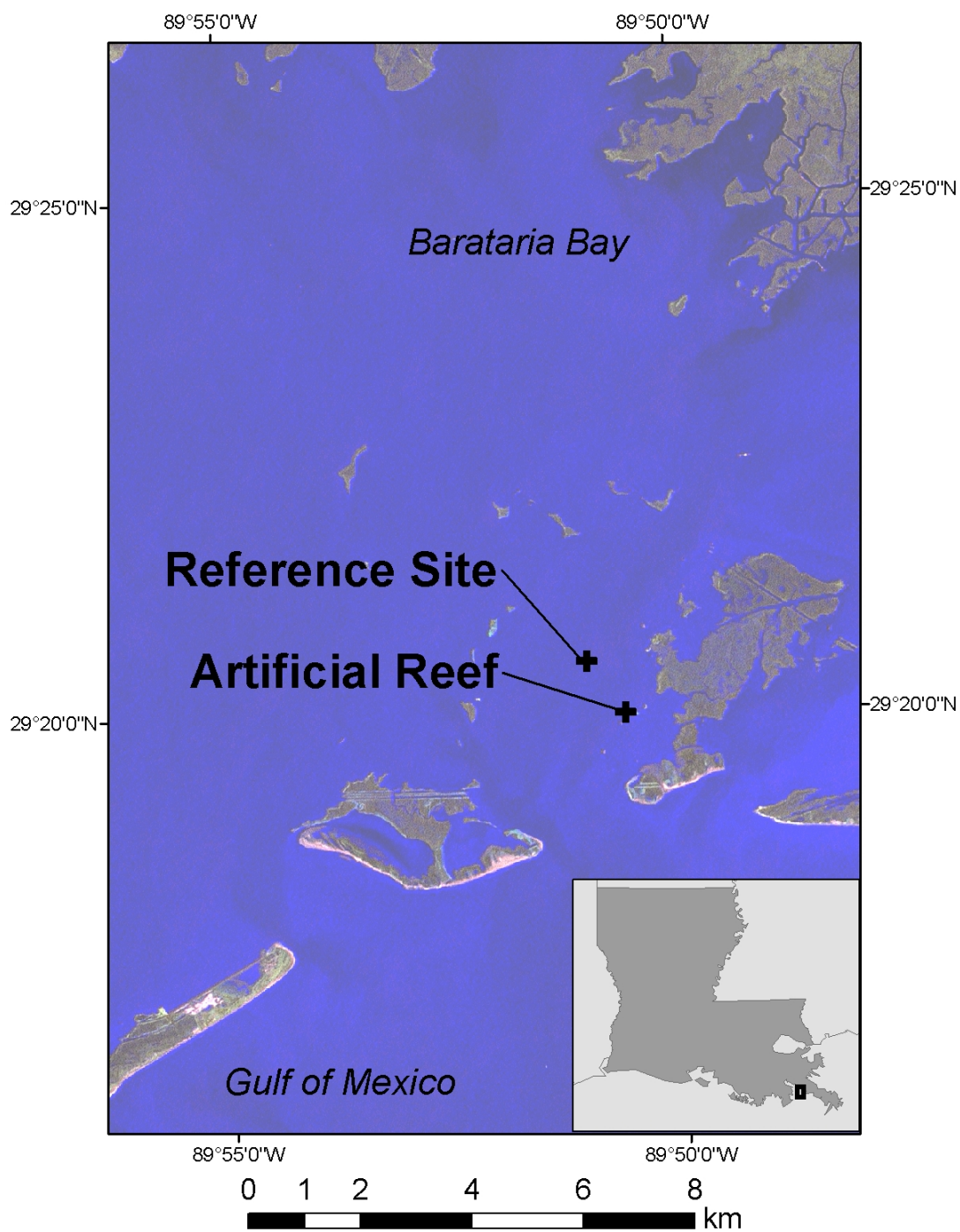


Figure 2.1: Location of sampling sites in Barataria Bay, Louisiana

cultch material by successfully attracting oyster larvae to settle and is, therefore, considered to be an effective alternative to oyster shell in creating artificial oyster reefs (Haywood, 1992; Coen and Luckenbach, 2000). Additionally, limestone cobble maintains the interstitial space that is necessary for the survival of larval oysters and small benthic fishes and macroinvertebrates (Coen and Luckenbach, 2000).

Sampling Protocol

Fish collection occurred from March 2005 – February 2007, and samples were collected twice per quarter, or season. Seasons were defined as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August) and fall (September, October, and November). Two types of gear were used to collect finfish over both sites, including gillnets and a purse seine. Due to the inherent selectivity of all gear types, I chose to utilize two gears that would effectively sample the larger adult estuarine species (gillnets), as well as smaller prey species and larval fishes higher in the water column (purse seine). The gillnets were 45.7m long and 1.8m deep, consisting of five 9.1m panels. Panels were randomly arranged with mesh sizes of 1.27, 1.91, 2.54, 3.18, and 3.81 cm. The purse seine measured 20m in length, with a mesh size of 2 x 2mm square. Gillnets were set for one hour at each site. After one hour, the gillnets were pulled, cleaned and reset in the same location to obtain replicates in time. The purse seine was set twice as well, to obtain a replicated sample in time. The first purse seine was set before the first gill net set, and the second after the final gillnet set. Fish were bagged by gear type, net panel (for gillnets), location (reef or reference) and set (first or second), and placed on ice. All fishes remained on ice until return to the laboratory for analysis. Those fish that were not analyzed immediately were frozen and stored at -80°C to ensure no degradation of gut content materials or stable isotopes in muscle tissue. All

fish collected were identified to species, and measured for total length and standard length to 1.0mm, and weight to 0.1g.

Supplementary sampling was conducted in June and July of 2007 in an attempt to collect benthic organisms from the artificial reef surface for stable isotope analysis. These samples were designed to provide a better overall picture of the food web dynamics of the reef. Several different techniques were tested to collect benthos, including ponar grabs, habitat trays, SCUBA and snorkeling sampling, suction pump and trawling, which met with little success, before settling on a 45.72cm wide oyster dredge equipped with 1.27cm mesh, which was used successfully to collect samples of small organisms associated with the cobble. The dredge was heavy enough to sink into the reef and collect cryptic animals living in interstitial spaces. Three dredge tows were made at each of the two sampling locations. Dredge tows on the mud-bottom site were five minutes long, while dredge tows over the reef were five, four and three minutes in tow duration. Tows over the reef were decreased in time due to the large amount of reef material collected in the dredge. After a few minutes of tow time the dredge became saturated with rock, decreasing catch efficiency. Due to the short tow duration, disturbance to the reef was assumed to be minimal, and all reef material was returned after collection to maintain reef size and structure. Samples collected were kept on ice until returned to the laboratory, where they were frozen at -80°C to prevent degradation of tissue for stable isotope analysis. All mud crabs collected were identified to genus, and later grouped together as xanthid crabs for all analyses. Mud crabs were weighed to the nearest 0.1g wet weight, and measured for carapace width to the nearest 1.0mm. All other invertebrates were identified to species and measured for wet weight to 0.1g, carapace length for hermit crabs to 1.0mm, and shell length for gastropods to 1.0mm.

In the laboratory, the stomachs and esophagus of the spotted seatrout and croaker were removed and weighed to the nearest 0.1g to determine full stomach wet weight. Stomachs were then fixed in 10% formalin for 24 to 48 hours, and subsequently transferred to ethanol and stored until analysis. Contents of the stomach and esophagus were removed, sorted under a dissecting microscope, and identified to the lowest taxonomic level possible. Gut contents then were separated and grouped by taxon and dried at 60°C for 24 hours in a DX 600 drying oven. When possible, individual organisms were counted and recorded. Once dried, contents were weighed using a Precision XB Series balance to 0.0001g to determine dry weight of each taxonomic grouping of prey (hereafter prey items).

Stable isotope analysis was conducted by sampling muscle tissue from the left side of the fish just anterior to the dorsal fin. Tissue samples for oyster drills were collected from the foot by removing the organism from its shell, and then dissecting away the operculum. Samples were rinsed with deionized (DI) water to make sure there was no shell residue left behind. Striped hermit crabs were also removed from their shell. Tissue samples for striped hermit crabs and brown shrimp were collected from the tail after the exoskeleton was removed. Mud crabs were analyzed whole after being soaked in 1 normal hydrochloric acid (1N HCl) for ten minutes to dissolve the CaCO_3 exoskeleton. Tissue samples were dried at 60°C for 24 hours in a DX 600 drying oven, and then pulverized using a Crescent Wig-L-Bug. A sample of ground tissue measuring between 4.0 – 5.0mg dry weight was placed in an aluminum capsule and mixed with approximately 10mg of Vanadium pentoxide (V_2O_5). Samples then were analyzed for isotopic composition of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ using a Finningan MAT DeltaPlus continuous-flow stable isotope mass spectrometer at Louisiana State University. Isotopic values are reported relative to known standards for carbon, nitrogen, and sulfur with the standard equation:

$$\delta\text{sample}(\text{‰}) = (R_{\text{sample}} / R_{\text{standard}} - 1) * 1000$$

where R represents the ratio of the heavy to light isotope ($^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$, $^{34}\text{S}/^{32}\text{S}$).

Data Analysis

Three different methods were used to analyze gut contents, including percent composition by weight, percent composition by number, and frequency of occurrence. Percent composition by weight (%W) was used for the majority of statistical analysis because it is believed to provide the best assessment of the nutritional contribution of individual prey items (Wells, 2007; McCawley, 2003; Bowen, 1996). As such, an index of relative importance (IRI) was constructed using the %W values for all prey items at each site using the formulas in McCawley and Cowan (2007). First the frequency of occurrence was calculated using the formula:

$$FO = \frac{\text{Number of stomachs containing one prey category}}{\text{Number of stomachs containing prey}}$$

The IRI was then calculated as:

$$IRI = (\%N + \%W) \times FO$$

where N is the number each prey item found, W is the total dry weight of each prey item and FO is the frequency of occurrence. Finally, a percent IRI (%IRI) was then calculated using:

$$\%IRI = \frac{IRI \text{ for each prey category}}{\text{Sum of all IRI values}} \times 100$$

The IRI was used to examine the overall composition of diets for each species (spotted seatrout and Atlantic croaker) at each site (artificial reef and mud-bottom reference site). The IRI was useful because it describes diets based on the contribution of each prey item by weight.

However, it does not address the fact that different prey items may have vastly different caloric densities at similar weights. For this reason, an index of caloric importance (ICI) also was used

to evaluate the contribution of each prey item to the diet of each species. The ICI was calculated using the formula derived by McCawley and Cowan (2007):

$$ICI = (\%W + C) \times FO$$

where W is the total dry weight of each prey item, C is the calories/g dry weight, and FO is the frequency of occurrence.

Percent ICI was also calculated, using the formula:

$$\% ICI = \frac{ICI \text{ for each prey category}}{\text{Sum of all ICI values}} \times 100$$

Values of caloric density in calories per gram dry weight (C/g dw) were obtained from the literature when possible, or measured directly using a Parr 6200 Adiabatic Bomb Calorimeter. The IRI and ICI were calculated for the eleven most numerous prey items for spotted seatrout and the ten most numerous prey items for Atlantic croaker. The remaining prey species contributed less than 4% and 1%, respectively to the total diets of spotted seatrout and croaker, and provided little information about their overall feeding ecology.

Gut content data were analyzed using PRIMER (Plymouth Routine in Multivariate Ecological Research; Warwick, 1990), which treats each individual stomach as a replicate. PRIMER was run using percent composition by dry weight following a square-root transformation to normalize the data, and reduce the importance of abundant prey items. A Bray-Curtis similarity index was constructed from the transformed data, and an analysis of similarity (ANOSIM) was run using this matrix to compare each stomach to every other stomach. A two-way ANOSIM was used to compare prey items between site and season, and the interaction between site and season. Following ANOSIM, the original square-root transformed data were analyzed using the similarity percentages (SIMPER) option, which examines the within group (site or season) similarity as well as the between group (site and

season) dissimilarity. This method allows the identification of prey items that contribute to the differences in diets between sites or season. Levels of significance were set to $p = 0.10$ for all PRIMER analyses.

Stable isotope data were assessed using an analysis of variance (ANOVA) (SAS Institute, 2002) to determine if there was a difference in mean values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ for each species between site and season. All significant main effects at the $p = 0.05$ level were further tested using a Tukey HSD post-hoc test to determine which variables contributed to the observed differences. Values of stable isotope ratios also were used to analyze the niche breadth of each species at each site, following Layman et al. (2007 a, b). Samples were individually plotted in their $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ niche space for comparisons of dietary breadth between sites, using two different metrics. Total area (TA) is a measure of overall niche space and is determined by calculating the area associated with the smallest polygon which contains all individuals (Layman et al., 2007 a, b). Centroid distance (CD) is a measure of the overall trophic diversity and is determined by recording the distance of each individual from the mean $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ value for the population (Layman et al., 2007 a, b). Mean centroid distances were compared between sites using an ANOVA and Tukey HSD post ANOVA tests for significant results at the $p = 0.05$ level. In addition, centroid distance was also analyzed from three-dimensional data, using $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ isotope values plotted as a three-dimensional niche space. The CD for three-dimensional data was measured as the distance of each individual point from the mean $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ - $\delta^{34}\text{S}$ value, or the geographic center of the cloud of points plotted in three-dimensional space. Mean three-dimensional centroid distances were compared using an ANOVA and Tukey HSD post-ANOVA test for results that were significant at the $p = 0.05$ level. Calculation of TA and CD were completed using MATLAB (2005).

The metrics established by Layman et al. (2007) also were used to examine community-wide variability of niche breadth. In this case, mean values for all three fish species at each site were plotted on the same $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ biplot space. Additionally, two invertebrates that were collected at both sites, the oyster drill and the striped hermit crab, were included as a measure of the overall community structure. The same metrics of TA and CD were calculated for this community biplot using MATLAB (2005). Mean centroid distance was analyzed using an ANOVA and Tukey HSD post-ANOVA test for results that were significant at the $p=0.05$ level.

Production Estimates

Estimates of biomass production attributable to the artificial reef were determined using the methods of Peterson et al. (2003) and Powers et al. (2003). First, annual production was calculated using the equation (Edgar and Shaw, 1995):

$$P = 0.00051 * B^{0.69} * T^{1.04}$$

where P is production (g dw yr^{-1}), B is mean biomass (g dry weight) and T is mean temperature ($^{\circ}\text{C}$). Grams dry weight was assumed to be $\text{g dw} = \text{g wet weight} * 0.20$ (Edgar and Shaw, 1995). Next an index of reef exclusivity was constructed from results of the gut content analysis by determining the percentage of dry weight of prey items exclusively found over the artificial reef site, where (Powers et al., 2003):

$$IRE = \frac{\text{sum of dry weight of prey items from artificial reef}}{\text{sum of dry weight of all prey items from all habitats}}$$

Finally, the relative production attributable to the artificial reef (AP) was calculated after Powers et al. (2003), where $AP = IRE * P$. Estimates of biomass production were calculated for spotted seatrout and Atlantic croaker.

RESULTS

A total of 4149 individuals were collected, distributed among 43 finfish and three shrimp species. Of these, 89 were spotted seatrout, 410 were Atlantic croaker, and 900 were bay anchovy. Stable isotopes were run on all 89 spotted seatrout, 243 of the Atlantic croaker, and 84 groups of bay anchovy. Sub-samples were analyzed for croaker and bay anchovies in instances of high catch totals. Samples of bay anchovies also were pooled due to the large catch totals and small tissue sample size for individuals. Gut content analysis was run on 88 of the 89 spotted seatrout collected and 237 of the croaker collected. Gut content analysis was not performed on bay anchovies because they feed on zooplankton, which are ubiquitous throughout the estuary. Therefore, I assumed that stable isotope analysis would be more effective at differentiating feeding behavior than enumerating bay anchovy prey items.

Gut Content Analysis

Spotted Seatrout

Spotted seatrout consumed mostly fish, primarily of the genus *Anchoa*, and penaeid shrimp. Five different families of fishes were collected from spotted seatrout stomachs, including Engraulidae (*Anchoa* sp.), Ariidae, Clupeidae (*Brevoortia patronus*), Sparidae, and Sciaenidae (*Cynoscion* spp. and *M. undulatus*). A variety of decapod crustaceans, in addition to penaeid shrimp, were found amongst gut contents, including hermit crabs (family Diogenidae), and swimming crabs (family Portunidae). Other prey items, including gastropods, bivalves, tunicates and isopods, were found relatively infrequently, and in small amounts. By dry weight (%W), penaeid shrimp, including both white shrimp (*Litopenaeus setiferus*), and brown shrimp made up the greatest percentage of spotted seatrout diets, while fish tissue was found more frequently, pooled over all sites and seasons. Over the artificial reef site, spotted seatrout

consumed more fish, with anchovies (*Anchoa* sp.) and gulf menhaden (*B. patronus*) making up the greatest percentage of dry weight (27% each), and unidentified fish material making up over 17% of weight (Figure 2.2). Penaeid shrimp constituted 14% of diets by dry weight over the reef, as compared to over 60% at the reference site (Figure 2.2). Anchovies and unidentified fish material made up less than 5% of prey items by weight over the reference site, with Atlantic croaker making up 15% of diets (Figure 2.2). Fifty-six stomachs were analyzed from fish collected over the artificial reef, and thirty-two from the reference site. Four stomachs from the reef site were empty and only one from the reference site, making up 7% and 3% of samples respectively.

The index of relative importance (IRI) shows that anchovies make up the greatest proportion of spotted seatrout diets over the artificial reef site (Table 2.1). Unidentified fish tissue, penaeid shrimp, and gulf menhaden also were key prey items for spotted seatrout over the artificial reef site (Table 2.1). Diets at the reference site were composed primarily of anchovies and penaeid shrimp as well, with lesser contributions of unidentified fish tissue, but higher contributions of bivalves, and detritus. Atlantic croaker also contributed to diets over the reference site. In terms of caloric density, anchovies were the most important contributor over the reef, with an ICI of 45%, followed by unidentified fish tissue at 35% (Table 2.1). Over the reference site, penaeid shrimp clearly dominated the diets in terms of caloric density of spotted seatrout with an ICI of 63% (Table 2.1).

Results of the PRIMER analysis indicate that there were no significant differences in diets of spotted seatrout between sites ($p > 0.1$, PRIMER). Penaeid shrimp appeared more frequently in stomachs over the reef site and unidentified material was observed more frequently

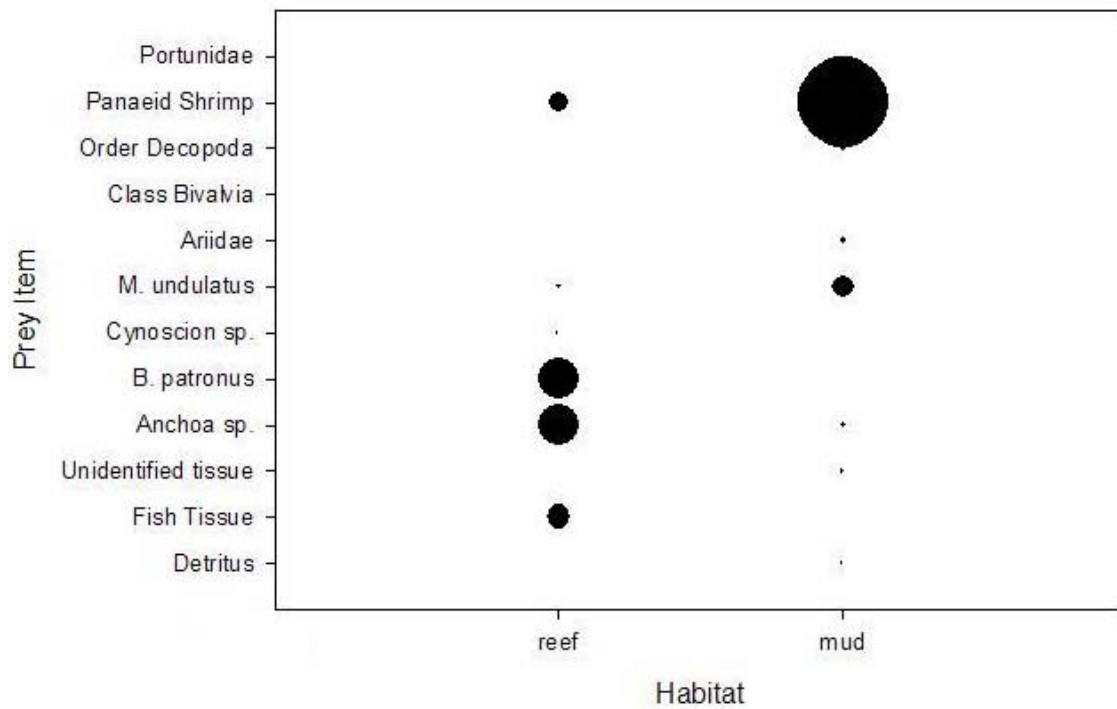


Figure 2.2: Bubble plot representing the diets of spotted seatrout over each habitat by percent dry weight of individual prey items. The twelve most numerous prey items by dry weight are included. The size of each bubble represents the percent contribution by dry weight to diets.

Table 2.1: Results of the IRI and ICI for the eleven most common prey items for spotted seatrout. The frequency of occurrence and caloric densities for prey items are also shown.

Spotted Seatrout Prey	caloric density (C/g dw)	Artificial Reef			Mud-Bottom		
		FO	% IRI	%ICI	FO	% IRI	%ICI
Detritus	3880	0.039	0.35	0.14	0.17	9.60	6.00
Fish Tissue	5014	0.31	36.46	34.20	0.21	15.61	3.63
Anchovies	5395	0.24	42.61	44.51	0.21	28.34	12.92
B. patronus	5376	0.039	4.95	7.41	0.00	0.00	0.00
Cynoscion sp.	4906	0.039	0.66	0.63	0.034	0.52	0.65
M. undulatus	4638	0.059	1.59	1.03	0.034	3.70	7.53
Ariidae	4833	0.00	0.00	0.00	0.034	1.76	2.41
Bivalve	4792	0.020	0.88	0.030	0.069	11.16	1.58
Decapod Crustacean	3820	0.039	0.27	0.050	0.069	2.72	3.25
Penaeid Shrimp	4749	0.14	11.73	11.57	0.069	26.60	62.02
Swimming Crab	2945	0.020	0.51	0.14	0.00	0.00	0.00

in stomachs over the reference site. However, these differences were not significantly different ($p > 0.10$, ANOSIM). This is also contrary to IRI analysis, which indicated that anchovies were found more frequently over the artificial reef. Of all the guts collected, twenty-five contained only unidentified material, here described as anything that has been digested beyond the point of recognition, indicating that the individual had not fed recently. A total of 33% of the fish collected over the mud-bottom site contained only unidentified material, compared with 24% of fish over the artificial reef site. These results were combined with the results of the empty stomach analysis to determine that 33% of spotted seatrout collected over the artificial reef had not consumed food recently, as compared to 36% of fish collected over the mud-bottom reference site.

In the spring months, spotted seatrout consumed more penaeid shrimp, while in the summer, stomachs contained more anchovies; however, results of the ANOSIM, showed no significant seasonal differences in diets ($p > 0.1$). SIMPER resulted in low percent similarity within spring and summer seasonal groups (16.54 and 18.61, respectively). Sample sizes in the fall and winter were small, so it is difficult to determine conclusively if diets were different in these months from those in the spring and summer. Only one spotted seatrout was caught in each fall and winter months. The spotted seatrout collected in the fall consumed a large number of swimming crabs (family Portunidae), while the fish collected in winter contained only a small amount of unidentified material in its stomach.

Atlantic Croaker

Diets of the Atlantic croaker were significantly different between the artificial reef site and the reference site (ANOSIM, $p < 0.1$; PRIMER). Croaker found over the artificial reef fed almost exclusively on mud crabs (family Xanthidae), and other unidentified crabs, which were

digested beyond the point of recognition (Figure 2.3). Mud crabs made up approximately 57% of croaker diets over the reef by dry weight. Penaeid shrimp contributed over 12% to diets, with unidentified crabs and other decapods crustaceans contributing an additional 15% to diets by dry weight. No mud crabs were found in stomachs of croaker collected at the reference site, and overall abundance of crabs and other decapods crustaceans was low (less than 4% of total dry weight). Diets over the reference site consisted primarily of bivalves, which contributed more than 35% of diets by dry weight (Figure 2.3). Fish material also made up a significant portion of croaker diets over the reference site, contributing 27% of total weight, as compared to only 3% over the artificial reef. Detritus was observed more frequently in the stomachs of croaker from the reference site. A large amount of unidentified material was also found in the guts of croaker over the reference site (Figure 2.3).

Results of the IRI indicate that mud crabs were the most important prey item for Atlantic croaker over the artificial reef, contributing nearly 40% of the total diet composition (Table 2.2). Decapod crustaceans, including unidentified crabs and penaeid shrimp, contributed another 8.5% to diets. Copepods also contributed significantly, making up over 20% of diets; however, copepods contributed little in terms of caloric importance (less than 1% of the ICI). Bivalves contributed the most to diets of croaker over the reference site, making up over 46% of the diet according the results of the IRI (Table 2.2). Unidentified fish tissue and polychaete worms were also important, contributing 4% and 3% respectively. Detritus was found to be important for fish over both sites, contributing 17% over the reef and 43% over the reference site, based on the IRI. However, detritus contributes far less in terms of caloric density, contributing only 5% and 26%, respectively, to diets based on the ICI. Results of the ICI for croaker over the artificial reef indicate that mud crabs contribute to over 70% of caloric intake for croaker, with an additional

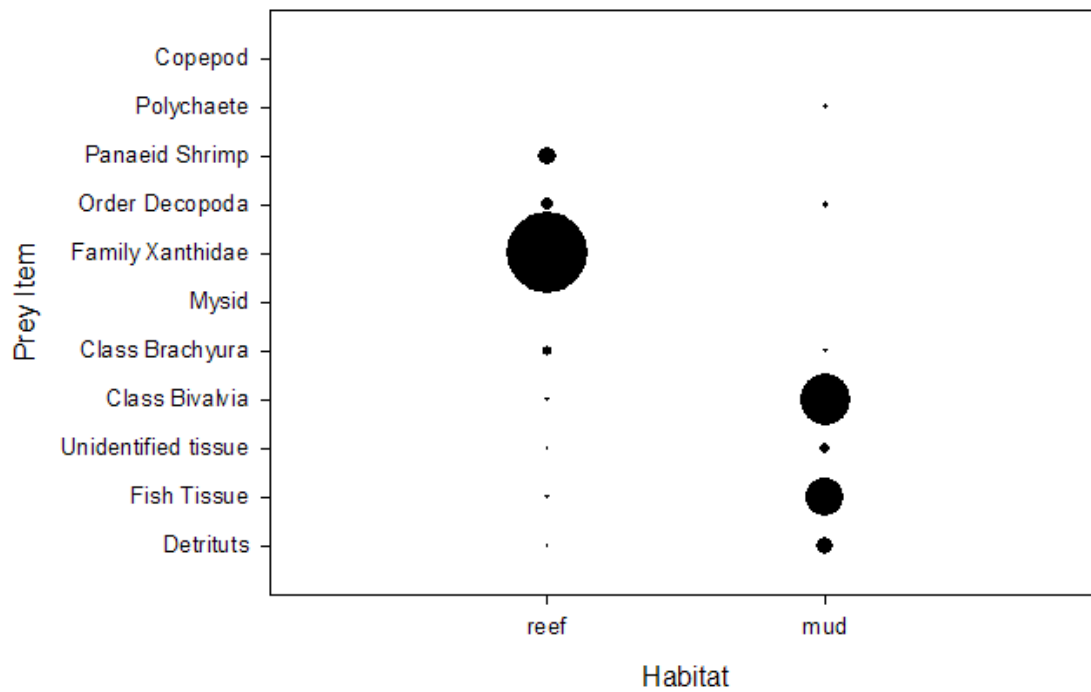


Figure 2.3: Bubble volumes representing the diets of Atlantic croaker over each habitat by percent dry weight of individual prey items. The eleven most numerous prey items by dry weight are included. The size of each bubble represents the percent contribution by dry weight to diets.

Table 2.2: Results of the IRI and ICI for the ten most common prey items for Atlantic croaker. The percent frequency of occurrence and caloric densities for prey items are also shown.

Atlantic Croaker Prey	Caloric Density (C/g dw)	Artificial Reef			Mud-Bottom		
		%FO	%IRI	%ICI	%FO	%IRI	%ICI
Detritus	3880	0.48	17.31	5.29	0.73	43.12	25.62
Fish Tissue	5014	0.017	0.27	0.46	0.097	4.42	9.63
Class Bivalvia	4792	0.13	4.50	3.45	0.47	46.53	59.80
Class Brachyura	3823	0.13	3.98	5.87	0.024	0.16	0.24
Mysid	7533	0.18	9.88	1.93	0.0061	0.023	0.0062
Family Xanthidae	3100	0.25	37.51	71.35	0.00	0.00	0.00
Order Decapoda	3820	0.12	2.88	6.01	0.12	1.41	1.31
Penaeid Shrimp	4749	0.050	1.58	5.01	0.00	0.00	0.00
Polychaete	4798	0.05	0.19	0.080	0.18	2.86	2.41
Copepod	6626	0.10	21.51	0.46	0.13	1.24	0.91

17% consisting of other decapods crustaceans, including unidentified crabs and penaeid shrimp (Table 2.2). Over the reference site, bivalves contributed 60% of the caloric intake of croaker, with unidentified fish material contributing 10%, based on the ICI. Sixty stomachs were analyzed from croaker collected over the artificial reef, and 172 from the reference site. Of these, two from the artificial reef site and seven from the reference site were empty, making up 3% and 4% of samples, respectively.

PRIMER failed to detect differences in the diets of croaker between seasons (ANOSIM, $p > 0.1$); however there appeared to be shifts in abundances of prey items by season. Croaker collected over the artificial reef site consumed more fish and penaeid shrimp in spring. During summer, diets consisted mostly of mud crabs, and other decapod crustaceans over the reef. Fall diets were composed of the greatest variety of organisms, with a relatively even distribution of prey items amongst diets. Mud crabs, unidentified crabs, penaeid shrimp, unidentified decapod crustaceans, and fish tissue all were found in stomachs in fall, in similar abundance over the reef. Cephalopods also were found more frequently in fall, though this may be due to two individual croaker that had a high percentage of cephalopod material in their stomachs. Only one croaker was analyzed for stomach contents over the artificial reef in winter months, and therefore comparison between seasons is not possible. This individual consumed mostly crabs that were digested beyond recognition. Croaker collected over the reference site consumed high numbers of bivalves in all seasons, as well as a large amount of detritus and unidentified material. Over the reference site, there was a higher abundance of fish tissue in the guts during summer, and higher abundances of polychaete worms in the fall, although these differences were not significant. No stomach contents were analyzed for croaker caught in winter over the reference site, so a comparison cannot be made for winter samples. All croaker collected over the

reference site, and all but one collected over the artificial reef site in the winter, measured less than 80mm TL, and thus were assumed to be young of the year based upon estimates of length at age from Chao and Musick (1977). Previous studies have shown that young-of-the-year croaker that had just recruited to the estuary fed primarily on zooplankton, particularly copepods (Chao and Musick, 1977). As such, no gut content analysis was performed on these fish, though they were used in stable isotope analysis, as this was assumed to provide better information on dietary differences between sites.

Stable Isotope Analysis

Spotted Seatrout

Mean values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ for spotted seatrout were -19.93‰, 14.21‰ and 11.16‰ over the reef and -19.51‰, 14.11‰ and 10.89‰ over the mud-bottom site, respectively (Figures 2.4 and 2.5). There were no significant differences in the mean isotopic values between sites for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, or $\delta^{34}\text{S}$ (ANOVA, $p > 0.05$) (Table 2.3). Values of $\delta^{13}\text{C}$ ranged from -23.19‰ to -17.02‰ over the artificial reef and -20.54‰ to -17.32‰ over the reference site. Values of $\delta^{15}\text{N}$ ranged from 11.74‰ to 16.28‰ over the artificial reef and 13.46‰ to 15.23‰ over the reference site.

Nitrogen isotopes differed significantly by season ($p < 0.01$, ANOVA) with a mean of 12.98‰ in winter, 14.37‰ in spring, 13.99‰ in summer and 15.04‰ in fall, pooled over all sites (Table 2.3). Tukey's test revealed that nitrogen isotopes differed between winter and spring, with significantly higher values of $\delta^{15}\text{N}$ in spring (Table 2.4). Care must be taken when interpreting these results due to the small sample sizes in fall and winter, when a total of three fish were collected over the reef combined, and no fish were collected over the mud-bottom.

Table 2.3: Results from the analysis of variance comparing spotted seatrout stable isotope values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ to site and season. Asterisk indicates a significant result at $p = 0.05$.

		df	F	MS	p-value
$\delta^{13}\text{C}$	Site	1	2.33	2.97	0.14
	Season	3	0.32	0.43	0.81
	Site x season	1	4.14	3.11	0.082
$\delta^{15}\text{N}$	Site	1	0.29	0.15	0.83
	Season	3	4.42	2.25	0.031 *
	Site x season	1	0.21	0.11	0.65
$\delta^{34}\text{S}$	Site	1	1.00	1.21	0.32
	Season	3	4.09	4.95	0.0095 *
	Site x season	1	0.66	0.80	0.42

Table 2.4: Mean stable isotope values for spotted seatrout between sites (pooled over season) and between seasons (pooled over sites). Tukey HSD post-ANOVA groupings are included to indicate significant differences between sites and seasons.

	$\delta^{13}\text{C}$	Tukey grouping	$\delta^{15}\text{N}$	Tukey grouping	$\delta^{34}\text{S}$	Tukey grouping
Artificial Reef	-19.93‰	A	14.21‰	A	11.16‰	A
Mud-bottom	-19.51‰	A	14.11‰	A	10.89‰	A
Winter	-19.66‰	A	12.98‰	A	10.48‰	AB
Spring	-19.34‰	A	14.37‰	B	11.77‰	A
Summer	-19.69‰	A	13.99‰	AB	10.67‰	B
Fall	-18.97‰	A	15.04‰	AB	12.45‰	AB

Carbon isotope values were similar across seasons, with mean values of -19.66‰ in winter, -19.34‰ in spring, -19.69‰ in summer and -18.97‰ in fall (Table 2.4). There were no differences in mean $\delta^{13}\text{C}$ values between seasons (ANOVA, $p > 0.05$).

Sulfur isotope values also differed by season (ANOVA, $p < 0.01$) with a mean of 10.48‰ in winter, 11.77‰ in spring, 10.67‰ in summer, and 12.45 in fall (Table 2.4). Tukey's test revealed that sulfur isotopes differed between spring and summer, with higher values of $\delta^{34}\text{S}$ in spring samples pooled over all sites.

The total niche space (TA) for spotted seatrout over the artificial reef was 15.03 as compared to 3.30 for the reference site (Figure 2.6). The mean two-dimensional CD of 1.2 ± 0.11 for samples from the artificial reef was significantly larger than the reference site CD of 0.66 ± 0.12 ($p = 0.002$, ANOVA). Analysis of three-dimensional centroid (3-DCD) distance revealed similar results, with a significantly larger 3-DCD for artificial reef samples than reference site samples. The mean 3-DCD distance for artificial reef samples was 1.69 ± 0.11 as compared to 1.27 ± 0.14 for reference site samples. Tukey's test confirmed the difference observed between sites for both 2-DCD and 3-DCD niche space analysis.

Atlantic Croaker

Nitrogen isotope values for croaker were significantly higher over the artificial reef site, (ANOVA, $p < 0.0001$), with a mean $\delta^{15}\text{N}$ value of 13.34‰ over the reef and 12.72‰ over the mud-bottom site (Figure 2.5) (Table 2.4). There was no statistical difference between values carbon and sulfur isotopes between sites. The mean $\delta^{13}\text{C}$ value for croaker over the reef was -18.31‰ as compared to -18.69‰ at the mud-bottom site, with mean $\delta^{34}\text{S}$ values of 12.40‰ over the reef and 12.33‰ over the mud-bottom. Values of $\delta^{13}\text{C}$ ranged from -22.13‰ to -15.68‰

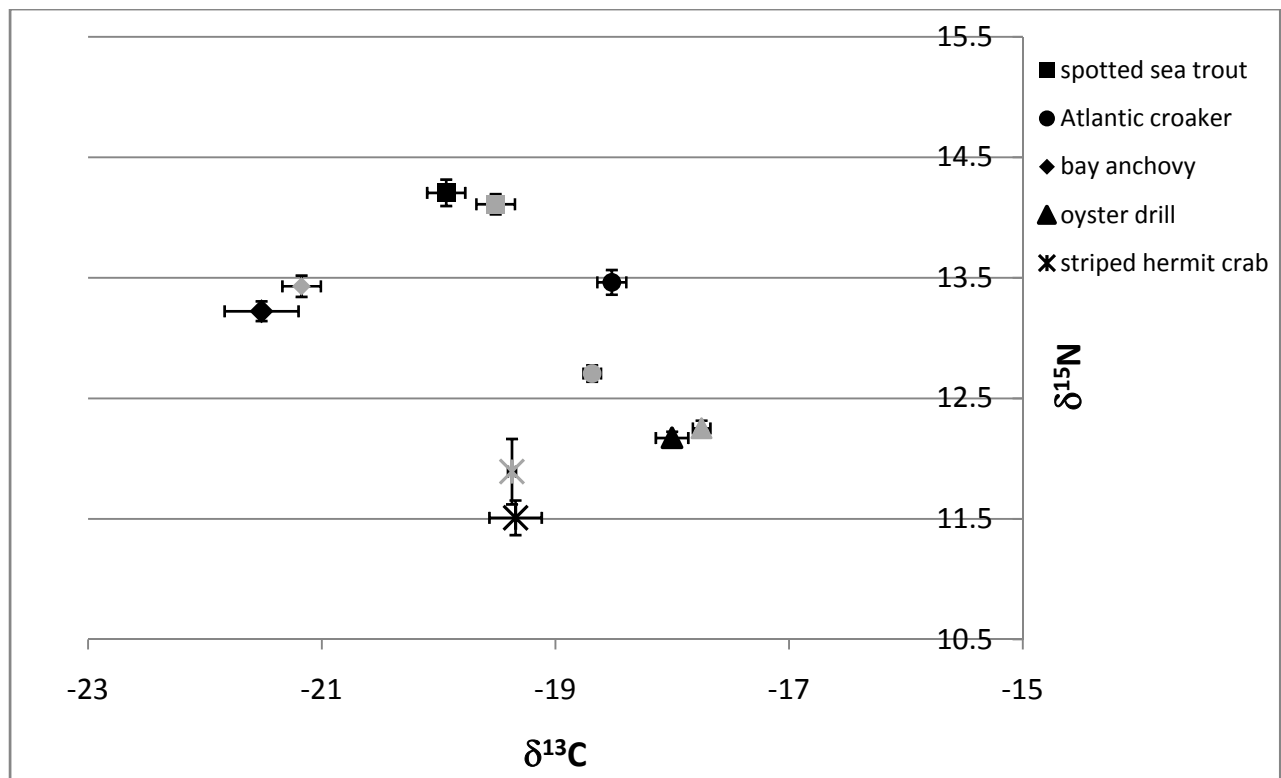


Figure 2.4: Mean stable isotope values for study species. Dark symbols represent artificial reef samples and light symbols represent reference site samples. Standard error bars are shown.

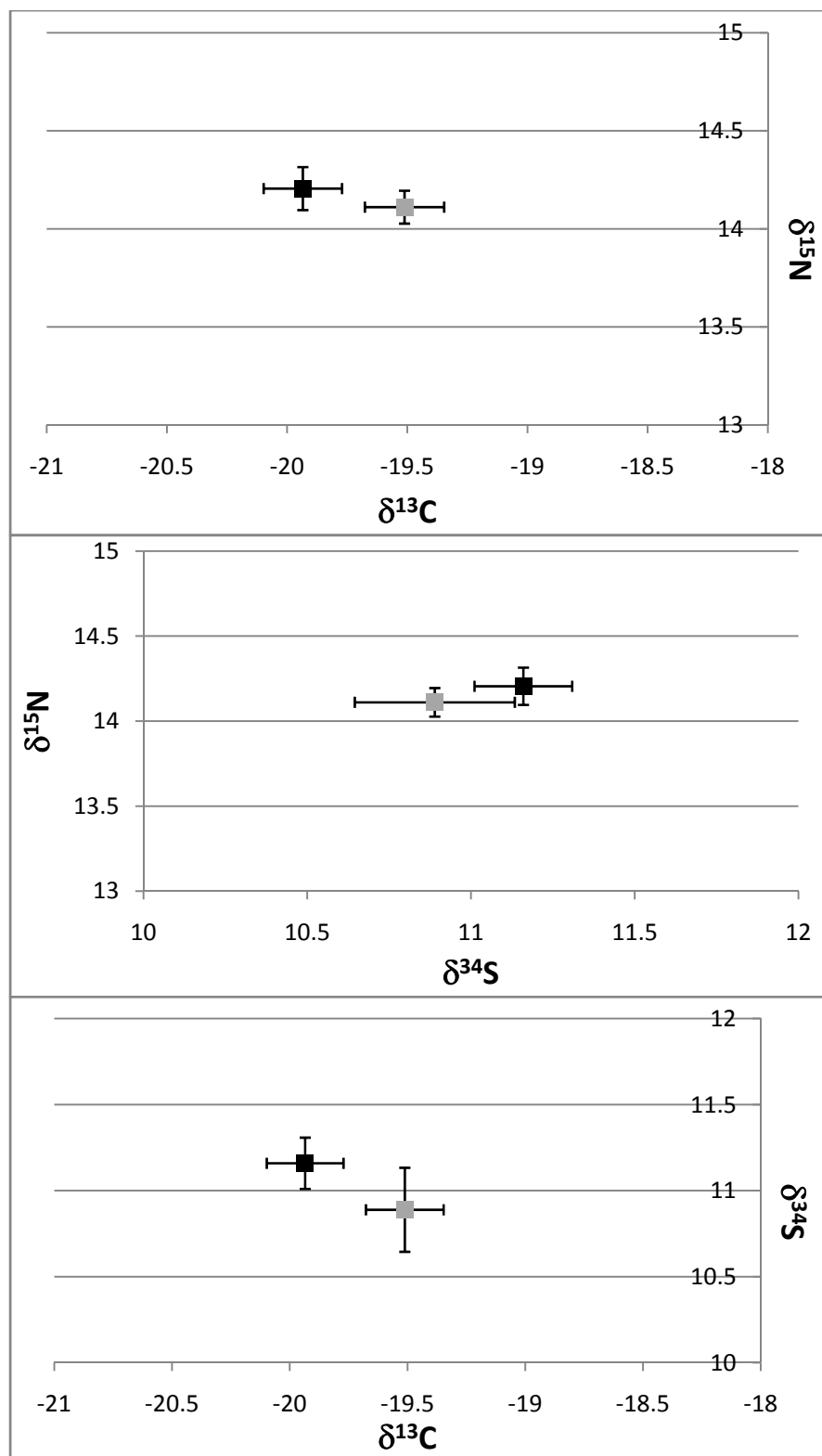


Figure 2.5: Mean stable isotope values for carbon ($\delta^{13}\text{C}$), nitrogen ($\delta^{15}\text{N}$), and ($\delta^{34}\text{S}$) for spotted seatrout over each habitat. Dark symbols represent artificial reef samples and light symbols represent reference site samples. Standard error bars are shown.

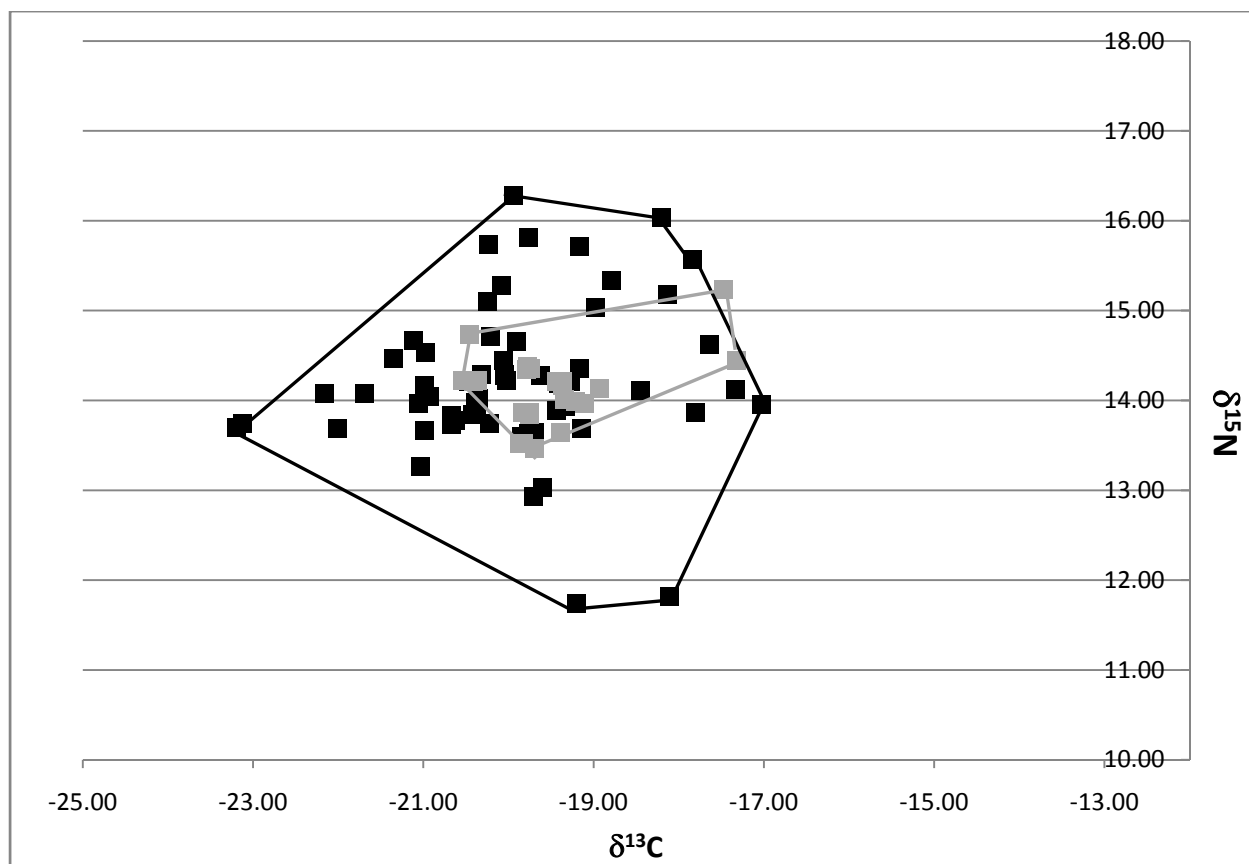


Figure 2.6: Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$), stable isotope values for all spotted seatrout collected. Dark symbols represent artificial reef samples and light symbols represent reference site samples. Outlines represent total area (TA) of $\delta^{13}\text{C} - \delta^{15}\text{N}$ biplot.

over the artificial reef and from -23.27‰ to -14.42‰ over the reference site. Values of $\delta^{15}\text{N}$ ranged from 10.11‰ to 14.90‰ and from 9.60‰ to 15.01‰ over the reference site.

There were seasonal differences in nitrogen isotopes for croaker (ANOVA, $p = 0.002$) (Table 2.5). Mean $\delta^{15}\text{N}$ values pooled over sites were 13.09‰ in winter, 13.16‰ in spring, 12.85‰ in summer and 12.70‰ in fall. Tukey's test revealed that $\delta^{15}\text{N}$ values differed significantly in spring and summer (Table 2.6).

Seasonal differences also were apparent for values of $\delta^{13}\text{C}$ (ANOVA, $p < 0.01$) (Table 2.5). Mean $\delta^{13}\text{C}$ values were -18.90‰ in winter, -18.62‰ in spring, -18.09‰ in summer and -18.96‰ in fall (Table 2.6). Results of the Tukey HSD post-ANOVA tests revealed several differences between seasons. Mean $\delta^{13}\text{C}$ values were significantly higher in the fall than winter and spring and significantly lower in summer than in winter and spring.

Sulfur isotopes differed significantly by season as well (ANOVA, $p < 0.0001$) (Table 2.5). Mean values of $\delta^{34}\text{S}$ were 12.81‰ in the winter, 12.85‰ in the spring, 11.29‰ in the summer, and 12.38‰ in the fall, pooled over all sites. Tukey's test revealed that $\delta^{34}\text{S}$ values in the summer were significantly lower than both winter and spring (Table 2.6).

Total niche space (TA) for croaker was 16.50 over the artificial reef as compared to 23.45 over the reference site. Mean 2-DCD was not significantly different between sites, with a mean of 1.14 ± 0.09 for artificial reef samples and 1.04 ± 0.06 for reference site samples (ANOVA, $p > 0.05$). The analysis of 3-DCD also showed no significant differences between sites, with a mean CD of 1.90 ± 0.15 over the artificial reef and 2.07 ± 0.11 over the reference site.

Bay Anchovy

Mean values for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ were -21.52‰, 13.22‰, and 13.60‰ over the artificial reef, and -21.17‰, 13.43‰, and 13.97‰ over the reference site, respectively (Figure

Table 2.5: Results from the analysis of variance comparing Atlantic croaker stable isotope values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ to site and season. Asterisk indicates a significant result at $p = 0.05$.

		df	F	MS	p-value
$\delta^{13}\text{C}$	Site	1	1.63	1.41	0.20
	Season	3	12.71	10.98	< 0.0001 *
	Site x season	3	0.90	0.77	0.44
$\delta^{15}\text{N}$	Site	1	43.0	228.71	< 0.0001 *
	Season	3	5.05	3.37	0.0021 *
	Site x season	3	4.74	3.16	0.0032 *
$\delta^{34}\text{S}$	Site	1	3.21	11.63	0.075
	Season	3	10.24	37.12	< 0.0001 *
	Site x season	3	0.57	2.06	0.63

Table 2.6: Mean stable isotope values for Atlantic croaker between sites (pooled over season) and between seasons (pooled over sites). Tukey HSD post-ANOVA groupings are included to indicate significant differences between sites and seasons.

	$\delta^{13}\text{C}$	Tukey grouping	$\delta^{15}\text{N}$	Tukey grouping	$\delta^{34}\text{S}$	Tukey grouping
Artificial Reef	-18.31‰	A	13.34‰	A	12.40‰	A
Mud-bottom	-18.69‰	A	12.72‰	B	12.33‰	A
Winter	-18.90‰	A	13.09‰	AB	12.81‰	B
Spring	-18.62‰	A	13.16‰	A	12.85‰	B
Summer	-18.09‰	B	12.85‰	B	11.29‰	A
Fall	-18.96‰	B	12.70‰	AB	12.38‰	AB

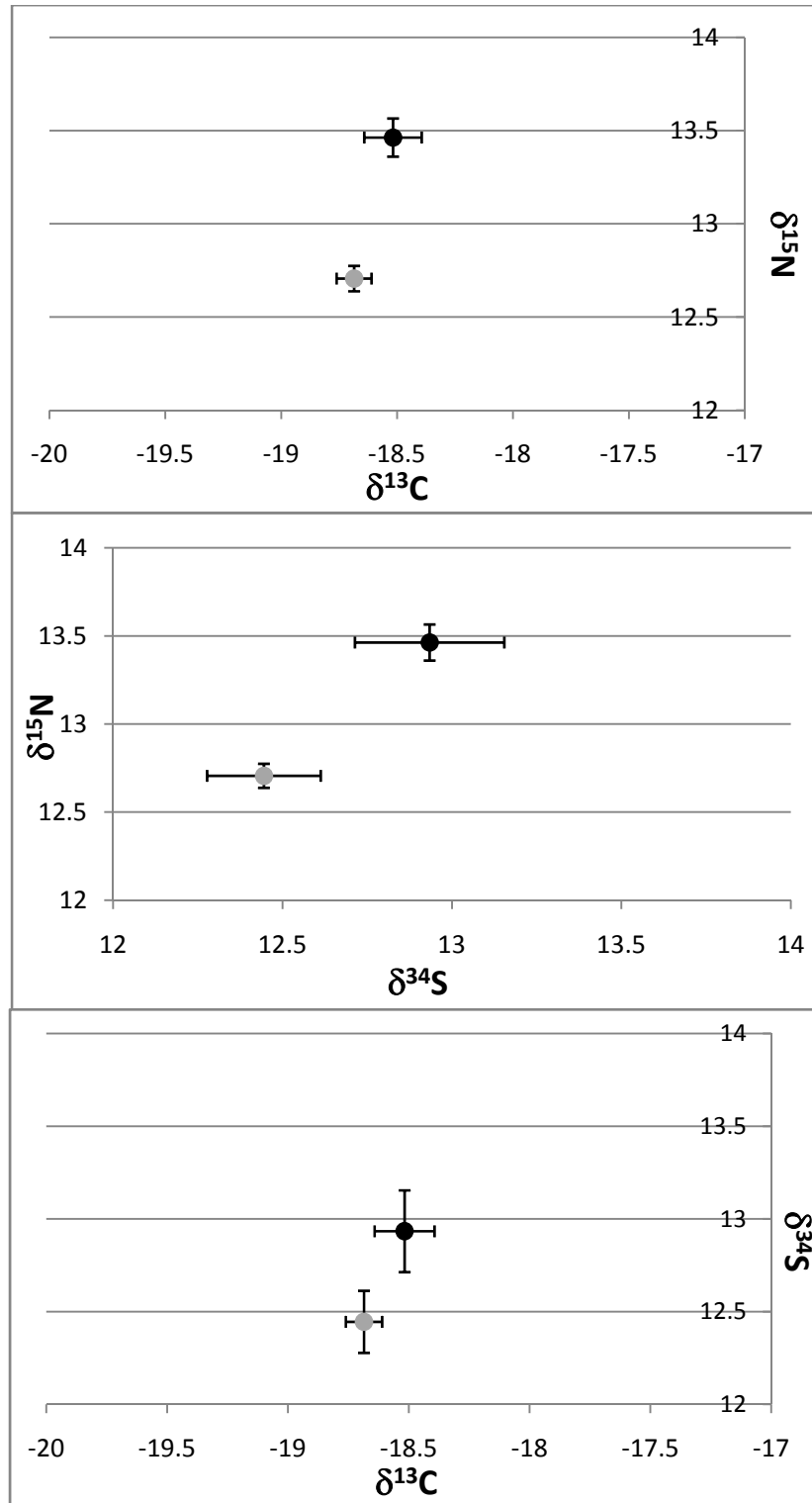


Figure 2.7: Mean stable isotope values for carbon ($\delta^{13}\text{C}$), nitrogen ($\delta^{15}\text{N}$), and ($\delta^{34}\text{S}$) for Atlantic croaker over each habitat. Dark symbols represent artificial reef samples and light symbols represent reference site samples. Standard error bars are shown.

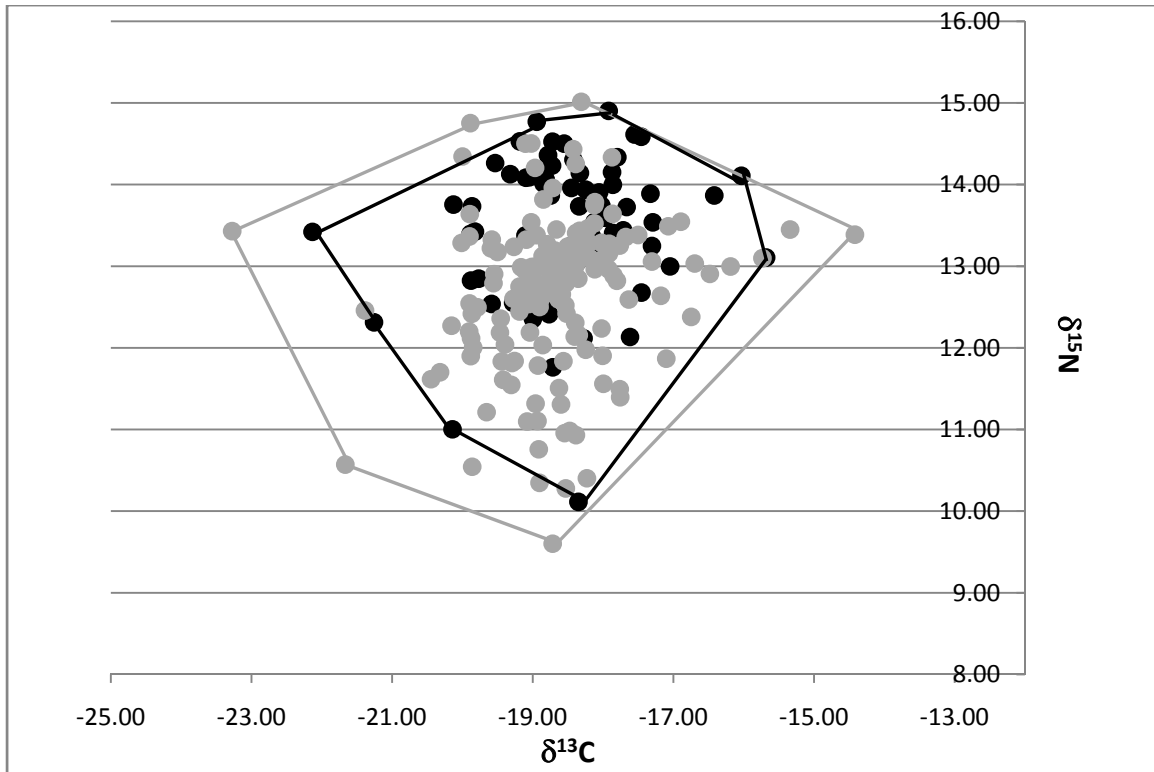


Figure 2.8: Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$), stable isotope values for all Atlantic croaker collected. Dark symbols represent artificial reef samples and light symbols represent reference site samples. Outlines represent total area (TA) of $\delta^{13}\text{C} - \delta^{15}\text{N}$ biplot.

2.4). Results of the ANOVA indicate that values of $\delta^{34}\text{S}$ are significantly different between sites ($p < 0.05$), while values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ showed no significant differences between sites ($p > 0.05$) (Table 2.7). Values of $\delta^{13}\text{C}$ ranged from -28.43‰ to -18.17‰ over the reef and from -24.05‰ to -19.21‰ over the reference site. Values of $\delta^{15}\text{N}$ ranged from 11.92‰ to 14.56‰ over the reef and from 12.51‰ to 15.17‰ over the reference site.

No seasonal differences existed for values of nitrogen isotopes (ANOVA, $p > 0.05$) (Table 2.7). Mean values for $\delta^{15}\text{N}$ were 13.28‰ in winter, 13.43‰ in spring, 13.49‰ in summer, and 13.82‰ in fall, pooled over all sites (Table 2.8).

There was a seasonal difference for carbon isotopes, pooled over all sites (ANOVA, $p < 0.05$). Mean values of $\delta^{13}\text{C}$ were -22.06‰ in winter, -21.46‰ in spring, -19.38‰ in summer, and -20.32‰ in fall (Table 2.8). Tukey's test indicated that summer samples were significantly higher than both winter and spring samples.

Mean values of sulfur isotopes were 13.65‰ in winter, 13.72‰ in spring, 14.59‰ in summer and 13.98‰ in fall (Table 2.8). Results of the ANOVA indicate that there were no differences in $\delta^{34}\text{S}$ values between seasons ($p > 0.05$).

Total niche space (TA) for bay anchovy over the artificial reef was 12.80 as compared to 7.07 over the reference site. Mean 2-DCD was 1.32 ± 0.24 for artificial reef samples and 1.07 ± 0.10 for reference site samples. Mean 3-DCD was 1.62 ± 0.23 for artificial reef samples and 1.32 ± 0.11 for reference site samples. Results of the ANOVA revealed that there were no significant differences in 2-DCD or in 3-DCD between sites ($p > 0.05$).

Benthic Invertebrates

Benthic sampling was only conducted in summer of 2007, and therefore these results are qualitative in nature, and no seasonal comparisons can be made. A total of two oyster drills were

Table 2.7: Results from the analysis of variance comparing bay anchovy stable isotope values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ to site and season. Asterisk indicates a significant result at $p = 0.05$.

		df	F	MS	p-value
$\delta^{13}\text{C}$	Site	1	1.31	2.42	0.26
	Season	3	5.99	11.11	0.001 *
	Site x season	3	3.16	5.86	0.0295 *
$\delta^{15}\text{N}$	Site	1	3.10	0.88	0.08
	Season	3	0.56	0.16	0.64
	Site x season	3	0.0085	1.19	0.0085 *
$\delta^{34}\text{S}$	Site	1	4.01	2.80	0.0488 *
	Season	3	1.86	1.30	0.14
	Site x season	3	0.26	0.18	0.85

Table 2.8: Mean stable isotope values for bay anchovy between sites (pooled over season) and between seasons (pooled over sites). Tukey HSD post-ANOVA groupings are included to indicate significant differences between sites and seasons.

	$\delta^{13}\text{C}$	Tukey grouping	$\delta^{15}\text{N}$	Tukey grouping	$\delta^{34}\text{S}$	Tukey grouping
Artificial Reef	-21.52‰	A	13.22‰	A	13.60‰	A
Mud-bottom	-21.17‰	A	13.43‰	A	13.97‰	A
Winter	-22.06‰	A	13.28‰	A	13.65‰	A
Spring	-21.46‰	A	13.43‰	A	13.72‰	A
Summer	-19.38‰	B	13.49‰	A	14.59‰	A
Fall	-20.32‰	AB	13.82‰	A	13.98‰	A

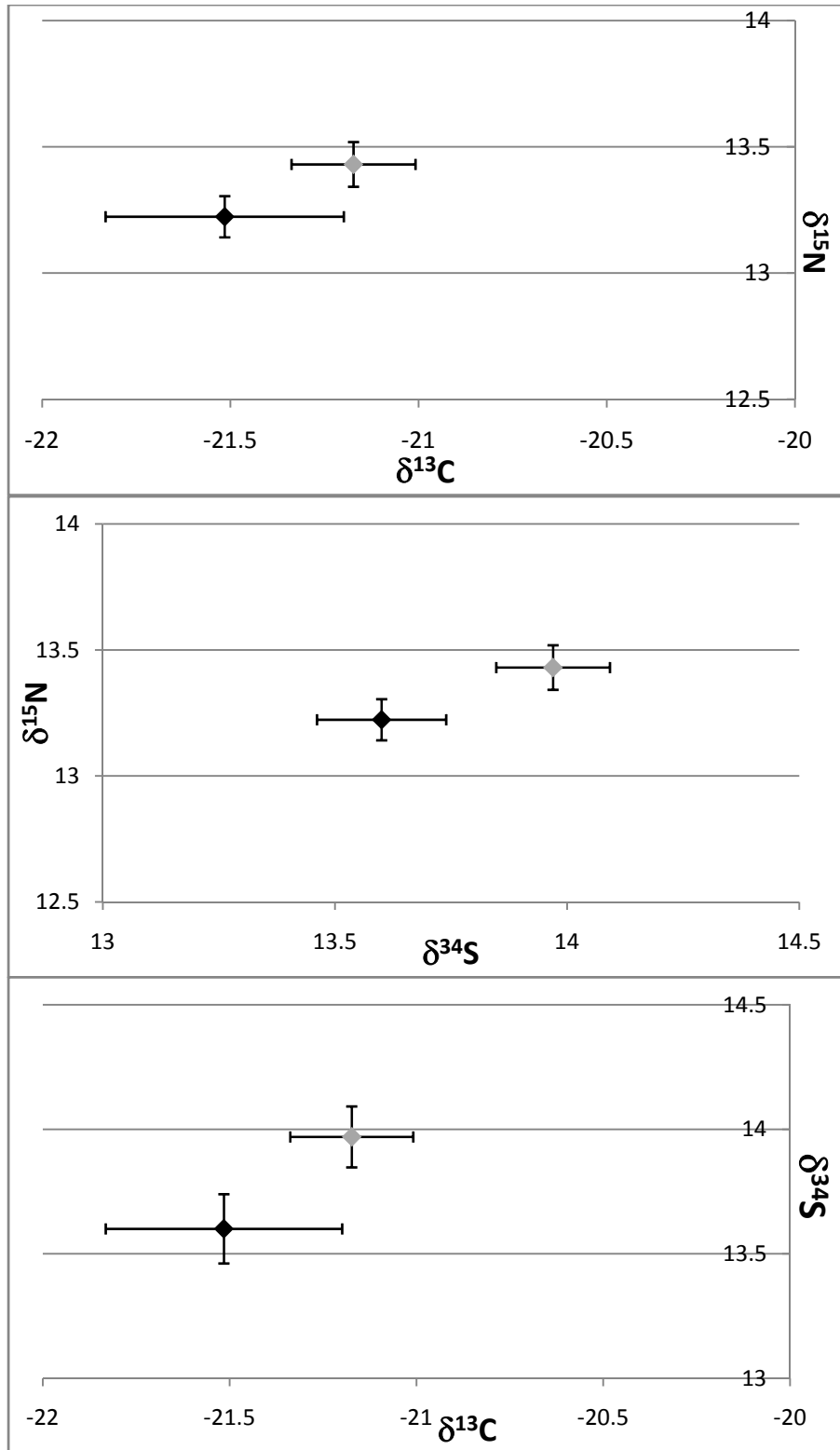


Figure 2.9: Mean table isotope values for carbon ($\delta^{13}\text{C}$), nitrogen ($\delta^{15}\text{N}$), and ($\delta^{34}\text{S}$) for bay anchovy over each habitat. Dark symbols represent artificial reef samples and light symbols represent reference site samples. Standard error bars are shown.

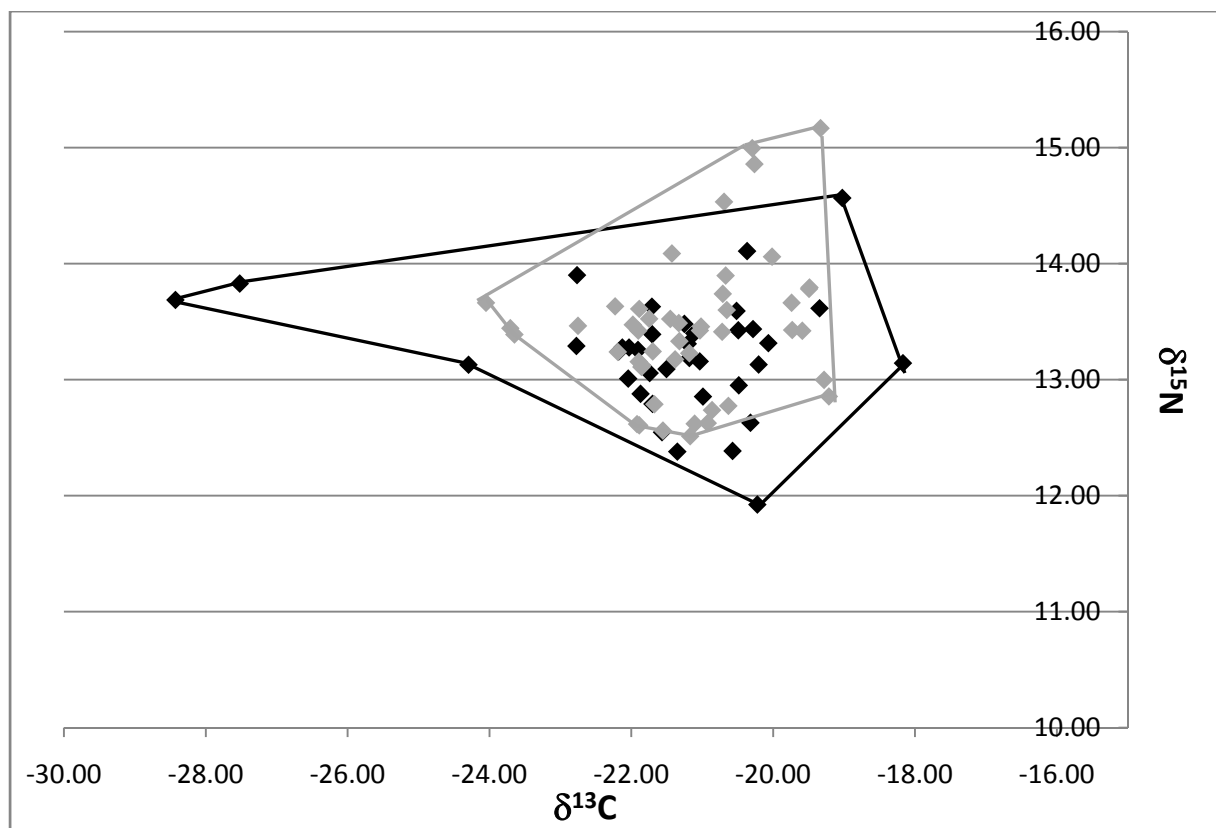


Figure 2.10: Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$), stable isotope values for all bay anchovy collected. Dark symbols represent artificial reef samples and light symbols represent reference site samples. Outlines represent total area (TA) of $\delta^{13}\text{C} - \delta^{15}\text{N}$ biplot.

collected over the artificial reef, and fourteen over the mud bottom site. Mean values of carbon, nitrogen, and sulfur isotopes were 12.17‰, -18.00‰, and 15.55‰ over the artificial reef, and 12.25‰, -17.75‰, and 14.65‰ over the reference site, respectively (Figure 2.4). There were no significant differences in mean values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, or $\delta^{34}\text{S}$ for oyster drills between sites. Five striped hermit crabs were collected over the artificial reef, and three were collected over the reference site. Mean values of carbon, nitrogen, and sulfur isotopes were 11.51‰, -19.34‰, and 13.76‰ over the reef, and 11.89‰, -19.37‰, and 15.08‰ over the reference site, respectively (Figure 2.4). There were no differences in mean values of carbon, nitrogen, and sulfur isotopes for oyster drills between sites. Mud crabs were collected only over the artificial reef site, and therefore comparisons between sites cannot be made. The mean values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ for mud crabs were 10.48‰, -19.41‰, and 15.11‰ respectively.

Overall Estuarine Community

Niche breadth analysis of the overall community structure revealed that the total niche area over the artificial reef site was 5.15, as compared to 3.25 over the reference site. Mean CD for artificial reef samples was 1.52 ± 0.16 as compared to 1.30 ± 0.24 over the reference site. Results of the ANOVA indicate that there was no significant difference in centroid distance between sites ($p > 0.05$).

Production Estimates

Results of the index of reef exclusivity (IRE) indicate that approximately 27% (IRE = 0.27) of spotted seatrout diets were attributable to the artificial reef. Estimates of production (P) for spotted seatrout were 247 g yr^{-1} over the artificial reef as compared to 123 g yr^{-1} over the reference site (Table 2.9). This relates to a rate of production attributable to the artificial reef (AP) of $67 \text{ g reef}^{-1} \text{ yr}^{-1}$. Atlantic croaker had an IRE of 0.50 indicating that 50% of diets are

attributable to the reef. The estimate of P for croaker over the artificial reef was 50 g yr⁻¹ as compared to 42 g yr⁻¹ over the reference site, which relates to an AP of 25 g reef⁻¹ yr⁻¹ (Table 2.9).

Table 2.9: Estimated relative production attributable (AP) to the artificial reef based on the index of reef exclusivity (IRE) and annual biomass production on the artificial reef site in g yr⁻¹ (P). AP values are in annual biomass production in g reef⁻¹ yr⁻¹.

Species	Prey Items exclusive to reef	IRE	P Reef (g yr ⁻¹)	P Mud-bottom (g yr ⁻¹)	AP (g reef ⁻¹ yr ⁻¹)
Spotted Seatrout	Gulf menhaden, Sparidae, hermit crabs, bryozoans,	0.27	247	123	67
Atlantic Croaker	Mud crabs, euphausiids, penaeid shrimp	0.50	50	42	25

DISCUSSION

While the artificial reef examined in this study shares many characteristics with natural high-relief oyster reefs, it is important to note that many ecological functions will differ from that of a natural oyster reef. Oyster growth gives natural oyster reefs a more complex structure that is likely absent in a relatively young limestone cobble artificial reef. Natural oyster reefs also grow in size as oysters grow and as new oysters are recruited, resulting in much larger reefs than those constructed for habitat enhancement projects. As such, it is likely that community complexity over the artificial reef examined in this study is less than that of natural oyster reefs. Coen et al. (1999) found approximately 80 species of fishes associated with natural oyster reefs, while the

current study identified 43 fish species of finfish associated with the artificial reef. The lower number of fish species found at the Barataria Bay reef may be due to the type of reef, the size of the reef, the age of the reef, or the location. Sampling large natural reefs in multiple locations was beyond the scope of this project and no conclusive results can be drawn about comparisons to natural reefs in this estuary. It is possible that with the lack of high-relief oyster reefs in Barataria Bay, this artificial reef may be acting as an ecological surrogate for oyster reefs as fish habitat. It may be possible to use the number of reef-dependent residents that are associated with the artificial reef to determine if the reef is, in fact, acting as a surrogate. Coen et al. (1999) described numerous species that can be considered “residents” of oyster reefs, and would therefore be found in higher abundance at reef locations than non-reef. However, these are mostly small benthic fishes, and due to the limitations of my sampling gear, could not be collected in this study. While I was able to collect a large number of mud crabs (Xanthidae), which are known to be reef-dependent and found in high abundance on oyster reefs (Minello, 1999; Luckenbach et al. 2005), future sampling should include additional gear types that facilitate the collection of small cryptic, benthic fish species. The presence of benthic, reef-associated species in high abundances would be a better indicator of overall reef function. However, due to the consistently high catches of finfish over the artificial reef, I believe that in the absence of natural oyster reef habitat, this type of artificial reef can act as an effective alternate fish habitat.

Spotted seatrout

Results of the PRIMER analysis and indices of relative (IRI) and caloric importance (ICI) were contradictory, which is likely due to the type of data used for each analysis. PRIMER relies solely on the percent weight of prey items, while the IRI takes frequency of occurrence and

the numbers of each prey item into account as well. For this reason, PRIMER analysis indicated that penaeid shrimp, which are generally more massive, were the more important prey item over the artificial reef, while results of the IRI indicated that anchovies were the most important prey item. Results of the ICI agree with the IRI when assigning significance to prey items. In addition, the ICI includes information on caloric density of each prey item, and therefore is a better indication of nutritional value of each prey item. Anchovies are far richer in calories than penaeid shrimp, which require more energy to digest. When this information is considered, the importance of teleost prey to spotted seatrout at the artificial reef site is evident.

Spotted seatrout are found ubiquitously throughout Louisiana estuaries and the northern Gulf of Mexico and are not known to be reef-dependent species. In this study, nearly twice as many spotted seatrout were collected over the artificial reef site, though this difference was not significant (see chapter 1). The higher number of spotted seatrout over the reef is similar to studies by Harding and Mann on bluefish (2001a) and striped bass (2003) in the Chesapeake Bay. These species occupy similar niches in their respective environments and are likely to utilize habitats in a similar manner. Because spotted seatrout are known to feed opportunistically and have relatively low site fidelity, the most important aspect of a habitat for such species may be the availability of prey. Numerous studies have recognized the ability of fishes to choose habitat based upon prey availability (Burke 1995, Eklov 1997), and the ability of oyster reefs to aggregate prey (Breitburg *et al* 1995, Coen *et al* 1999, Harding and Mann 2001a, 2001b; Stunz and Minello, 2001; Harding and Mann, 2003). Harding and Mann (2001a, 2003) concluded that the increased abundance of bluefish and striped bass over oyster reefs was likely due to the increased availability of teleost prey. The authors regularly observed approximately thirty fish species in the vicinity of reef structure, which may make oyster reefs an attractive foraging

ground for piscivorous fishes such as bluefish, striped bass, and by inference spotted seatrout on the reef site I studied. In addition to being more numerous, spotted seatrout found over the reef site were also significantly larger than those found over the reference site (see chapter 1). This is also consistent with a study of transient fish species on oyster reefs in the Chesapeake Bay (Harding and Mann 2001b), as well as previously mentioned studies of bluefish and striped bass. The authors found that as habitat complexity increased, the size of several transient fish species increased.

The higher number and increased size of spotted seatrout over the artificial reef is likely an effect of the site-specific prey availability influenced by the presence of reef structure. This is further supported by the higher abundance of teleost prey in stomachs of spotted seatrout at the reef (41% anchovies), and more fish with recently consumed prey (76%) than the mud bottom site. While there were no overall differences in spotted seatrout diet between sites, the difference in abundance of certain prey items may be attributed to the presence of the artificial reef structure. An alternative explanation is that the artificial reef acts to aggregate prey in a smaller area, which may increase the encounter rate of spotted seatrout with preferred prey (anchovies) and lead to an increased rate of capture (Fuiman and Margurran, 1994; Rooker et al., 1998).

Overall mean stable isotope values showed no significant differences between sites, indicating that spotted seatrout were feeding on similar prey items at both sites. This is consistent with the dietary analysis, which also showed no significant difference in diets of spotted seatrout between sites. However, further analysis examining the variability of stable isotope data suggests differences in the dietary breadth between sites. Layman et al (2007a) demonstrated how variability in stable isotope data can be used to further evaluate fish diets in different environments. Layman et al (2007a) argued that greater variability in stable isotope

values and greater range in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ are an indication of greater dietary breadth. A wider range of $\delta^{13}\text{C}$ indicates a greater number of primary producers, and may also be an indication of a healthier environment, while a wider range of $\delta^{15}\text{N}$ indicates feeding over a wider range of trophic levels (Layman et al 2007a, 2007b). Analysis of stable isotope variability indicates that the artificial reef site provided greater dietary breadth than the mud-bottom reference site, even though difference in gut contents and mean stable isotope values appeared to be minimal. The limestone cobble that composes the artificial reef may act as ideal substrate for the growth of benthic microalgae, providing a source of primary production that is not available on the soft-bottom reference site. There also appears to be a greater trophic diversity in the diets, indicating there may be a greater diversity of prey items available to spotted seatrout over the artificial reef site. Additionally, the dietary breadth of bay anchovy, one of the key prey species for spotted seatrout, was also wider over the reef. This indicates there may be a wider variety of prey items available to lower trophic levels as well, which will be expressed in higher trophic levels as these species are consumed. Taken together, the evidence indicates that the artificial reef has a greater variety of prey items available to spotted seatrout than does the reference site.

Atlantic croaker

Atlantic croaker are known to be generalist feeders that search for prey in the substrate and buried in soft sediments (Chao and Musick, 1977; Overstreet and Heard, 1978; Petrik et al., 1999). As such, their diet can be greatly affected by the type of habitat in which they are found. This is clearly illustrated in the diet analysis conducted here, which shows significantly different diets between two habitat types that are relatively close together. Both PRIMER analysis and the dietary indices used in this study showed significant differences in diets between sites. Previous studies have illustrated differences in diets between inshore and offshore environments

(Overstreet and Heard, 1978), over salinity gradients (Nemerson and Able, 2004), and seasonally (Matlock and Garcia, 1983; Powers, et al., 2005). These studies all illustrate the generalist feeding behavior of Atlantic croaker, and their ability to opportunistically feed in several habitat types. However, my study demonstrated differences in diets on a much smaller spatial scale. Most diet studies of Atlantic croaker indicate that annelid worms and bivalves compose the majority of prey, with lesser contributions of crustaceans and fishes. The current study showed a clear dominance of crustacean prey over the artificial reef site, with results from the reference site more closely resembling previous studies of diets over soft bottom sediments. There may be several reasons for these results. The structure of the artificial reef provides refugia for many benthic invertebrates that are common prey for Atlantic croaker, including polychaete worms, bivalves and benthic fishes. The high abundance of mud crabs over the reef may make them easier prey for the Atlantic croaker, as compared to polychaetes and benthic fishes.

The stable isotope analysis supports the diet analysis and showed a significant difference between sites. Mean $\delta^{15}\text{N}$ values indicated that croaker were feeding at a higher trophic level over the artificial reef than at the reference site. Mud crabs, which made up the majority of croaker diets over the reef, are more enriched in $\delta^{15}\text{N}$, and therefore exist at a higher trophic level than the bivalves making up the majority of diets over the reference site. Additionally, a large amount of detritus, most of which appeared to be plant material, was found in the stomachs of croaker over the reference site, which was likely ingested incidentally along with other prey items. Plant material naturally has a lower $\delta^{15}\text{N}$ value than other prey items, and may lower the overall mean $\delta^{15}\text{N}$ value for fish collected over the reference site. Though the diets were different between sites, there were no differences in the centroid distance (2-D or 3-D), $\delta^{15}\text{N}$ range, or $\delta^{13}\text{C}$ range between sites, which likely is due to the generalist and opportunistic feeding

behavior of Atlantic croaker. This study indicated that different prey items are available to croaker at each study site. Croaker can consume a wide variety of prey items and as such have diverse diets over both sites, exhibiting no site-specific difference in the overall trophic diversity, as evident by similar values of CD over both sites. The total area of the $\delta^{15}\text{N}$ - $\delta^{13}\text{C}$ biplot was larger over the reference site, indicating greater dietary breadth than the reef, a trend opposite from that seen with spotted seatrout. Atlantic croaker are found mostly on soft-bottom sediments, and have specific adaptations to feed in such an environment. These adaptations, including chin barbells and an inferior mouth, facilitate the location and capture of infauna (Overstreet and Heard, 1977), and may be less efficient for finding prey over the rocky structure of the artificial reef. Thus the diets of Atlantic croaker may be more varied over the mud-bottom reference site, where more prey items are susceptible to capture and consumption.

While there is evidence of site-specific prey availability for a demersal fish species, the opportunistic nature and generalist feeding strategy of Atlantic croaker may lead them to be less affected by the addition of structure to the environment than other species. For a species like spotted seatrout, the presence of the artificial reef increased abundance at the site and provided additional sources of prey. Atlantic croaker were found in similar abundance at both sites, with different, but equally diverse diets, indicating that croaker may be able to effectively utilize different habitat types, regardless of the substrate or type of prey available.

Bay Anchovy

Bay anchovy are found ubiquitously in the estuary and in high numbers, and make up a majority of the biomass in most estuaries in the northern Gulf of Mexico (Rozas and Zimmerman, 2000; Jones et al., 2002). They are schooling zooplanktivores, and as such are not known to be habitat specific. Of the three species studied here they were hypothesized to exhibit

the least differentiation between sites. Though the mean values of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ were not significantly different between sites, the TA for the $\delta^{15}\text{N} - \delta^{13}\text{C}$ biplot over the reef was larger than that over the reference site. There were significantly higher values of $\delta^{34}\text{S}$ over the reference site, which has been shown to be an indicator of Mississippi River influence (Fry 2002; Wissel and Fry, 2005). Though the sites are relatively close together (approximately 1km) (see Figure 1), the reference site is more open to the Gulf of Mexico and more likely to be influenced by Mississippi River water that is transported by tidal currents from offshore. No hydrologic sampling was conducted during this study, and salinities were not significantly different between sites, so it is difficult to determine conclusively if there was a Mississippi River influence at the sampling locations. Furthermore, there was no significant difference in $\delta^{34}\text{S}$ between sites for any of the other species examined. The majority of anchovy diets consist of copepods, which are found ubiquitously throughout the estuary and on the shallow continental shelf and are subjected to passive transport by tidal currents. The difference in $\delta^{34}\text{S}$ between sites may be a result of anchovies eating zooplankton that were previously feeding offshore.

Production Estimates

The estimates of production (P) based on Edgar and Shaw (1995) indicate that production of spotted seatrout biomass over the artificial reef is approximately twice that of the reference site. This difference is likely due to the greater number of spotted seatrout collected over the reef site and the larger size of these fish (see Chapter 1), and is likely influenced by site-specific prey availability. Production of Atlantic croaker is approximately equal between the two sites, despite the large percentage of diet attributed to the reef as indicated by the index of reef exclusivity (IRE). This further emphasizes the generalist nature of Atlantic croaker, and their ability to feed

over a wide range of habitat types and prey availability. As a result, there is no discernable site-specific difference in biomass production of Atlantic croaker based on the methods used here.

Caution should be exercised when extrapolating these data, as this method is used only to formulate a simple comparison of biomass production. It is important to consider that these methods to estimate production do not take into account parameters such as growth and mortality. Mortality, particularly fishing mortality, is not considered in this analysis, as it was beyond the scope of this project. The artificial reef was not designated as a no-take reserve and is subjected to fishing pressure. The reef is also located in an area subjected to inshore trawling, and spotted seatrout is heavily fished as part of the recreational fishery in south Louisiana. As such, though production is higher over the artificial reef, it is also likely that fishing pressure is high, resulting in higher mortality.

This study also provided a unique opportunity to reevaluate the metrics suggested by Layman et al. (2007a) to analyze the variability of stable isotope values. Layman et al. (2007a) used these metrics primarily as a tool to evaluate habitat alterations and the adverse effects they had on feeding ecology of top carnivores such as grey snapper (*Lutjanus griseus*). The metrics worked well to describe changes in food availability in an environment that transitioned from a more natural, complex habitat to a fragmented or altered habitat. The habitats used in this study can act as a proxy for a “complex” habitat, the structured artificial reef site, and “fragmented”, or the simpler, unstructured mud-bottom site. Layman et al. (2007b) concluded that a fragmented habitat will provide diets that have lower trophic diversity than a healthy environment for a top carnivore. The stable isotope results for spotted seatrout in my study, a piscivorous fish that occupies a similar trophic niche as the grey snapper, were consistent with those of Layman et al. (2007b).

When using these techniques for a species occupying a different trophic niche, the results are not consistent. A demersal species, such as Atlantic croaker, has been shown in my study to opportunistically change diets to adapt to site-specific prey availability, while dietary breadth remained the same. If the metrics established by Layman et al. (2007a) were solely used to describe croaker diets at the two different sites, one conclusion could be that similar diets were consumed at both sites. However, gut-content analysis indicates significant differences in diets. Using this combination of techniques, I conclude that both habitats provide high-quality prey that differs in composition. As such, caution must be exercised when using these metrics to describe trophic diversity between habitats. The difference in results for spotted seatrout and Atlantic croaker may be due to the ability of croaker to opportunistically switch diets over different habitats, and therefore this technique may be more effective when combined with diet analysis. As such, it is important to consider life history and feeding strategies of the species used to examine differences in habitats, as fishes with different foraging strategies will use habitats in very different ways. The results of this study and the studies by Layman et al. (2007 a, b) show that these metrics may be used effectively to describe differences in diets, provided that they are interpreted in the context of species-specific foraging strategies.

LITERATURE CITED

- Araujo, M.S., D.I. Bolnick, G. Machado, A.A. Giaretta, and S.F. dos Reis. 2007. Using $\delta^{13}\text{C}$ stable isotopes to quantify individual-level diet variation. *Oecologia* **152**(4): 643 – 654.
- Baltz, D. M., C. F. Rakocinski, et al. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. *Environmental Biology of Fish* **36**: 109 - 126.
- Bearhop, S., C.E. Adams, S. Waldrons, R.A. Fuller, and H. MacLeod. 2004. Determining trophic niche width: a novel approach using stable isotope analysis. *Journal of Animal Ecology* **74**(5): 1007 – 1012.

- Bohnsack, J. A., A.-M. Ecklund, A.M. Szmant. 1997. Artificial reef research: Is there more than the attraction-production issue? *Fisheries* **22**(4): 14-16.
- Breitburg, D. L., M. A. Palmer, and T. Loher. 1995. Larval distributions and the spatial patterns of settlement of an oyster reef fish: response to flow and structure. *Marine Ecology Progress Series* **125**: 45-60.
- Breitburg, D. 1999. Are three dimensional structure and healthy oyster populations the keys to an ecologically interesting and important fish community. In M.W. Luckenbach, R. Mann and J.A. Wesson, editors. *Oyster reef habitat restoration. A synopsis and synthesis of approaches*. Virginia Institute of Marine Science Press, Gloucester Point, Virginia. pp 239 – 250.
- Breitburg, D. L., L. D. Coen, M.W. Luckenbach, R. Mann, M. Posey, and J. Wesson. 2000. Oyster reef restoration: convergence of harvest and conservation strategy. *Journal of Shellfish Research* **19**(1): 371 – 377.
- Breitburg, D. L., L. D. Coen, M.W. Luckenbach, R. Mann, M. Posey, and J.Wesson. 2000. Oyster reef restoration: convergence of harvest and conservation strategy. *Journal of Shellfish Research* **19**(1): 371 - 377.
- Bucci, J.P., S. Rebach, D. DeMaster, and W.J. Showers. 2007. A comparison of blue crab and bivalve $\delta^{15}\text{N}$ tissue enrichment in two North Carolina estuaries. *Environmental Pollution* **145**: 299 – 308.
- Burke, J. S. 1995. Role of feeding and prey distribution of summer and southern flounder in selection of estuarine nursery habitats. *Journal of Fish Biology* **47**: 355-366.
- Chao, L.N., and J.A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York River estuary, Virginia. *Fishery Bulletin* **75**(4): 657 – 700.
- Cocheret de la Moriniere, E., B. J. A. Pollux, I. Nagelkerken, M. A. Hemminga, A. H. L. Huiskes, and G. Velde. 2003. Ontogenetic dietary changes of coral reef fishes in the mangrove-seagrass-reef continuum: stable isotopes and gut-content analysis. *Marine Ecology Progress Series* **246**: 279-289.
- Coen, L. D., M. W. Luckenbach, D.L. Breitburg. 1999. The role of oyster reefs as Essential Fish Habitat: a review of current knowledge and some new perspectives. *AFS Symposium* **22**: 438 - 454.
- Coen, L. D. and M. W. Luckenbach. 2000. Developing success criteria and goals for evaluating oyster reef restoration: Ecological function or resource exploitation? *Ecological Engineering* **15**: 323 - 343.

- Coen, L. D. and R. E. Grizzle. 2007. The importance of habitat created by molluscan shellfish to managed species along the Atlantic coast of the United States. ASMFC Management Series #8. 109pp.
- Connell, S. D. and J. P. Jones. 1991. The influence of habitat complexity on postrecruitment processes in a temperate reef fish population. *Journal of Experimental Marine Biology and Ecology*. **151**: 271-294.
- Deegan, L.A., B.J. Peterson, and R. Portier. 1990. Stable isotopes and cellulose activity as evidence for detritus as a food source for juvenile Gulf menhaden. *Estuaries*. **13**: 14-19.
- Eklov, P. 1997. Effects of habitat complexity and prey abundance on the spatial and temporal distributions of perch (*Perca fluviatilis*) and pike (*Esox lucius*). *Canadian Journal of Fisheries and Aquatic Sciences* 54: 1520-1531.
- Fry, B. 2002. Stable isotopic indicators of habitat use by Mississippi River fish. *Journal of the North American Benthological Society*. **21**: 676-685.
- Fry, B., P. L. Mumford, F. Tam, D. D. Fox, G. L. Warren, K. E. Havens, and A. D. Steinman. 1999. Trophic position and individual feeding histories of fish from Lake Okeechobee, Florida. *Canadian Journal of Fisheries and Aquatic Sciences* 56: 590-600.
- Fuiman, L.A. and A.E. Margurran. 1994. Development of predator defenses in fishes. *Reviews in Biology and Fisheries* **4**: 103 – 141.
- Grey, J., S.J. Thackeray, R.I. Jones and A. Shine. 2002. Ferox Trout (*Salmo trutta*) as ‘Russian dolls’: complementary gut content and stable isotope analyses of the Loch Ness foodweb. *Freshwater Biology*. **47**: 1235-1243.
- Guiguer, K.R.R.A., J.D. Reist, M. Power and J.A. Babaluk. 2002. Using stable isotopes to confirm the trophic ecology of Arctic charr morphotypes from Lake Hazen, Nunavut, Canada. *Journal of Fish Biology*. **60**: 348-362.
- Hartman, K.J., J. Howell, and J.A. Sweka. 2004. Diet and daily ration of bay anchovy in the Hudson River, New York. *Transactions of the American Fisheries Society* **133**: 762 – 771.
- Harding, J. M. and R. Mann. 1999. Fish species richness in relation to restored oyster reefs, Piankatank River, Virginia. *Bulletin of Marine Science* **61**: 289 – 300.
- Harding, J. M. and R. Mann. 2001a. Oyster reefs as fish habitat: opportunistic use of the restored reefs by transient fishes. *Journal of Shellfish Research* **20**(3): 951 - 959.
- Harding, J. M. and R. Mann. 2001b. Diet and habitat use by bluefish, *Pomatomus saltatrix*, in a Chesapeake Bay estuary. *Environmental Biology of Fish* **60**: 401 - 409.

- Harding, J. M. and R. Mann. 2003. Influence of habitat on diet and distribution of striped bass (*Morone saxatilis*) in a temperate estuary. *Bulletin of Marine Science* **72**(3): 841 – 845.
- Haywood, E.L., and T.M. Soniat. 1992. The use of cement stabilized gypsum as cultch for the American oyster, *Crassostrea virginica*, and its effectiveness as compared to clamshell and limestone. *Journal of Shellfish Research*. **11**(1): 197.
- Herzka, S. Z. and G. J. Holt. 2000. Changes in isotopic composition of red drum (*Sciaenops ocellatus*) larvae in response to dietary shifts: potential applications to settlement studies. *Canadian Journal of Fisheries and Aquatic Sciences*. **57**: 137-147.
- Hyslop, E. J. 1980. Stomach contents analysis – a review of methods and their application. *Journal of Fish Biology* 17: 411 – 429.
- Jones, R. F., D. M. Baltz, and R.L. Allen. 2002. Patterns of resource use by fishes and macroinvertebrates in Barataria Bay, Louisiana. *Marine Ecology Progress Series* **237**: 271 - 289.
- Jung, S., and E.D. Houde. 2004. Production of bay anchovy *Anchoa mitchilli* in Chesapeake Bay: application of size-based theory. *Marine Ecology Progress Series* **281**: 217 – 232.
- Kneib, R.T. 1987. Predation risk and the use of intertidal habitats by young fishes and shrimp. *Ecology* **68**: 379 – 386.
- Lassuy, D.R. 1983. Species profiles: life histories and environmental requirements (Gulf of Mexico) – spotted seatrout. U.S. Fish and Wildlife Service, Division of Biological Services. FWS/OBS-82/11.4. U.S. Army Corps of engineers, TR EL-82-4. 14 pp.
- Layman, C.A., D.A. Arrington, C.G. Montana, and D.M. Post. 2007a. Can stable isotope ratios provide for community-wide measures of trophic structure? *Ecology* **88**(1): 42 – 48.
- Layman, C.A., J.P. Quattrochi, C.M. Peyer, and J.E. Allgeier. 2007b. Niche width collapse in a resilient top predator following ecosystem fragmentation. *Ecology Letters* **10**: 937 – 944.
- Luckenbach, M. W., L. D. Coen, P.G. Ross Jr., and J.A. Stephen. 2005. Oyster reef habitat restoration: Relationships between oyster abundance and community development based on two studies in Virginia and South Carolina. *Journal of Coastal Research* **SI-40**: 64 – 78.
- Lugendo, B.R., I. Nagerlkerken, G. van der Velde, and Y.D. Mgaya. 2006. The importance of mangroves, mud and sand flats, and seagrass beds as feeding areas for juvenile fishes in Chwaka Bay, Zanzibar: gut content and stable isotope analyses. *Journal of Fish Biology* **69**: 1639 – 1661.

- MacRae, P.S.D. 2006. A community approach to indentifying essential fish habitat of spotted seatrout, *Cynoscion nebulosus*, in Barataria Bay, Louisiana. Louisiana State University Dissertation, Department of Oceanography and Coastal Sciences. 161 pp.
- MATLAB version 7.0.4. 2005. Computer software, The MathWorks Inc., Natick, Massachusetts
- McCawley, J. R. 2003. Diet and prey demand of red snapper, *Lutjanus campechanus*, on Alabama artificial reefs. Masters thesis. University of South Alabama, 205 pp.
- McCawley, J. R., and J.H. Cowan, Jr. 2007. Seasonal and size specific diet and prey demand of red snapper on Alabama artificial reefs. In W.F. Patterson, J.H. Cowan Jr., G.R. Fitzhugh, and D.L. Nieland, editors. Red Snapper Ecology and Fisheries in the U.S. Gulf of Mexico. American Fisheries Symposium 60, Bethesda, Maryland. pp 77 – 104.
- Minello, T. J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of Essential Fish Habitat. AFS Symposium **22**: 43 - 75.
- Overstreet, R.M., and R.W. Heard. 1978. Food of the Atlantic croaker, *Micropogonias undulatus*, from Mississippi Sound and the Gulf of Mexico. Gulf Research Reports **6(2)**: 145 – 152.
- Peterson, B.J., R.W. Howarth and R.H. Garritt. 1985. Multiple isotopes used to trace organic matter flow in the salt-marsh estuarine food webs. Science **227**: 1361-1363.
- Peterson, B.J. and B. Fry. 1987. Stable isotopes in ecosystem studies. Annual Review of Ecology and Systematics. **18**: 293-320.
- Petrik, R., P. S. Levin, G.W. Stunz and J. Malone. 1999. Recruitment of Atlantic croaker, *Micropogonias undulatus*: Do postsettlement processes disrupt or reinforce initial patterns of settlement? Fisheries Bulletin **97**: 954 - 961.
- Polovina, J. J. 1989. Artificial reefs: Nothing more than benthic fish aggregators. California Cooperative Oceanic Fisheries Investigations Reports. **30**: 37-39.
- Rakocinski, C. F., D. M. Baltz, and J.W. Fleeger. 1992. Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. Marine Ecology Progress Series **80**: 135 - 148.
- Rooker, J.R., G.J. Holt and S.A. Holt. 1998. Vulnerability of newly settled red drum *Sciaenops ocellatus* to predatory fish: is early-life survival enhanced by seagrass meadows? Marine Biology **131** 145 – 151.
- Russell, M. 2004. Spotted seatrout (*Cynoscion nebulosus*) and pinfish (*Lagodon rhomboides*) dietary analysis according to habitat type. Masters Thesis, Louisiana State University, BatonRouge, Louisiana. 82pp.

- SAS Institute Inc., 2002. Version 9.1. Cary, North Carolina, USA.
- Stunz, G.W., and T.J. Minello. 2001. Habitat-related predation on juvenile wild-caught and hatchery-reared red drum *Sciaenops ocellatus* (Linnaeus). *Journal of Experimental Marine Biology and Ecology*. **260**: 13 – 25.
- Versar. 2008. Literature search and data synthesis of biological information for use in management decisions concerning decommissioning of offshore oil and gas structures in the Gulf of Mexico.
- Wells, R.J.D. 2007. The effects of trawling and habitat use on red snapper and the associated community. Louisiana State University Dissertation, Department of Oceanography and Coastal Sciences. 179 pp.
- Wissel, B. and B. Fry. 2005. Tracing Mississippi River influences in estuarine food webs of coastal Louisiana. *Oecologia* **144**: 659 – 672.

GENERAL SUMMARY AND CONCLUSIONS

My overall goal for this study was to determine how the presence of an artificial reef constructed of limestone cobble would affect the community structure and trophic dynamics of an estuarine fish community. To accomplish this goal, I used two different gear types to sample fish communities using the whole water column above each site. In addition to examining the community structure of the two sampling sites, I looked at how the addition of structure affected the feeding ecology of species of economic and ecological importance. This allowed me to examine the extent to which species of interest are using the reef structure.

Chapter 1 examined the overall community structure of large fishes at the two sites by comparing species richness, overall abundance, and catch-per-unit-effort. Additionally, I examined the abundance and CPUE of the most abundant species to see how the reef affected fishes on a species-specific, as well as community-wide level. I then looked specifically at species of economic and ecological interest to determine if use of the reef was influenced by any environmental factors.

Chapter 2 examined the feeding ecology of economically and ecologically important species that covered a range of trophic niches. The goal was to describe how the presence of the reef affected species with different life histories to get a better understanding of the overall feeding ecology over the sites. The results show that using different techniques to examine feeding will give a better understanding of how diet is influenced by habitat.

The findings of the artificial reef study suggest that although overall community structure of large fishes was not affected by the presence of the reef, the feeding ecology of some estuarine fish species can be positively affected by the addition of structure. My study indicates that the presence of the artificial reef has the ability to increase the dietary breadth of spotted seatrout,

and therefore may make the reef an attractive habitat for foraging. This could potentially have management implications in an effort to enhance and restore fish habitat that has been altered by anthropogenic influences. However, these results do not necessarily hold true for all estuarine species. For demersal species, such as Atlantic croaker, the presence of the reef provides a different group of available prey. Reef structure will cause diets to shift to include more reef-associated prey taxa, but it is not clear whether reef habitat will improve feeding ecology.

VITA

Kirsten Ann Simonsen was born in November 1979, in Washington, D.C. She grew up in West Islip, New York, and graduated from West Islip Senior High School in 1997. She attended Roger Williams University in Bristol, Rhode Island and graduated *cum laude* with a Bachelor of Science in marine biology in 2001. During her tenure at Roger Williams University, Kirsten participated in many research projects, both home and abroad. In fall of 1999, she attended the Sea Education Association Sea Semester program in Woods Hole, Massachusetts. She also participated in two short course study abroad programs in the Azores and Jamaica, where she gained valuable hands-on field experience. After graduation, Kirsten worked for the Chesapeake Biological Laboratory in Solomons, Maryland as a research assistant in the Environmental Chemistry Department. She then moved back to New York to work for the River Project, a non-profit marine education field station on the Hudson River in New York City. There, Kirsten helped to mentor high school students and teach local school groups about the Hudson River estuary. In the fall of 2004, Kirsten entered the masters program in the Department of Oceanography and Coastal Sciences at Louisiana State University in the Fisheries Biology Laboratory under the supervision of Dr. James H. Cowan Jr. She will earn a Master of Science degree in May of 2008. Kirsten has accepted a position in the doctoral program in the Department of Oceanography and Coastal Sciences at Louisiana State University to continue working with Dr. James H. Cowan Jr., and will begin work on her dissertation in the summer of 2008.