2013

Impacts of artificial reef addition on the nekton community of Louisiana marsh ponds: a before-after-control-impact analysis

Kari Elizabeth Klotzbach
Louisiana State University and Agricultural and Mechanical College

IMPACTS OF ARTIFICIAL REEF ADDITION ON THE NEKTON COMMUNITY OF LOUISIANA MARSH PONDS: A BEFORE-AFTER-CONTROL-IMPACT ANALYSIS

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
Master of Science

in

The Department of Oceanography and Coastal Sciences

by
Kari Elizabeth Klotzbach
B.S. Louisiana State University, 2007
December 2013

I would like to dedicate this thesis to my family. The love and support that I receive from my entire family is unconditional and absolutely vital to my success.

ACKNOWLEDGEMENTS

I would like to acknowledge and thank my advisor, Dr. James Cowan, Jr., for all his help, guidance, understanding, and patience throughout my graduate career. I would also like to thank my committee members, Dr. Sibel Bargu Ates and Dr. Jay Geaghan, the many members of the Cowan Lab, and others at LSU that have helped me complete this project. I would especially like to thank and acknowledge my colleagues on this project: Dr. Joris van der Ham, Steven Garner, and Dr. Kevin Boswell. These gentlemen are not only extremely intelligent and hard working, but they all have a great sense of humor and a positive attitude that made working in the marsh for 20 hours in the hot Louisiana sun after spending all night on the boat covered in bugs some of the most fun and rewarding experiences of my life.

I would like to thank Grace Harwell for taking my place in the field when I wasn't able to be there. I would also like to thank Kirsten Simonsen, Ryan Klotzbach, and Dr. Matthew Campbell for volunteering to shovel limestone cobble from boat to boat to help create our artificial reefs. I would also like to thank Jackie McCool, Christine Ford, Elise Roche, and Caroline Tulloh for being wonderful student workers, who helped defrost, identify, and measure over 113,000 specimens, a feat which would have taken me years to complete without their help.

This project was funded by Louisiana Department of Wildlife and Fisheries and for that I thank them.

Finally, I want to thank my family, friends, and everyone I've come to know over the past 5 years at LSU. From physical labor to comments and suggestions on this thesis and

encouraging words, many people were involved in the making and completion of this study and I can definitively say that I could not have done it without each and every one of you.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS........iii

LIST OF TABLES........vi

LIST OF FIGURES........x

ABSTRACT........xiv

CHAPTER 1: INTRODUCTION........1
1.1 Overview of Coastal Louisiana and It's Importance to Fisheries........1
1.2 Oyster Reefs as Habitat........3
1.3 Artificial Reefs and Habitat Enhancement........5
1.4 Before-After-Control-Impact (BACI) Design........7
1.5 Research Goals and Objectives........8
1.6 Literature Cited........8

CHAPTER 2: MATERIALS AND METHODS........13
2.1 Study Area........13
2.2 Field Methods........13
2.3 BACI Design........16
2.4 Statistical Analysis........18
2.5 Literature Cited........20

CHAPTER 3: RESULTS........21
3.1 Environmental Variables........21
3.2 Catch Descriptions........21
3.3 Nekton Abundance........26
3.4 Nekton Biomass........28
3.5 Species Richness........31
3.6 Shannon-Weaver Diversity (H')........32
3.7 Community Abundance Distributions........35
3.8 Community Biomass Distributions........37
3.9 SIMPER Analysis........37
3.10 Individual Species: Fyke Nets........40
3.11 Individual Species: Purse Seine........64

CHAPTER 4: DISCUSSION........83
4.1 Sampling Design and Statistical Inference........83
4.2 Results........84
4.3 Deepwater Horizon Oil Spill........89
4.4 Conclusions........89
4.5 Literature Cited........90

THE VITA........93

LIST OF TABLES

Table 3.1. Total numbers and percentage of total catch of specimens by taxa that were collected by purse seine and fyke nets in order of abundance....................................23

Table 3.2. Total numbers of specimens by taxa that were collected on soft-bottom, marsh edge, and reef habitats in order of total abundance..25

Table 3.3. PERMANOVA output of log(n+1) transformed nekton abundance distributions per hour from fyke net samples (α=0.01)...36

Table 3.4. PERMANOVA output of log(n+1) transformed nekton abundance distributions per m^2 from purse seine samples (α=0.01)...36

Table 3.5. PERMANOVA output of log(n+1) transformed nekton biomass per hour from fyke net samples (α=0.01)..37

Table 3.6. PERMANOVA output of log(n+1) transformed nekton biomass distributions per m^2 from purse seine samples (α=0.01)..38

Table 3.7. SIMPER output of the species that explain >90% of the dissimilarity in fyke net community abundance distributions (N/hour) at impact areas before and after artificial reef addition...38

Table 3.8. SIMPER output of the species that explain >90% of the dissimilarity in fyke net community biomass distributions (g/hour) at impact areas before and after artificial reef addition...39

Table 3.9. SIMPER output of the species that explain >90% of the dissimilarity in purse seine community abundance distributions (N/m^2) at impact areas before and after artificial reef addition..40

Table 3.10. SIMPER output of the species that explain >90% of the dissimilarity in purse seine community biomass distributions (g/m^2) at impact areas before and after artificial reef addition...41

Table 3.11. Atlantic croaker (*Micropogonias undulatus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites...42

Table 3.12. Blue crab (*Callinectes sapidus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g) , and mean individual carapace width (mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....................44

Table 3.13. Brown shrimp (*Farfantepenaeus aztecus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual rostrum length (mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....46

Table 3.14. Gulf killifish (*Fundulus grandis*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites...48

Table 3.15. Highfin goby (*Gobionellus oceanicus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites...50

Table 3.16. Pinfish (*Lagodon rhomboides*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....52

Table 3.17. Sand seatrout (*Cynoscion arenarius*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites...54

Table 3.18. Silver perch (*Bairdiella chrysoura*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites...56

Table 3.19. Spot (*Leiostomus xanthurus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....58

Table 3.20. Striped mullet (*Mugil cephalus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....60

Table 3.21. White shrimp (*Litopenaeus setiferus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....62

Table 3.22. Atlantic croaker (*Micropogonias undulatus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....64

Table 3.23. Bay anchovy (*Anchoa mitchilli*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....66

Table 3.24. Bay whiff (*Citharichthys spilopterus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....68

Table 3.25. Brown shrimp (*Farfantepenaeus aztecus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual rostrum length (mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....70

Table 3.26. Gulf menhaden (*Brevoortia patronus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites........72

Table 3.27. Hardhead catfish (*Ariopsis felis*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites........74

Table 3.28. Pinfish (*Lagodon rhomboides*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....76

Table 3.29. Spot (*Leiostomus xanthurus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites....78

Table 3.30. White shrimp (*Litopenaeus setiferus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual rostrum length (mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites........80

LIST OF FIGURES

Figure 2.1. Map of study area and experimental marsh ponds near Empire, Louisiana........14

Figure 2.2. Map of the five sampling sites within Perfect Pond; North, East, South, West, and Marsh Edge. Sites in the other three ponds were oriented similarly............15

Figure 2.3. Fyke net configuration consisted of two fyke nets facing each other connected by a lead, with net frames, wings, and cod ends held in place by PVC poles........17

Figure 3.1. Water a) pH, b) temperature (°C), c) depth (m), and d) salinity (ppt) profiles for each pond during the study; Big pond (blue), Ovary pond (red), Perfect pond (green), and Triangle pond (purple). Vertical line marks time of artificial reef addition..22

Figure 3.2. Monthly log (n+1) transformed mean CPUE (N per hour) collected by fyke nets at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition..27

Figure 3.3. Monthly log (n+1) transformed mean density (N per m^2) collected by purse seine at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition..28

Figure 3.4. Monthly log (n+1) transformed mean CPUE (g per hour) collected by fyke nets at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition..29

Figure 3.5. Monthly log (n+1) transformed mean density (g per m^2) collected by purse seine at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition..30

Figure 3.6. Monthly mean species richness collected by fyke nets at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition...32

Figure 3.7. Monthly mean species richness collected by purse seine at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition...33

Figure 3.8. Monthly mean Shannon-Weaver diversity (H') collected by fyke nets at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition..34

Figure 3.9. Monthly mean Shannon-Weaver diversity (H') collected by purse seine at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition..35

Figure 3.10. Fyke net catches of Atlantic croaker (*Micropogonias undulatus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error....43

Figure 3.11. Fyke net catches of blue crab (*Callinectes sapidus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean carapace width (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error....45

Figure 3.12. Fyke net catches of brown shrimp (*Farfantepenaeus aztecus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean rostrum length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error....47

Figure 3.13. Fyke net catches of Gulf killifish (*Fundulus grandis*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour,) c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error....49

Figure 3.14. Fyke net catches of highfin goby (*Gobionellus oceanicus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.51

Figure 3.15. Fyke net catches of pinfish (*Lagodon rhomboides*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error....53

Figure 3.16. Fyke net catches of sand seatrout (*Cynoscion arenarius*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.55

Figure 3.17. Fyke net catches of silver perch (*Bairdiella chrysoura*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.57

Figure 3.18. Fyke net catches of spot (*Leiostomus xanthurus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error....59

Figure 3.19. Fyke net catches of striped mullet (*Mugil cephalus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error..........61

Figure 3.20. Fyke net catches of white shrimp (*Litopenaeus setiferus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean rostrum length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.63

Figure 3.21. Purse seine catches of Atlantic croaker (*Micropogonias undulatus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error...65

Figure 3.22. Purse seine catches of bay anchovy (*Anchoa mitchilli*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.67

Figure 3.23. Purse seine catches of bay whiff (*Citharichthys spilopterus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error...69

Figure 3.24. Purse seine catches of brown shrimp (*Farfantepenaeus aztecus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean rostrum length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error...71

Figure 3.25. Purse seine catches of Gulf menhaden (*Brevoortia patronus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error...73

Figure 3.26. Purse seine catches of hardhead catfish (*Ariopsis felis*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.75

Figure 3.27. Purse seine catches of pinfish (*Lagodon rhomboides*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.77

Figure 3.28. Purse seine catches of spot (*Leiostomus xanthurus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.79

Figure 3.29. Purse seine catches of white shrimp (*Litopenaeus setiferus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean rostrum length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error..81

ABSTRACT

Louisiana's coastal estuaries are dynamic, highly variable environments that provide nursery areas for numerous recreationally and commercially important species. Louisiana's coastline is constantly changing due to natural and anthropogenic processes, and it is important to know how nektonic species are impacted by such changes. This study sought to assess the effects of introducing a hard substrate artificial reef on the nekton community of a Louisiana estuary. A before-after-control-impact (BACI) design was used to assess the impacts of artificial reef addition on nektonic fishes and crustaceans in four shallow marsh ponds near Empire, Louisiana. Marsh ponds were sampled by purse seine and fyke nets every other month from May 2009 to November 2010. Five sites within each pond, four consisting of soft-bottom habitat and one of marsh edge habitat, were sampled. Midway through the study period (March 2010), 110 tons of limestone cobble were distributed across two soft-bottom sites in two of the ponds to mimic oyster reefs. Over 113,000 individuals comprising 57 species were collected. A combination of statistical analyses, including ANOVA, PERMANOVA, and ANOSIM, were used on a variety of nekton community parameters, including species richness, diversity, nekton density, and community structure, to determine the impacts of artificial reef addition on the nekton community. Individual species shown to contribute to changes at impacted areas were also examined. Overall, the addition of artificial reefs had no significant effect on the nekton community as a whole. Select life-stages of estuarine nekton may be positively or negatively affected by reef presence depending on ontogenetic shifts in prey and habitat selection of each species. Once colonized and evolved into functioning oyster reefs, I believe in the absence of natural oyster reefs that the artificial reefs constructed in this

study can act as quality nekton habitat. Longer study periods as well as further information on the movement behavior and habitat utilization of individual estuarine species may help elucidate the relationship between estuarine nekton and the habitats they occupy.

CHAPTER 1: INTRODUCTION

1.1 Overview of Coastal Louisiana and It's Importance to Fisheries

Southeastern Louisiana's coastline is a mosaic of wetlands with estuarine ponds and lakes, tidal creeks, canals, emergent marsh grasses, and submerged aquatic vegetation. These wetlands are part of the complex Mississippi River deltaic ecosystem, which is one of the largest (~25,000 km^2) coastal ecosystems in North America (Day et al. 2007; Day et al. 2009; De Mutsert 2010). Louisiana's coastal waters receive high amounts of nutrients from the Mississippi River, which in turn supports high primary and secondary productivity both within the coastal estuaries as well as offshore in the Gulf of Mexico (Chesney et al. 2000; Day et al. 2007). Among the species that are harvested by either recreational or commercial fishers are Gulf menhaden (*Brevoortia patronus*), spotted seatrout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), and white shrimp (*Litopenaeus setiferus*). In the past decade, Louisiana alone landed nearly 5 billion metric tons, and accounted for 73% of commercial fisheries landings in the Gulf of Mexico (http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html). Upwards of 85% of Louisiana's important commercial and recreational species utilize wetlands as a nursery habitat for seasonal residence (Gunter 1967; McHugh 1984; Baltz et al. 1993; Houde and Rutherford 1993; Chesney et al. 2000; Cowan et al. 2008; De Mutsert 2010).

Coastal wetlands in Louisiana disappeared at rates as high as >100 km^2 per year during the 1960s and 1970s with recent land loss rates still exceeding 50 km^2 per year (Britsch and Dunbar 1993; Chesney et al. 2000; Barras et al. 2003; Cowan et al. 2008;

Couvillion et al. 2011). Land loss is attributable to both natural and anthropogenic processes, including canal and pipeline dredging, sediment deprivation, subsidence, and salt-water intrusion (Britsch and Dunbar 1993; Chesney et al. 2000; Barras et al. 2003; Cowan et al. 2008; Couvillion et al. 2011). Dredging for the creation of canals, channels, and pipelines for the oil and gas industry has greatly increased the rate of erosion and salt water intrusion in coastal Louisiana. The degradation and loss of estuarine ecosystems pose a significant threat to the viability of fisheries not only in Louisiana but worldwide (Lenihan and Peterson 1998; Coen et al. 2007). Surprisingly, given the habitat loss and other anthropogenic stressors, Louisiana estuaries and coastal waters continue to support primary and secondary production at near historical levels (Chesney et al. 2000; Cowan et al. 2008). Since 1972, fisheries independent data shows many highly exploited species, such as brown shrimp (*F. aztecus*), white shrimp (*L. setiferus*), Atlantic croaker (*Micropogonias undulatus*), sand seatrout (*Cynoscion arenarius*), and blue crab (*C. sapidus*), have shown no significant trend while others, such as Gulf menhaden (*B. patronus*) and bay anchovy (*Anchoa mitchilli*), have increased (Chesney et al. 2000). Fisheries managers struggle to understand and explain this perplexing situation, which illustrates the need to further explore the relationship between estuarine nekton and the habitats they utilize, as well as how anthropogenic changes to natural habitats affect the nekton community.

In Louisiana, three habitat types dominate in coastal estuaries: marsh edge habitats, including fresh, brackish and salt marshes, soft-bottom habitats (i.e. mud), and biogenic reefs, mostly formed by eastern oysters (*Crassostrea virginica*). Many studies assessing habitat utilization in estuaries of the southeastern United States, including Louisiana, have focused on habitats such as intertidal marshes, seagrasses, and soft-bottom habitats like

mud flats (Day et al. 1989; Minello et al. 2003; Stunz et al. 2010). However, the past decade has seen an increase in studies exploring the role of hard substrate estuarine habitats, such as oyster reefs (Coen and Luckenbach 2000; Luckenbach et al. 2005; Rodney and Paynter 2006; Coen and Grizzle 2007; Simonsen and Cowan 2013; Simonsen et al. 2013).

1.2 Oyster Reefs as Habitat

Oysters, particularly the eastern oyster (*C. virginica*), are important to the ecological function of estuaries in many ways, the most obvious being the role oyster filtration plays on water quality and phytoplankton dynamics as seen in Chesapeake Bay (Rothschild et al. 1994; Coen et al. 1999). The decline of oysters in Chesapeake Bay led to a decrease in water quality causing trophic cascades and reductions in ecosystem functioning (Rothschild et al. 1994; Coen et al. 1999). Another beneficial aspect of oyster presence in an ecosystem is the presence of its shell. Oyster shells provide hard substrate essential for the settlement and growth of oyster spat, which leads to a cycle of settlement that results in the creation and expansion of an oyster reef (Breitburg 1999; Coen and Grizzle 2007). Oyster reefs can vary in size from 10 to 1000 m^2 with highest abundances occurring in low salinities (>15) and in the intertidal zone (Coen and Luckenbach 2000). Oyster reefs are utilized by a broad range of species, from fishes and crustaceans to sea birds and mammals (Steimle and Zetlin 2000; Coen and Grizzle 2007). Oyster reefs have long been considered essential habitat for oysters themselves, but recent studies indicate that oyster reefs play essential roles in habitat utilization by invertebrates and fishes (Coen et al. 1999; Luckenbach et al. 2005; Coen and Grizzle 2007). The three-dimensional structure of oyster reefs provides substrate for primary producers, such as algae (Coen et al. 1999; Fabi et al. 2006), and the vertical relief can change hydrodynamics to enhance settlement and entrain

plankton (Breitburg 1999; Koehl 2007). The various interstitial spaces between shells provide shelter and refuge for benthic infauna, epifauna, and macrofauna providing the additional ecosystem benefit of benthic-pelagic coupling (Coen et al. 2007).

In addition to supporting diverse benthic communities, oyster reefs support resident and transient fishes and crustaceans, including early life stages of larger species such as black sea bass (*Centropristis striata*), gag grouper (*Mycteroperca microlepis*), black drum (*Pogonias cromis*), and blue crab (*Callinectes sapidus*) (Steimle and Zetlin 2000; Lehnert and Allen 2002). Invertebrates, crustaceans, and fishes utilize oyster reefs as sources of refuge, shelter, foraging, and nesting. Grass shrimp (*Palaemonetes* sp.) take refuge in the interstitial spaces of an oyster reef when a predator is present (Posey et al. 1999). Both live and dead oyster shells are utilized as nesting sites by resident fishes such as oyster toadfish (*Opsanus tau*), skillet fish (*Gobiesox strumosus*), blennies, and gobies (Breitburg 1999; Coen and Luckenbach 2000). In Chesapeake Bay, high abundances of larval naked gobies (*Gobiosoma bosc*) are able to settle and take refuge on the down-current side of oyster reefs while developing and exhibiting high rates of zooplankton predation as larvae and juveniles (Breitburg, 1999). These resident gobies are then fed upon by striped bass (*Morone saxatilis*), a larger transient species, which also occurs in high densities on oyster reefs (Breitburg, 1999). Prey aggregations around oyster reefs create attractive foraging grounds for opportunistic, piscivorous fishes with no habitat preferences such as spotted seatrout (*C. nebulosus*) and Atlantic croaker (*M. undulatus*) (Coen and Grizzle 2007; Simonsen and Cowan, 2013). For estuarine-dependent species, availability and quality of nursery habitats can greatly reduce mortality from predation and

starvation thus increasing the chances of survival from larval to juvenile stages (Chesney et al. 2000; Beck 2001).

Studies on habitat value often cite species richness, abundance, biomass, and density as measures of habitat quality. Oyster reefs and hard substrate artificial reefs often have higher abundance, diversity, and biomass of invertebrate fauna and finfishes, including recreationally and commercially important fish, shrimp, and crab species, compared to soft-bottom habitats or unstructured habitats (Wenner et al. 1996; Coen et al. 1999; Coen and Luckenbach 2000; Luckenbach et al. 2005; Rodney and Paynter 2006; ASMFC 2007; Coen and Grizzle 2007; Stunz et al. 2010). Oyster reefs can have greater species richness, fish density, and benthic crustacean density than both vegetated marsh edge and non-vegetated bottom habitats (Stuntz et al. 2010). Not every individual species shows preference for oyster reefs and size comparisons of nekton species over oyster reefs and soft-bottom habitats have shown various trends with some species larger on reefs, some larger on soft-bottom habitats, and most displaying no trend (Stuntz et al. 2010; Simonsen et al. 2013).

1.3 Artificial Reefs and Habitat Enhancement

Despite the benefits of oyster reefs to estuarine ecosystems, populations of oysters in the southeastern United States and around the world are declining due to overfishing, habitat degradation, and disease (Rothschild et al. 1994; Lenihan and Peterson 1998). One approach to mitigate the loss of oyster reefs is through habitat enhancement and artificial reef deployment. Artificial reefs are man-made underwater structures designed to influence biological or physical processes, and are widely acknowledged as habitat for fish.

Once deployed, various fouling organisms encrust the structure and are subsequently consumed by primary and secondary consumers (Breitburg 1999; Fabi et al. 2006). The growth and survival of fishes can potentially be enhanced by such an increase in prey availability and refuge, thereby increasing fish production (Chesney et al. 2000; Beck 2001). Fisheries managers have deployed various artificial habitats in many locations, usually for the purpose of increasing catches. In the Gulf of Mexico, millions of dollars are spent annually on artificial reefs aimed at enhancing finfish and shellfish habitats with many restoration projects put into effect to restore and enhance oyster reefs (VanderKooy and Freitas 2006).

While oyster reef populations have been declining worldwide, production in Louisiana remains high, partly due to the put-and-take nature of the oyster fishery. Oyster fishermen deploy oyster and clam shells as sources of hard substrate to promote the settlement and growth of new oysters in addition to seeding the reefs. Along the southeastern Louisiana coast, reductions in the availability of clam and oyster shells have required the use of alternative hard substrates to build and maintain oyster reefs. Limestone cobble has proven to be a cost-effective alternative to oyster shells as hard substrate to establish an oyster reef (Haywood et al. 1999; Soniat and Burton 2005; Schulte et al. 2009). Reductions in available oyster reef habitat as well as increasing demand for oysters have caused increased focus on the conservation and restoration of oyster reefs. While the goal of most oyster reef restoration and enhancement projects in the Gulf of Mexico is enhanced oyster production, the potential to enhance nursery habitats for estuarine nekton through such projects has also warranted investigation (Steimle and Meier 1997; Peterson et al. 2003; Geraldi et al. 2009). Established oyster reefs have proven

to support diverse estuarine communities, however the ecosystem services associated with creating new oyster reefs is still in question. Peterson et al. (2003) estimated the potential enhancement of nekton production resulting from oyster reef restoration based on published life-history information, growth parameters, diet analysis, and density data on nekton utilizing oyster reefs. The authors estimated that 10 m^2 of restored oyster reef would yield an additional 2.3 kg of annual fish and large mobile crustacean production (Peterson et al. 2003).

1.4 Before-After-Control-Impact (BACI) Design

Assessing the impacts of habitat enhancement on an estuarine environment can be difficult due to high ecological variance occurring on differing temporal and spatial scales. One approach to account for such natural variance when assessing an environmental impact is through the use of a Before-After-Control-Impact (BACI) design. A BACI design involves sampling before and after the impact event to account for natural temporal variation. Spatial variation is accounted for by sampling at impacted areas as well as non-impacted control areas. With natural temporal and spatial variations accounted for, impact assessment can be achieved by analyzing the time*space interaction (Stewart-Oaten et al. 1986; Underwood 1992; Downes et al. 2002; Smith 2002).

A BACI design was used by Geraldi et al. (2009) to explore the effects of habitat enhancement on nektonic fishes and crustaceans in tidal marsh creeks of southern Alabama. Their analysis showed the addition of oyster reefs had no significant effects on fish or crustacean assemblages, though demersal fishes displayed a weak positive effect (Geraldi et al. 2009). This implies that oyster reef enhancement may not truly enhance

nekton production, although it is often used as an argument for restoration projects. Additional research on habitat enhancement is needed to elucidate the effects of reef addition on estuarine nekton communities.

1.5 Research Goals and Objectives

This study is part of a larger project aimed at assessing ecosystem-wide effects of habitat enhancement on marsh ponds of southeastern Louisiana. This component of that project aimed to assess the impacts of artificial mimic oyster reef addition on the nekton community. In an effort to assess the effects on the community level, multiple metrics were used ranging from univariate analyses, such as species richness and total biomass, to multivariate analyses including each individual species in the community. The following null hypotheses were evaluated:

H_0 1) The addition of an artificial mimic oyster reef has no effect on nekton abundance, nekton biomass, species richness, or species diversity.

H_0 2) The addition of an artificial mimic oyster reef has no effect on nekton community composition and structure.

H_0 3) The addition of an artificial mimic oyster reef has no effect on the abundance, biomass, or size of individual nektonic fish and crustacean species.

1.6 Literature Cited

ASMFC. 2007. The importance of habitat created by shellfish and shell beds along the Atlantic coast of the U.S. Prepared by Coen, L.D., R. Grizzle, with contributions by J. Lowery and K.T. Paynter, Jr. Atlantic States Marine Fisheries Commission, Washington, DC, p. 1-116.

Baltz, D., C. Rakocinski and J. Fleeger. 1993. Microhabitat se by marsh-edge fishes in a Louisiana estuary. Environmental Biology of Fishes 36: 109-126.

Barras, J., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota and J. Suhayda. 2003. Historical and projected coastal Louisiana land changes: 1978-2050. USGS Open File Report 03-334, 39 p. (Revised January 2004).

Beck, M., K. Heck, Jr., K. Able, D. Childers, D. Eggleston, B. Gillanders, B. Halpern, C. Hays, K. Hoshino, T. Minello, R. Orth, P. Sheridan and M. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51(8): 633-641.

Boesch, D. and R. Turner. 1984. Dependence of fishery species on salt marshes: the role of food and refuge. Estuaries. 7(4A): 460-468.

Bohnsack, J. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? Bulletin of Marine Science 44(2): 631-645.

Breitburg, D. 1999. Are three-dimensional structure and healthy oyster populations the keys to an ecologically interesting and important fish community? In: Luckenbach, M., Mann, R., Wessen, J. (eds) Oyster reef habitat restoration: a synopsis of approaches. Virginia Institute of Marine Science Press, Williamsburg, Virginia, p. 239-250.

Britsch, L. and J. Dunbar. 1993. Land-loss rates: Louisiana coastal plain. Journal of Coastal Research 9: 324-338.

Chesney, E., D. Baltz and R. Thomas. 2000. Louisiana estuarine and coastal fisheries and habitats: perspectives from a fish's eye view. Ecological Applications 10(2): 350-366.

Clark, K. and R. Warwick. 2001. Changes in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E: Plymouth.

Coen, L. and R. Grizzle. 2007. The importance of habitat created by molluscan shellfish to managed species along the Atlantic coast of the United States. ASMFC Management Series #8 109 p.

Coen, L. and M. Luckenbach. 2000. Developing success criteria and goals for evaluating oyster reef restoration: ecological function or resource exploitation? Ecological Engineering 15: 323-343.

Coen, L., M. Luckenbach and D. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. American Fisheries Society Symposium 22: 438-454.

Coen, L., R. Brumbaugh, D. Bushek, R. Grizzle, M. Luckenbach, M. Posey, S. Powers and S. Tolley. 2007. Ecosystem services related to oyster restoration. Marine Ecology Progress Series 341: 303-307.

Couvillion, B., J. Barras, G. Steyer, W. Sleavin, M. Fischer, H. Beck, N. Trahan, B. Griffin and D. Heckman. 2011. Land area change in Coastal Louisiana form 1932 to 2010: U.S. Geological Survey Scientific Investigations Map 3164, scale 1:265,000, pamphlet. 12 p.

Cowan Jr., J., C. Grimes and R. Shaw. 2008. Life history, history, hysteresis, and habitat changes in Louisiana's coastal ecosystem. Bulletin of Marine Science 83(1): 197-215.

Day Jr., J., M. Kemp and A. Yez-Arancibia. 1989. Estuarine Ecology. Wiley Interscience, New York. 576 p.

Day Jr., J., D. Boesch, E. Clairain, G. Kemp, S. Laska, W. Mitsch, K. Orth, H. Mashriqui, D. Reed, L. Shabman, C. Simenstad, B. Streever, R. Twilley, C. Watson, J. Wells and D. Whigham. 2007. Restoration of the Mississippi Delta: lesson from Hurricanes Katrina and Rita. Science 315: 1679-1684.

Day Jr., J., J. Cable, J. Cowan Jr., R. DeLaune, K. de Mutsert, B. Fry, H. Mashriqui, D. Justic, P. Kemp, R. Lane, J. Rick, S. Rick, L. Rozas, G. Snedden, E. Swenson, R. Twilley and B. Wissel. 2009. The impacts of pulsed reintroduction of river water on a Mississippi Delta coastal basin. Journal of Coastal Research 54: 225-243.

De Mutsert, K. 2010. The effects of a freshwater diversion on nekton species biomass distributions, food web pathways, and community structure in a Louisiana estuary. Doctoral Dissertation 188 p. Louisiana State University.

Downes, B., L. Barmuta, P. Fairweather, D. Faith, M. Keuogh, P. Lake, B. Mapstone and G. Quinn. 2002. Monitoring Ecological Impacts: Concepts and Practice in Flowing Waters. Cambridge University press, Cambridge, UK.

Fabi, G., S. Manoukian and A. Spagnolo. 2006. Feeding behavior of three common fishes at an artificial reef in the northern Adriatic Sea. Bulletin of Marine Science 78(1): 39-56.

Geraldi, N., S. Powers, K. Heck and J. Cebrian. 2009. Can habitat restoration be redundant? Response of mobile fishes and crustaceans to oyster reef restoration in marsh tidal creeks. Marine Ecology Press Series 389: 171-180.

Gunter, G. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. Pages 621-638 *in* G.H. Lauff, editor. Estuaries. American Association for the Advancement of Science, Washington, DC.

Haywood, III, E., T. Soniat and R. Broadhurst, III. 1999. Alternatives to clam and oyster shell as cultch for eastern oysters. In M.W. Luckenbach, R. Mann, J.A. Wesson (eds) Oyster reef habitat restoration: a synopsis and synthesis of approaches. Virginia Institute of Marine Science Press, Williamsburg, Virginia.

Houde, E. and E. Rutherford. 1993. Recent trends in estuarine fisheries: predictions of fish production and yields. Estuaries 16: 161-176.

Koehl, M. 2007. Mini review: Hydrodynamics of larval settlement into fouling communities. Biofouling 23(5): 357-368.

Lehnert, R. and D. Allen. 2002. Nekton use of subtidal oyster shell habitat in a southeastern US estuary. Estuaries 25: 1015-1024.

Lenihan, H. and C. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological Applications 8: 128-140.

Luckenbach, M., L. Coen, P. Ross and J. 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.

McHugh, J. 1967. Estuarine nekton. Pages 581-620 *in* G.H. Lauff, editor. Estuaries. American Association for the Advancement of Science, Washington, DC.

McHugh, J. 1984. Fishery Management. Springer-Verlag, Berlin.

Minello, T., K. Able, M. Weinstein and C. Hays. 2003. Salt marshes as nurseries for nekton: testing hypotheses on density, growth, and survival through meta-analysis. Marine Ecology Progress Series 246: 39-59.

Peterson, C., J. Grabowski and S. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative evaluation. Marine Ecology Progress Series 264: 249-264.

Pickering, H. and D. Whitmarsh. 1997. Artificial reefs and fisheries exploitation: a review of the 'attraction versus production' debate, the influence of design and its significance for policy. Fisheries Reviews 31(1-2): 39-59.

Posey, M., T. Alphin, C. Powell and E. Townsend. 1999. Oyster reefs as habitat for epibenthic fishes and decapods. In M. Luckenbach, R. Mann and J. Wesson (eds) Oyster reef habitat restoration: a synopsis and synthesis of approaches. Virginia Institute of Marine Science Press, Williamsburg, Virginia, 229-237.

Rodney, W. and K. Paynter. 2006. Comparisons of macrofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland. Journal of Experimental Marine Biology and Ecology 335: 39-51.

Rothschild, B., J. Ault, P. Goulletquer 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.

Schulte, D., R. Burke and R. Lipcius. 2009. Unprecedented restoration of a native oyster metapopulation. Science 325: 1124-1128.

Simonsen, K. and J. Cowan, Jr. 2013. Effects of an inshore artificial reef on the trophic dynamics of three estuarine fishes. Bulletin of Marine Science 89(3): 657-676.

Simonsen, K., J. Cowan, Jr. and A. Fischer. 2013. Examination of an estuarine fish assemblage over an inshore artificial reef. The Open Fish Science Journal 6: 48-57.

Smith, E. 2002. BACI design. Pages 141-148 in A. El-Shaarawi and W. Piegorsch, editors. Encyclopedia of environmetrics. John Wiley and Sons, Ltd, Chichester.

Soniat, T. and G. Burton. 2005. A comparison of the effectiveness of sandstone and limestone as cultch for oysters, *Crassostrea virginica*. Journal of Shellfish Research 24: 483-485.

Steimle, F. and M. Meier. 1997. What information do artificial reef managers really want from fishery science? Fisheries 22(4): 6-8.

Steimle, F. and C. Zetlin. 2000. Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities, and fishery resource use. Marine Fisheries Review 62: 24-42.

Stewart-Oaten, A., W. Murdoch and K. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? Ecology 67(4): 929-940.

Stunz, G., T. Minello and L. Rozas. 2010. Relative value of oyster reef as habitat for estuarine nekton in Galveston Bay, Texas. Marine Ecology Progress Series 406: 147-159. VanderKooy, S. and T. Freitas. 2006. Fifty-seventh annual report of the Gulf States Marine Fisheries Commission. Ocean Springs, MS.

Underwood, A. 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but viable, world. Journal of Experimental Marine Biology and Ecology 161: 145-178.

VanderKooy, S. and T. Freitas. 2006. Fifty-seventh annual report of the Gulf States Marine Fisheries Commission. Ocean Springs, Mississippi.

Wenner, E., H. Beatty and L. Coen. 1996. A method for quantitatively sampling nekton on intertidal oyster reefs. Journal of Shellfish Research 15: 769-775.

CHAPTER 2: MATERIALS AND METHODS

2.1 Study Area

The study area is located near Empire, Louisiana in lower Plaquemines Parish approximately 29 km east of Barataria Bay and 4 km west of the Mississippi River. Four marsh ponds, referred to as Big Pond (BP), Ovary Pond (OP), Perfect Pond (PP), and Triangle Pond (TP), were selected for study (Figure 2.1). These ponds were selected based upon proximity to one another and similarity of physical characteristics. All ponds are intertidal, oligohaline (5-25 ppt), and connected to neighboring bodies of water via a single tidal channel. The ponds are located within 4.5 km of one another and pond surface areas are approximately 6,700 m^2 – 17,000 m^2. The ponds consist of non-vegetated mud bottoms surrounded by emergent vegetation mostly consisting of smooth cordgrass (*Spartina alterniflora*). Water depth ranges from 0 to approximately 1 m in all ponds depending upon tide and meteorological factors. Within each pond, five fixed sampling sites were identified as North (N), South (S), East (E), West (W), and Marsh Edge (ME) (Figure 2.2). Buoys were placed on individual sites within each pond to ensure that sampling occurred over the same sites during each sampling trip.

2.2 Field Methods

Biological and environmental sampling occurred every two months between May 2009 and November 2010. Each trip consisted of four consecutive days of sampling. An YSI 6920 V2 multi-parameter hydrosonde was deployed in a pond each day of sampling for approximately 12 hours, taking measurements of water depth (m), temperature (°C), pH, salinity (ppt), and dissolved oxygen (mg/L) every 5 minutes. The hydrosonde was positioned in the middle of each pond and was not site-specific, so environmental data was

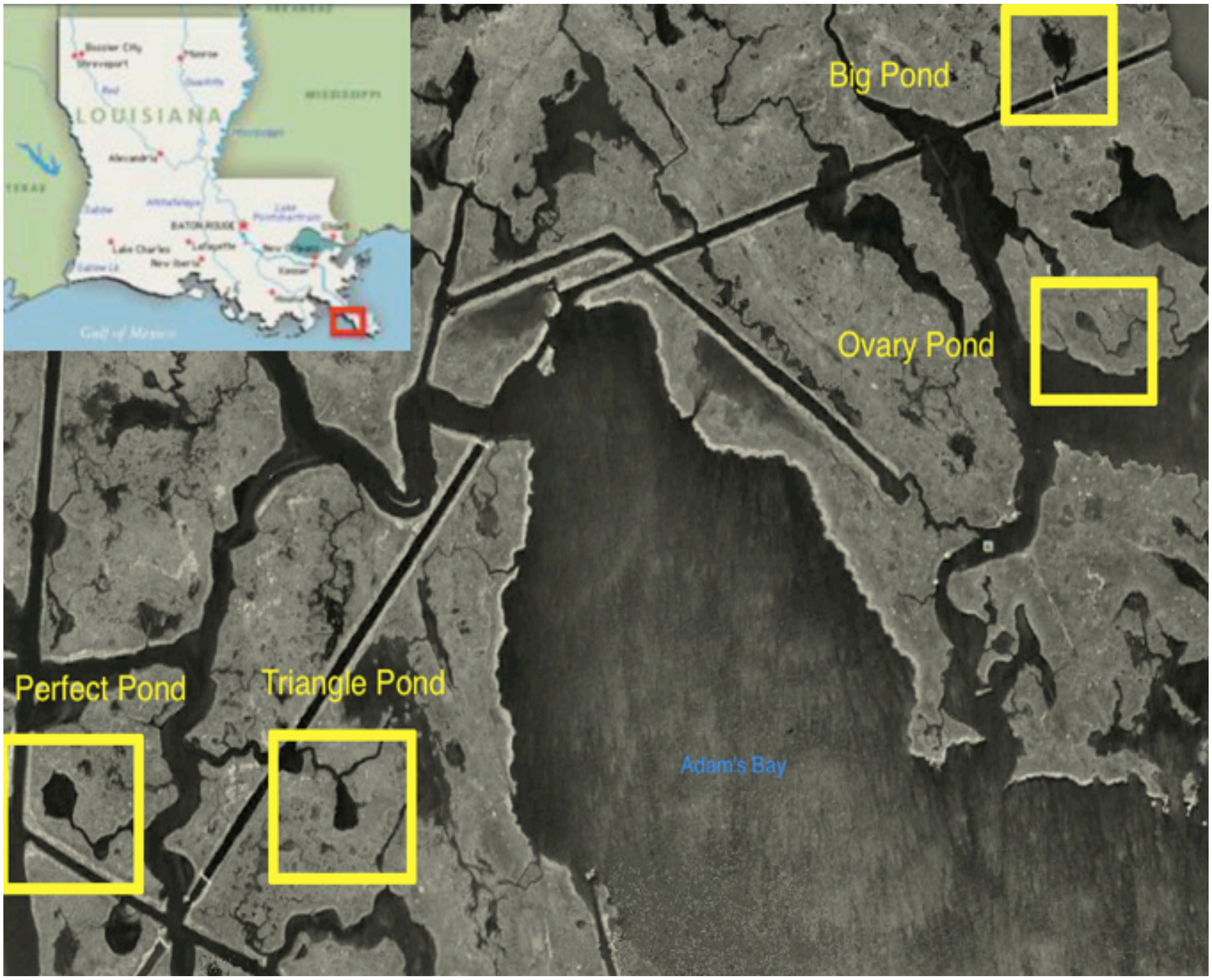

Figure 2.1. Map of study area and experimental marsh ponds near Empire, Louisiana.

only used for comparisons among ponds. Nekton sampling was conducted using fyke nets and a purse seine. Fyke nets (2, one with 6 mm mesh and another with 12 mm mesh) were deployed on each of the 5 sites within a randomly selected pond on the first day of sampling. Fyke net configuration at each site consisted of two fyke nets positioned to face one another, connected by a lead, and held in place by polyvinyl chloride (PVC) poles (Figure 2.3). For ME sites, fyke nets were positioned next to one another facing the marsh, with nets and wings parallel to the shore, and leads extending into the marsh. The fyke nets were left to fish undisturbed for ~12 hours surrounding high tide. While the fyke nets

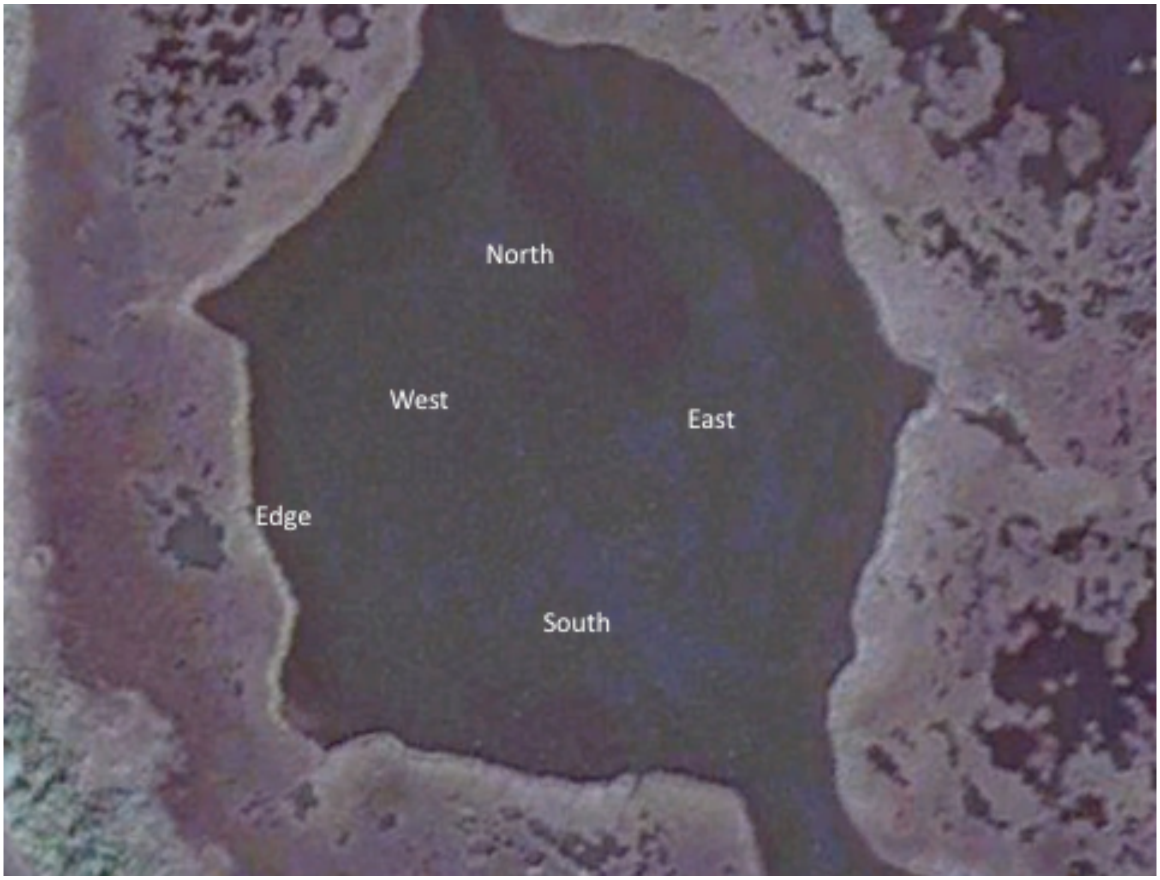

Figure 2.2. Map of the five sampling sites within Perfect Pond; North, East, South, West, and Marsh Edge. Sites in the other three ponds were oriented similarly.

and hydrosonde were deployed in one pond, purse seine tows were conducted at the 5 sites in another pond. The purse seine was 15.24 m long with 0.63 cm mesh and a bag size of 1.44 m^2. Two tows were made per site on opposite sides of the marker buoy to avoid depletion effects. This duel pond/technique sampling routine was repeated for the remaining sampling days creating 20 fyke net samples (4 ponds x 5 sites) and 40 purse seine samples (4 ponds x 5 sites x 2 tows) per sampling trip. Fishes and crustaceans captured were immediately placed on ice then stored in a freezer until the sampling period was over, at which time the samples were transported to the laboratory at Louisiana State University (LSU) and stored in a freezer until analyzed.

The species I collected were identified to the lowest taxonomic level possible, and length (mm) and wet weight (10^{-2} g) were recorded. Length was recorded as standard length (SL) for fishes, carapace width for crabs, and rostrum length for shrimps. If a large number of individuals of a specific taxa were present in a single sample, a random subsample of 100 were measured, and the additional individuals were counted, weighed as a group, and each individual was assigned the group mean weight for analysis. Some individuals were identified and measured in the field, then released after inserting a PIT tag for a concurrent movement study. Subsamples of Atlantic croaker (*Micropogonias undulatus*), bay whiff (*Citharichthys spilopterus*), sand seatrout (*Cynoscion arenarius*), and spot (*Leiostomus xanthurus*) were collected from purse seine samples and preserved in 95% ethanol for a concurrent gut content study. The effect of ethanol preservation on the wet weight of these species was analyzed in the laboratory and weight measurements were adjusted accordingly.

2.3 BACI Design

A Before-After-Control-Impact (BACI) design was used to allow for both temporal and spatial comparisons. This design allows for changes over time in the impact areas that are unrelated to the impact to be accounted for by changes in the control area (Downes et al., 2002; De Mutsert, 2010). In March 2010, OP and PP received artificial habitat enhancement. Over 110 tons of #57 limestone cobble were added to the N and E sites of these experimental ponds, creating an artificial reef designed to mimic an oyster reef. Mesh netting was secured on the sediment surface using PVC poles prior to cobble deployment to prevent the reefs from sinking into the mud bottom. Due to a difference in pond sizes, reefs created in OP measured 15 x 15 x 0.05 m while the reefs in PP measured

Figure 2.3. Fyke net configuration consisted of two fyke nets facing each other connected by a lead, with net frames, wings, and cod ends held in place by PVC poles.

22 x 22 x 0.05m to create reef surface areas approximately 3% of pond surface area. The other two ponds were left unmodified to account for non-impact related changes. Sampling did not occur in March 2010 to allow settling and acclimation of the new habitat. Sampling resumed in May 2010 and continued through November 2010. Sampling trips from May 2009 to November 2009 comprised the "before" period while trips from May 2010 to November 2010 comprised the "after" period. The sampling trip from January 2010 was not included in impact analysis since a matching January trip in the "after" period did not occur, and samples during this time were relatively small. All ME sites were classified as "edge" areas. The N and E sites of OP and PP comprised the "impact" areas for

both “before” and “after” periods, despite these sites being soft-bottom habitat prior to impact. The S and W sites in OP and PP, as well as all N, S, E, and W sites in BP and TP served as “control” areas.

2.4 Statistical Analysis

Due to pond proximity and similar physical characteristics, it was assumed that the ponds had similar hydrographic conditions. Environmental variables were analyzed individually as the response variable in a mixed-model analysis of variance (ANOVA, SAS 9.2) to test the validity of this assumption. Each model included three factors: A. Period (2 levels; before and after); B. Month (4 levels; May, July, September, and November); C. Pond (4 levels; Big, Ovary, Perfect, and Triangle). The significance level was set at $p=0.05$. Significant results were further compared using pairwise tests of Tukey-adjusted LSMeans.

All fyke net samples and purse seine samples were analyzed separately. Fyke net samples were standardized to catch per hour of soak time while purse seine samples were standardized to catch per square meter. Total abundance (N), total biomass (g), species richness, and Shannon-Weaver diversity (H’) were analyzed using a general linear mixed-model ANOVA in SAS (version 9.2). Species richness was defined as the number of species collected at each area within each pond during each sampling trip. The model included four factors: A. Period (fixed with 2 levels; before and after); B. Month (random with 4 levels; May, July, September, and November); C. Pond (random with 4 levels; Big, Ovary, Perfect, and Triangle); and D. Area (fixed, nested within factor C with 3 levels; control, impact, and edge). Significant results were further compared using pairwise tests of Tukey-adjusted LSMeans ($\alpha=0.05$).

Nekton community abundance distributions and biomass distributions for both fyke net and purse seine samples were analyzed using the PERMANOVA add-on package in PRIMER 6. PERMANOVA is a semi-parametric, permutational equivalent of MANOVA that was specifically designed for analysis of community structure and density in ecological studies (Clark and Warwick, 2001; Anderson et al., 2008; De Mutsert, 2010). All taxonomic groupings were used as variables. All sample data were log (n+1) transformed then used to create Bray-Curtis resemblance matrices. The PERMANOVA model included 4 factors: A. Period (fixed with 2 levels; before and after); B. Month (random with 4 levels; May, July, September, and November); C. Pond (random with 4 levels; Big, Ovary, Perfect, and Triangle); D. Area (fixed nested within factor C with 3 levels; control, impact, and edge). PERMANOVA models were run using 9999 permutations with a significance level of p=0.01. Significant results were further evaluated using ANOSIM, which is a non-parametric equivalent of ANOVA, with a significance level of p=1%. An additional factor called Interaction with 6 levels, before-control (BC), before-impact (BI), before-edge (BE), after-control (AC), after-impact (AI), and after-edge (AE), was created for ANOSIM comparisons and for SIMPER comparisons of dissimilarity. The SIMPER procedure was used to determine which species contributed most to dissimilarities between area types before and after artificial reef addition. Another additional factor called Habitat (3 levels; soft-bottom, reef, and edge) was created for species comparisons during the after period only.

Species determined to have contributed the most to dissimilarities at impact sites between the before period and the after period (BI vs. AI) were individually evaluated for impact assessment. Abundance, biomass, average weight, and average length of these individual species were analyzed using ANOSIM.

2.5 Literature Cited

Anderson, M., R. Gorley and K. Clarke. 2008. PERMANOVA+ for PRIMER: Guide to software and statistical methods. PRIMER-E: Plymouth, UK.

Clark, K. and R. Warwick. 2001. Changes in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E: Plymouth.

De Mutsert, K. 2010. The effects of a freshwater diversion on nekton species biomass distributions, food web pathways, and community structure in a Louisiana estuary. Doctoral Dissertation 188p. Louisiana State University.

Downes, B., L. Barmuta, P. Fairweather, D. Faith, M. Keuogh, P. Lake, B. Mapstone and G. Quinn. 2002. Monitoring Ecological Impacts: Concepts and Practice in Flowing Waters. Cambridge University press, Cambridge, UK.

CHAPTER 3: RESULTS

3.1 Environmental Variables

Data on depth (m), pH, salinity (ppt), dissolved oxygen (mg/L), and water temperature (°C) were collected before reef construction during the September 2009 and November 2009 sampling trips and during all sampling trips thereafter (May-November 2010). Dissolved oxygen measurements indicate a malfunction in this specific sensor so it was not included in analyses. Mixed-model ANOVAs for each remaining environmental variable showed significant differences between periods ($p<0.0001$), months ($p<0.0001$), and ponds ($p<0.0001$). Salinity ranged from 4.5 to 23.6 ppt and showed a seasonal trend with highest values occurring during November and lowest values occurring during summer months (Figure 3.1b). Temperature ranged from 14.8 to 34.5 °C and also followed a seasonal trend with lowest values in November and highest values during July and September (Figure 3.1a). Water depth (Figure 3.1c) and pH (Figure 3.1d) showed no clear trend over time ranging from 0.4 to 1.3 m, and 6.7 to 8.6, respectively. While the comparisons of all environmental variables were statistically significant, they are not likely to be biologically meaningful. The statistical significance is likely a result of such large sample sizes (measurements taken every 5 minutes).

3.2 Catch Descriptions

A total of 113,106 individuals were collected. Catches were comprised of 51 species and 6 groups identified to the family or genus level (Table 3.1). The 19 most commonly caught species comprised over 95% of the total catch. Gulf menhaden (*Brevoortia patronus*) was the most common species, accounting for 66% of the total catch. Brown shrimp (*Farfantepenaeus aztecus*) and white shrimp (*Litopenaeus setiferus*) were the next

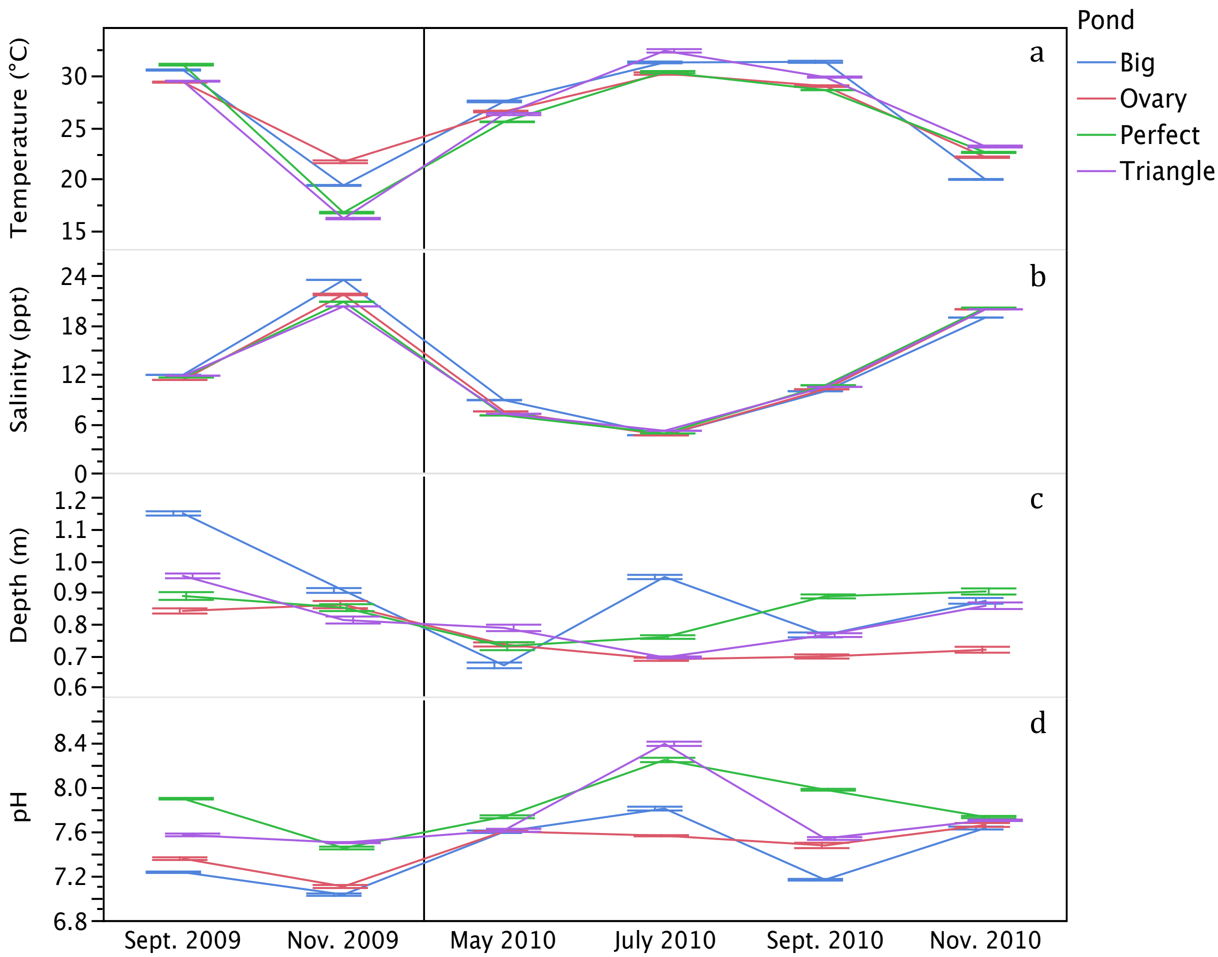

Figure 3.1. Water a) temperature (°C), b) salinity (ppt), c) depth (m), and d) pH profiles for each pond during the study; Big pond (blue), Ovary pond (red), Perfect pond (green), and Triangle pond (purple). Vertical line marks time of artificial reef addition.

most abundant species, each accounting for ~8% of the total catch. Soft-bottom habitats were the most frequently sampled habitats comprising 70% of all sites, while marsh edge and reef habitats comprised 20% and 10% of sites, respectively. Approximately 72%, 24%, and 4% of all individuals collected were collected over soft-bottom, edge, and reef habitats, respectively (Table 3.2). Gulf menhaden were the most abundant species on both soft-bottom and marsh edge habitats; however, brown shrimp, white shrimp, bay anchovy (*Anchoa mitchilli*), and Atlantic croaker (*Micropogonias undulatus*) were more abundant

than Gulf menhaden on reef habitats. In all, 54 taxa were collected on soft-bottom habitats, 49 taxa were collected on marsh edge habitats, and 33 taxa were collected on reef habitats. Seven taxonomic groups were collected exclusively on soft-bottom habitats, with two taxa collected on marsh edge habitats only, and one taxon collected exclusively on reef habitats. All taxa collected exclusively on one habitat type were rarely observed and represented less than 0.01% of the total catch.

Table 3.1. Total numbers and percentage of total catch of specimens by taxa that were collected by purse seine and fyke nets in order of abundance.

Species	Common Name	Purse Seine	Fyke Nets	Total Catch	% Total Catch
Brevoortia patronus	Gulf menhaden	73856	652	74508	65.87
Farfantepenaeus aztecus	Brown shrimp	6542	2577	9119	8.06
Litopenaeus setiferus	White shrimp	6515	5058	9047	8.00
Anchoa mitchilli	Bay anchovy	3989	21	6536	5.78
Micropogonias undulatus	Atlantic croaker	3101	141	3242	2.87
Leiostomus xanthurus	Spot	1919	357	2276	2.01
Palaemonetes pugio	Grass shrimp	1047	142	1158	1.02
Citharichthys spilopterus	Bay whiff	1016	39	1086	0.96
Cynoscion arenarius	Sand seatrout	863	209	1072	0.95
Callinectes sapidus	Blue crab	449	552	1001	0.89
Lagodon rhomboides	Pinfish	594	276	870	0.77
Ariopsis felis	Hardhead catfish	304	114	418	0.37
Mugil cephalus	Striped mullet	305	40	345	0.31
Bairdiella chrysoura	Silver perch	109	201	310	0.27
Menidia beryllina	Inland silverside	224	23	247	0.22
Gobionellus oceanicus	Highfin goby	135	95	230	0.20
Dorosoma petenense	Threadfin shad	155	73	228	0.20
Fundulus grandis	Gulf killifish	81	93	174	0.15
Cynoscion nebulosus	Spotted seatrout	119	21	140	0.12
Dorosoma cepedianum	Gizzard shad	120	18	138	0.12
Symphurus plagiusa	Blackcheek tonguefish	119	1	120	0.11
Eucinostomus sp.	mojarra sp.	105	6	111	0.10
Gobionellus boleosoma	Darter goby	101	5	106	0.09
Sphoeroides parvus	Least puffer	72	14	86	0.08
family *Carangidae*	jack sp.	14	55	69	0.06

(Table 3.1 continued)

Species	Common Name	Purse Seine	Fyke Nets	Total Catch	% Total Catch
Bagre marinus	Gafftopsail catfish	50	17	67	0.06
Sciaenops ocellatus	Red drum	53	9	62	0.05
Chaetodipterus faber	Atlantic spadefish	19	26	45	0.04
Paralichthys lethostigma	Southern flounder	20	25	45	0.04
Poecilia latipinna	Sailfin molly	8	33	41	0.04
Cyprinodon variegatus	Sheepshead minnow	19	5	24	0.02
Membras martinica	Rough silverside	23	0	23	0.02
Mugil curema	White mullet	9	7	16	0.01
Elops saurus	Ladyfish	10	5	15	0.01
Oligoplites saurus	Leatherjack	10	5	15	0.01
Dasyatis sabina	Atlantic stingray	14	0	14	0.01
Archosargus probatocephalus	Sheepshead	6	4	10	0.01
Fundulus similis	Striped killifish	4	6	10	0.01
Pogonias cromis	Black drum	5	5	10	0.01
Evorthodus lyricus	Lyre goby	6	3	9	0.01
family *Panopeidae*	mud crab sp.	7	2	9	0.01
Prionotus tribulus	Bighead searobin	9	0	9	0.01
Eleotris pisonis	Spinycheek sleeper	2	5	7	0.01
Strongylura marina	Atlantic needlefish	4	3	7	0.01
family *Gobiidae*	goby sp.	3	3	6	0.01
Gobioides broussonnetii	Violet goby	1	4	5	<0.01
Synodus foetens	Inshore lizardfish	4	0	4	<0.01
Gobiosoma bosc	Naked goby	3	0	3	<0.01
Bothidae sp.	flounder sp.	1	1	2	<0.01
Lutjanus griseus	Mangrove snapper	2	0	2	<0.01
Microgobius gulosus	Clown goby	2	0	2	<0.01
Syngnathus sp.	pipefish sp.	2	0	2	<0.01
Achirus lineatus	Lined sole	1	0	1	<0.01
Adinia xenica	Diamond killifish	1	0	1	<0.01
Dormitator maculatus	Fat sleeper	1	0	1	<0.01
Gobiesox strumosus	Skilletfish	1	0	1	<0.01
Ophichthus gomesi	Shrimp eel	1	0	1	<0.01
TOTAL	57	102155	10951	113106	100

Table 3.2. Total numbers of specimens by taxa that were collected on soft-bottom, marsh edge, and reef habitats in order of total abundance.

Species	Common Name	Mud	Edge	Reef
Brevoortia patronus	Gulf menhaden	58116	15998	394
Farfantepenaeus aztecus	Brown shrimp	4884	3186	1049
Litopenaeus setiferus	White shrimp	5736	2710	601
Anchoa mitchilli	Bay anchovy	4706	1162	668
Micropogonias undulatus	Atlantic croaker	2007	728	507
Leiostomus xanthurus	Spot	1490	626	160
Palaemonetes pugio	Grass shrimp	294	837	27
Citharichthys spilopterus	Bay whiff	712	245	129
Cynoscion arenarius	Sand seatrout	701	260	111
Callinectes sapidus	Blue crab	741	187	73
Lagodon rhomboides	Pinfish	362	347	161
Ariopsis felis	Hardhead catfish	310	54	54
Mugil cephalus	Striped mullet	179	149	17
Bairdiella chrysoura	Silver perch	238	52	20
Menidia beryllina	Inland silverside	127	110	10
Gobionellus oceanicus	Highfin goby	134	84	12
Dorosoma petenense	Threadfin shad	164	62	2
Fundulus grandis	Gulf killifish	16	145	13
Cynoscion nebulosus	Spotted seatrout	58	76	6
Dorosoma cepedianum	Gizzard shad	56	76	6
Symphurus plagiusa	Blackcheek tonguefish	96	11	13
Eucinostomus sp.	mojarra sp.	64	47	0
Gobionellus boleosoma	Darter goby	64	42	0
Sphoeroides parvus	Least puffer	41	35	10
family *Carangidae*	jack sp.	46	18	5
Bagre marinus	Gafftopsail catfish	46	16	5
Sciaenops ocellatus	Red drum	8	43	11
Chaetodipterus faber	Atlantic spadefish	25	16	4
Paralichthys lethostigma	Southern flounder	24	15	6
Poecilia latipinna	Sailfin molly	10	31	0
Cyprinodon variegatus	Sheepshead minnow	2	21	1
Membras martinica	Rough silverside	8	14	1
Mugil curema	White mullet	4	11	1
Elops saurus	Ladyfish	7	8	0
Oligoplites saurus	Leatherjack	6	9	0
Dasyatis sabina	Atlantic stingray	11	2	1
Archosargus probatocephalus	Sheepshead	3	7	0
Fundulus similis	Striped killifish	2	8	0
Pogonias cromis	Black drum	6	4	0
Evorthodus lyricus	Lyre goby	3	6	0
family *Panopeidae*	mud crab sp.	5	4	0

(Table 3.2 continued)

Species	Common Name	Mud	Edge	Reef
Prionotus tribulus	Bighead searobin	7	1	1
Eleotris pisonis	Spinycheek sleeper	4	3	0
Strongylura marina	Atlantic needlefish	1	6	0
family *Gobiidae*	goby sp.	4	2	0
Gobioides broussonnetii	Violet goby	4	1	0
Synodus foetens	Inshore lizardfish	4	0	0
Gobiosoma bosc	Naked goby	3	0	0
Bothidae sp.	flounder sp.	2	0	0
Lutjanus griseus	Mangrove snapper	0	2	0
Microgobius gulosus	Clown goby	0	2	0
Syngnathus sp.	pipefish sp.	1	1	0
Achirus lineatus	Lined sole	1	0	0
Adinia xenica	Diamond killifish	1	0	0
Dormitator maculatus	Fat sleeper	0	0	1
Gobiesox strumosus	Skilletfish	1	0	0
Ophichthus gomesi	Shrimp eel	1	0	0
TOTAL	57	81546	27480	4080

3.3 Nekton Abundance

3.3.1 Fyke Nets

Fyke nets collected a total of 10,951 individuals during this study. Mean catch per unit effort (CPUE; N/hour) peaked in September 2009 before artificial reef construction, then again in May 2010 after reef addition (Figure 3.2). Overall fyke net catches increased after reef construction. Likewise, impact, control, and edge areas also displayed increases in CPUE from the before period to the after period when analyzed separately. In both periods, edge areas had the highest mean CPUE, as well as the largest increase in mean CPUE after reef construction (Figure 3.2). Impact areas had the lowest mean CPUE in both periods and increased the least after reef construction. ANOVA results show the Period*Area interaction term was not significant (p=0.75).

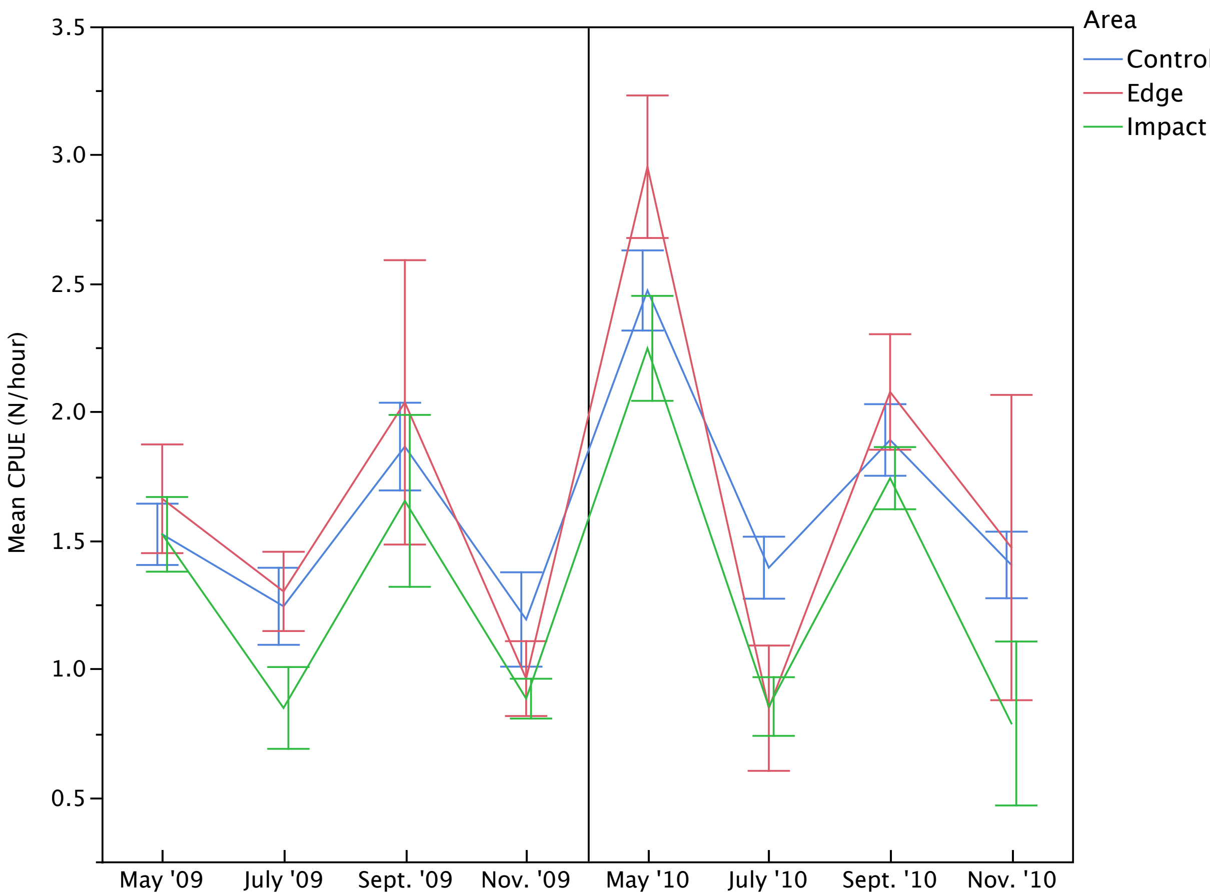

Figure 3.2. Monthly log (n+1) transformed mean CPUE (N per hour) collected by fyke nets at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition.

3.3.2 Purse Seine

Purse seine tows collected a total of 102,155 individuals during this study. Abundance peaked in May 2010 (Figure 3.3). Overall, 13,422 individuals were collected before the reef was constructed while 88,733 individuals were collected afterwards, representing an increase of > 5-fold. Impact, control, and edge areas also displayed increases in mean density (N/m^2) between periods when analyzed separately. Edge areas had the highest mean density before reef construction, while control areas, which increased by ~9-fold, had the highest mean density after reef addition (Figure 3.3). Mean

density at the marsh edge areas also increased dramatically (> 3-fold), while impact areas increased by 58% after the reefs were constructed. ANOVA results showed no significance in the Period*Area interaction term (p=0.28).

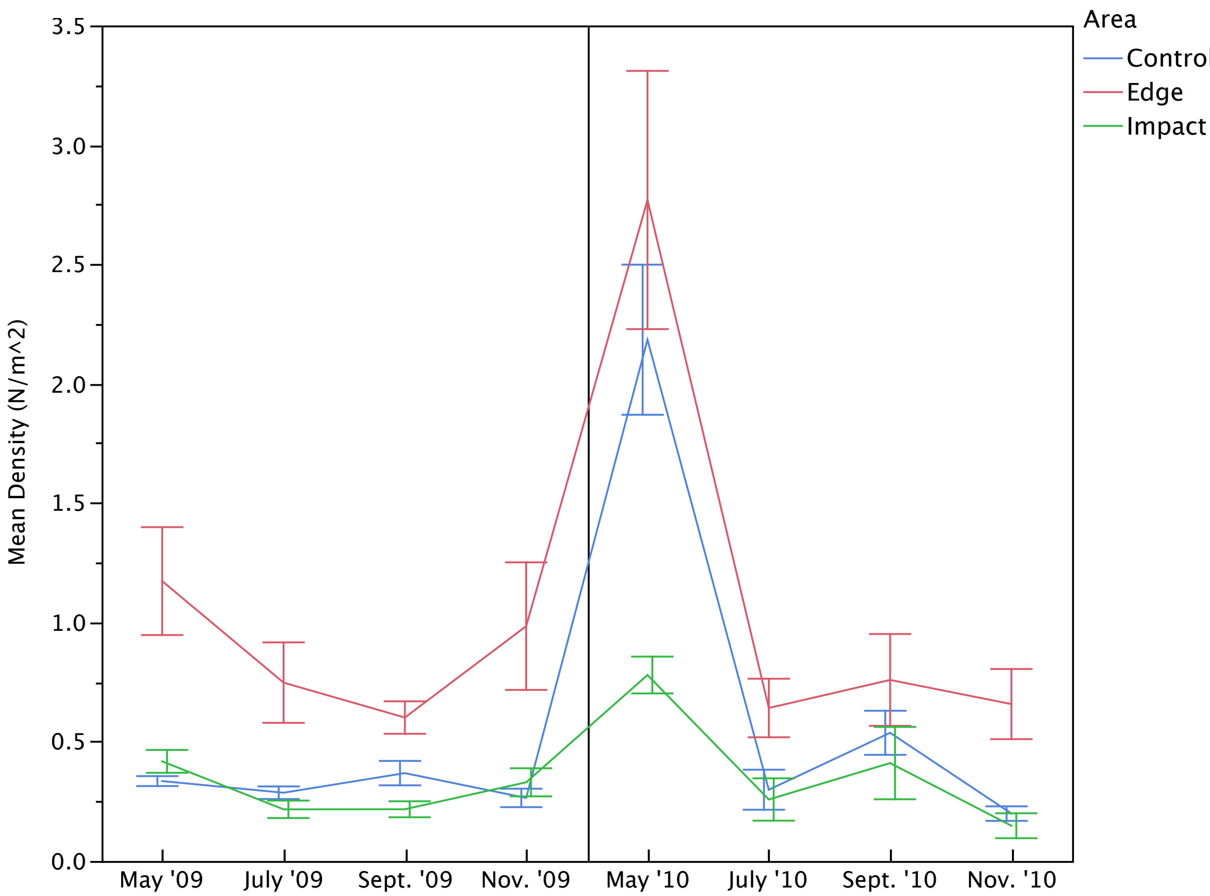

Figure 3.3. Monthly log (n+1) transformed mean density (N per m^2) collected by purse seine at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition.

3.4 Nekton Biomass

3.4.1 Fyke Nets

Over 92,327g of biomass were collected by fyke nets during this study. Mean CPUE (g/hour) was highest in September 2009 before the reefs were constructed and was lowest

during November both before and after reef construction (Figure 3.4). Overall, mean CPUE decreased after artificial reef construction. When analyzed separately, CPUE at impact, control, and edge areas also decreased after the reef was constructed (Figure 3.4). Edge areas had the highest mean CPUE in both periods despite decreasing the most between periods. Impact areas had the lowest mean CPUE in both periods. Control areas decreased in mean CPUE between periods with mean CPUE similar to edge areas in the after period. ANOVA results showed the Period*Area interaction term to not be significant (p=0.18).

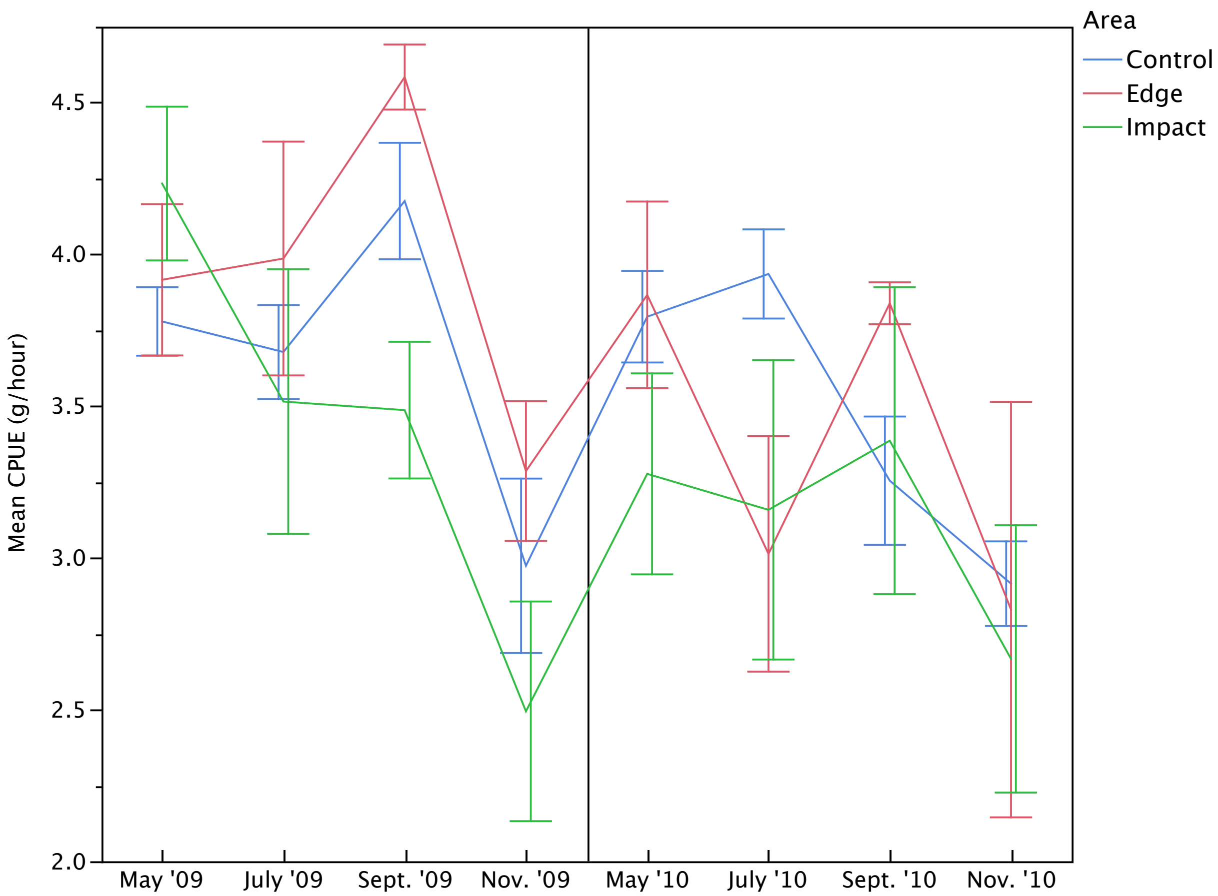

Figure 3.4. Monthly log (n+1) transformed mean CPUE (g per hour) collected by fyke nets at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition.

3.4.2 Purse Seine

Over 146,022g of biomass were collected by purse seine during this study. Purse seine tows collected over 54,676g of biomass before reef construction, and over 91,346g of biomass after reef addition. Mean densities (g/m^2) peaked in May 2010 after artificial reef addition (Figure 3.5). Impact, control, and edge areas also increased in mean density between periods when analyzed separately (Figure 3.5). Edge areas had the highest mean density in both periods, while impact areas had the lowest mean density throughout the study.

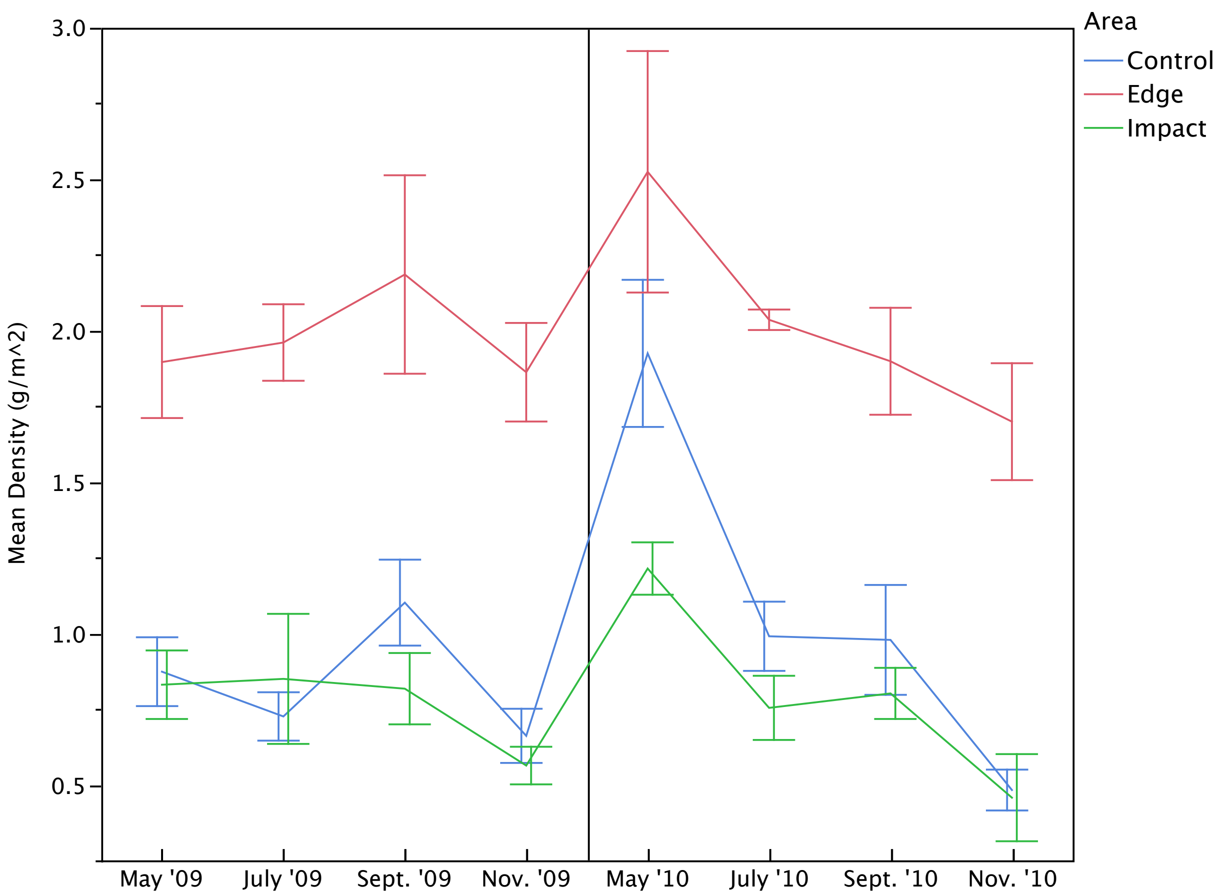

Figure 3.5. Monthly log (n+1) transformed mean density (g per m^2) collected by purse seine at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition.

Control areas showed the greatest increase, more than doubling in mean density collected between periods. Impact areas and edge areas increased slightly in mean density between periods. ANOVA results showed no significance in the Period*Area interaction term (p=0.22).

3.5 Species Richness

3.5.1 Fyke Nets

Fyke nets collected 44 different taxonomic groups during this study. Species richness peaked in May 2010 after artificial reef deployment and was lowest during the month of November in both periods (Figure 3.6). Species richness ranged from 0 to 17 and mean species richness was 7 during both before and after periods. Mean species richness at edge areas was 8 during both periods, which was the highest mean species richness of all areas. Control areas maintained a mean species richness of 7 during both periods, while impact areas decreased slightly from a mean species richness of 7 during the before period to 6 during the after period. ANOVA results showed no significance in the Period*Area interaction term (p=0.84).

3.5.2 Purse Seine

A total of 57 taxonomic groups were collected by purse seine during this study. Species richness of purse seine samples ranged from 3 to 22. Mean species richness was highest during July 2009 before artificial reef construction and was lowest in November 2010 after reef addition (Figure 3.7). Mean species richness during the before period was 12 and decreased slightly to 11 in the after period. Edge areas had the highest mean species richness in both periods, with a mean species richness of 17 during the before period and

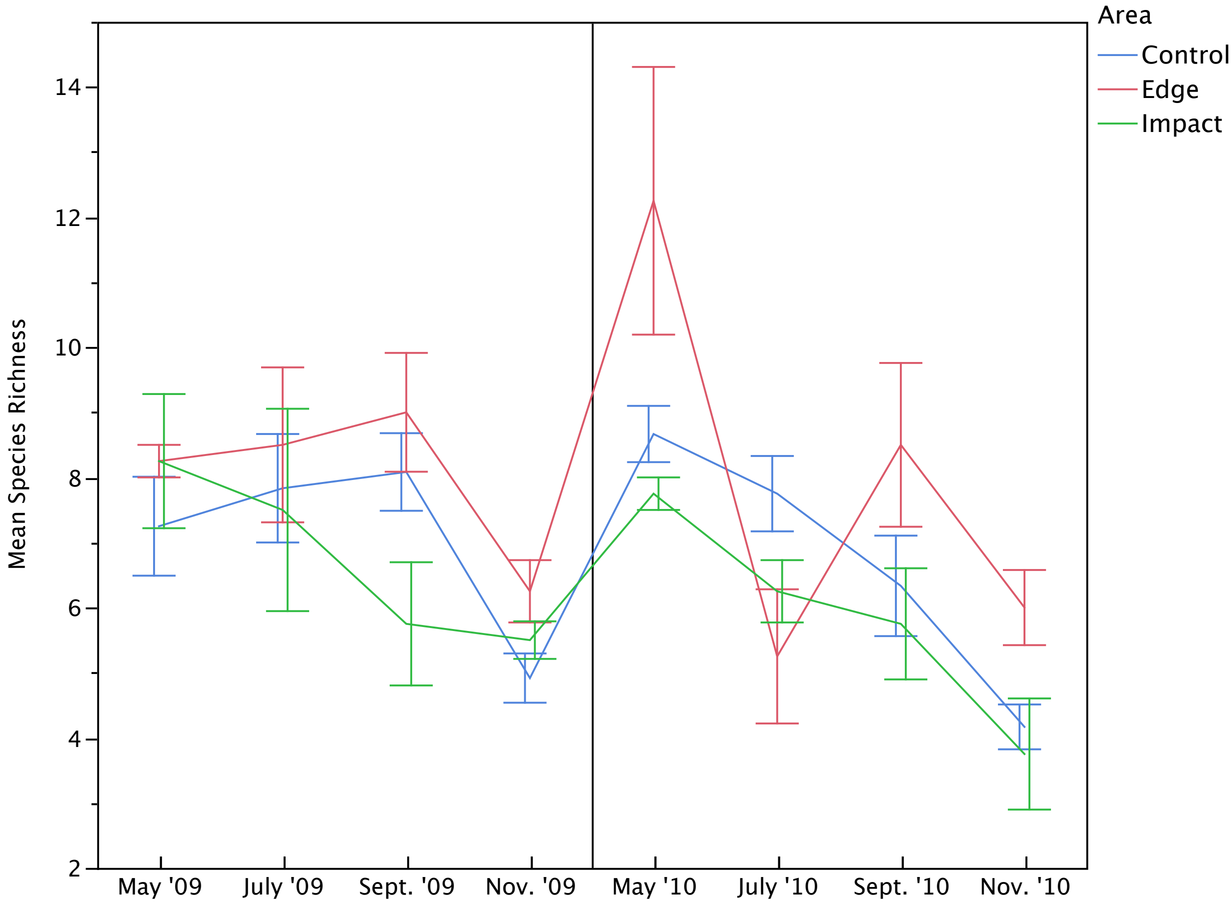

Figure 3.6. Monthly mean species richness collected by fyke nets at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition.

14 in the after period. Mean species richness at impact areas was 11 during both periods. Mean species richness at control areas decreased from 11 to 10 after reef addition. ANOVA results show no significance in the Period*Area interaction term (p=0.06).

3.6 Shannon-Weaver Diversity (H')

3.6.1 Fyke Nets

Shannon-Weaver diversity (H') of fyke net samples ranged from 0 to 2.07 with an overall mean diversity of 1.16. Diversity peaked during the month of July in both periods and was lowest in November 2010 after reef deployment (Figure 3.8). Mean diversity was

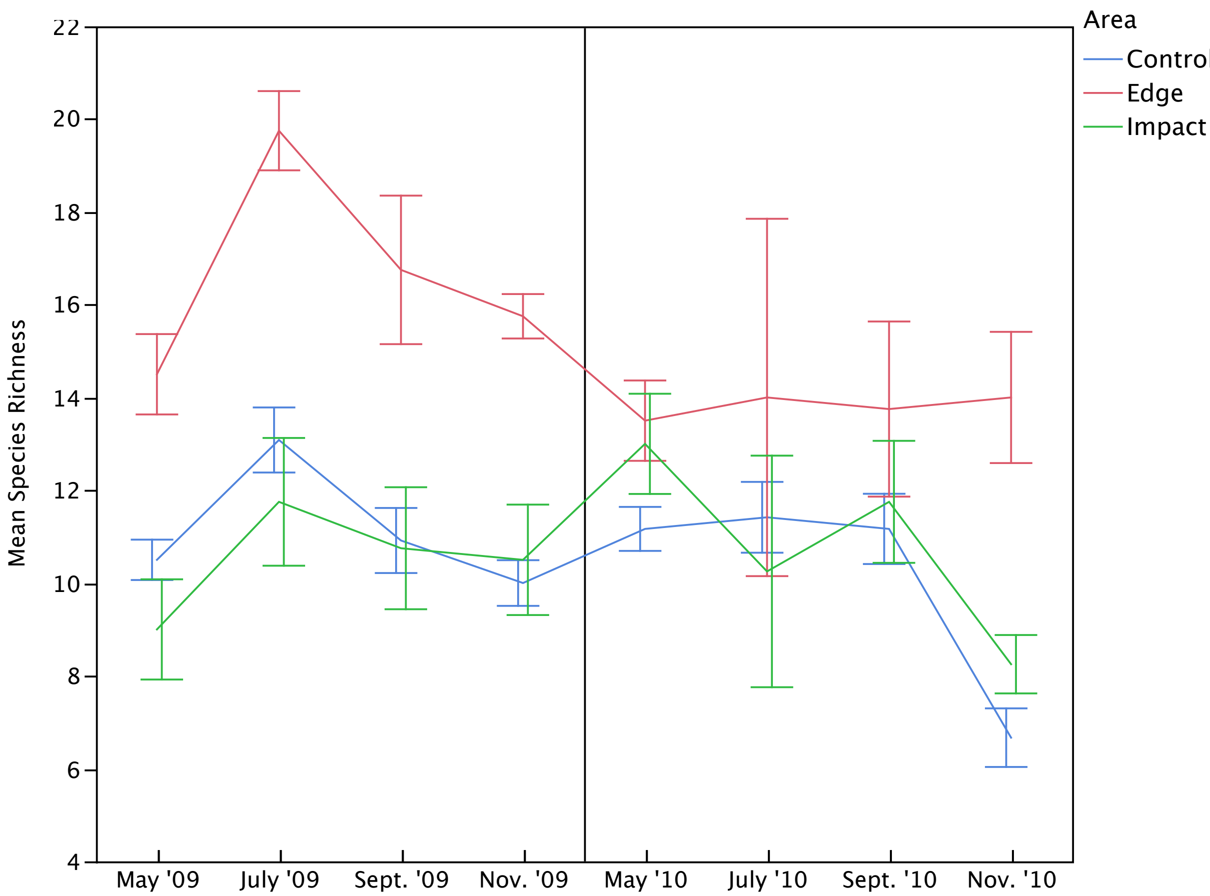

Figure 3.7. Monthly mean species richness collected by purse seine at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition.

1.28 before the reefs were constructed and decreased to 1.04 after reef addition. In both periods, mean diversity was highest at edge areas, followed by impact areas, and lowest at control areas. Edge areas decreased in mean diversity from 1.43 to 1.13 between periods. Impact and control areas also decreased in mean diversity between periods from 1.30 and 1.22, respectively, to 1.10 and 0.99, respectively. ANOVA results of diversity comparisons showed no significant Period*Area interaction (p=0.71).

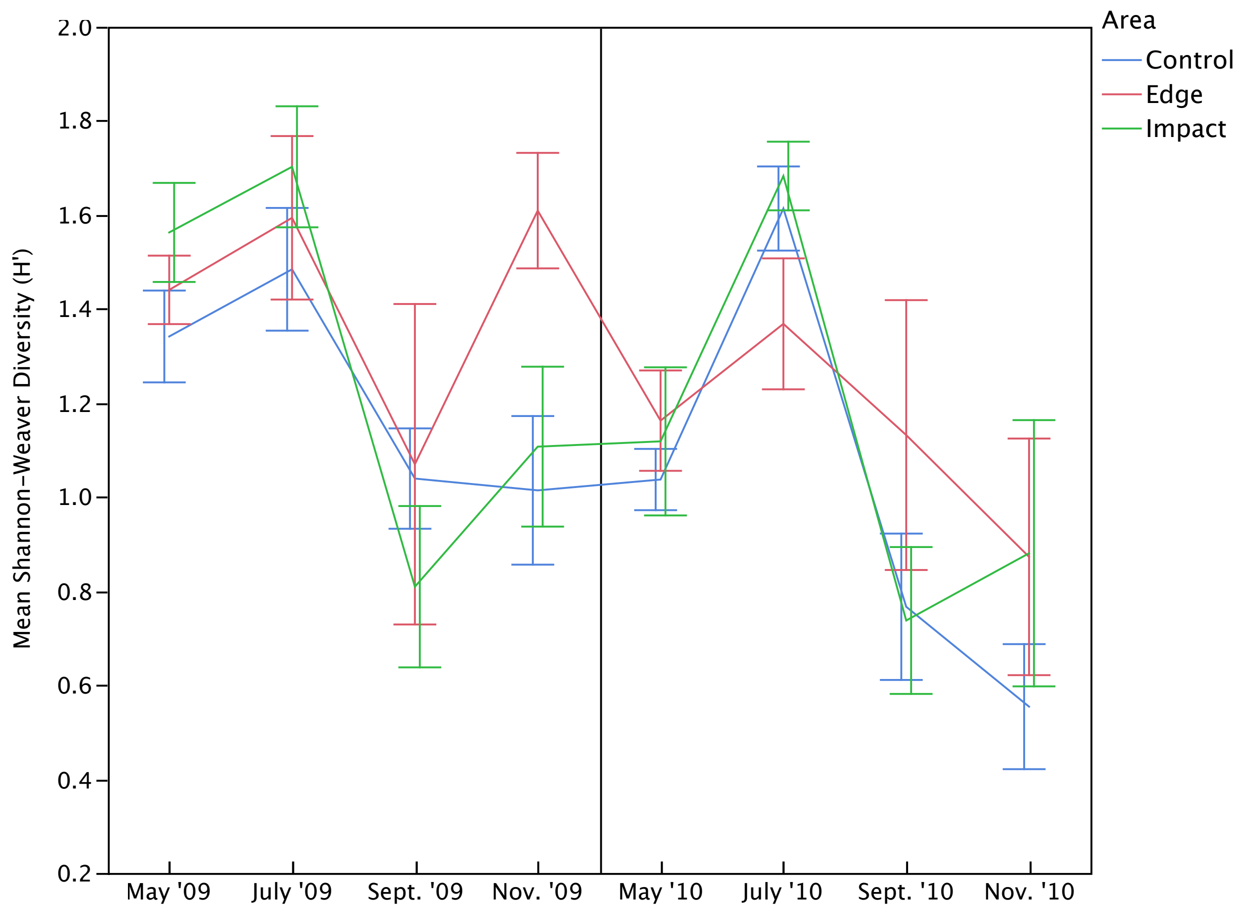

Figure 3.8. Monthly mean Shannon-Weaver diversity (H') collected by fyke nets at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition.

3.6.2 Purse Seine

Shannon-Weaver diversity of purse seine samples ranged from 0.16 to 2.54 with an overall mean diversity of 1.53. Mean diversity peaked in July 2009 and was lowest in May 2010 (Figure 3.9). Mean diversity was 1.72 during the before period and decreased to 1.34 in the after period. Prior to artificial reef construction mean diversity was lowest at impact areas where H'=1.66, while mean diversity at control areas and edge areas were 1.73 and 1.72, respectively (Figure 3.9). After reef addition, mean diversity at all areas decreased. Mean diversity decreased the least at impact areas, which had the highest mean diversity

after artificial reef construction (H'=1.51). Edge areas decreased in mean diversity to 1.36 during the after period, while control areas decreased to a mean diversity of 1.28. ANOVA results showed no significance in the Period*Area interaction term (p=0.15).

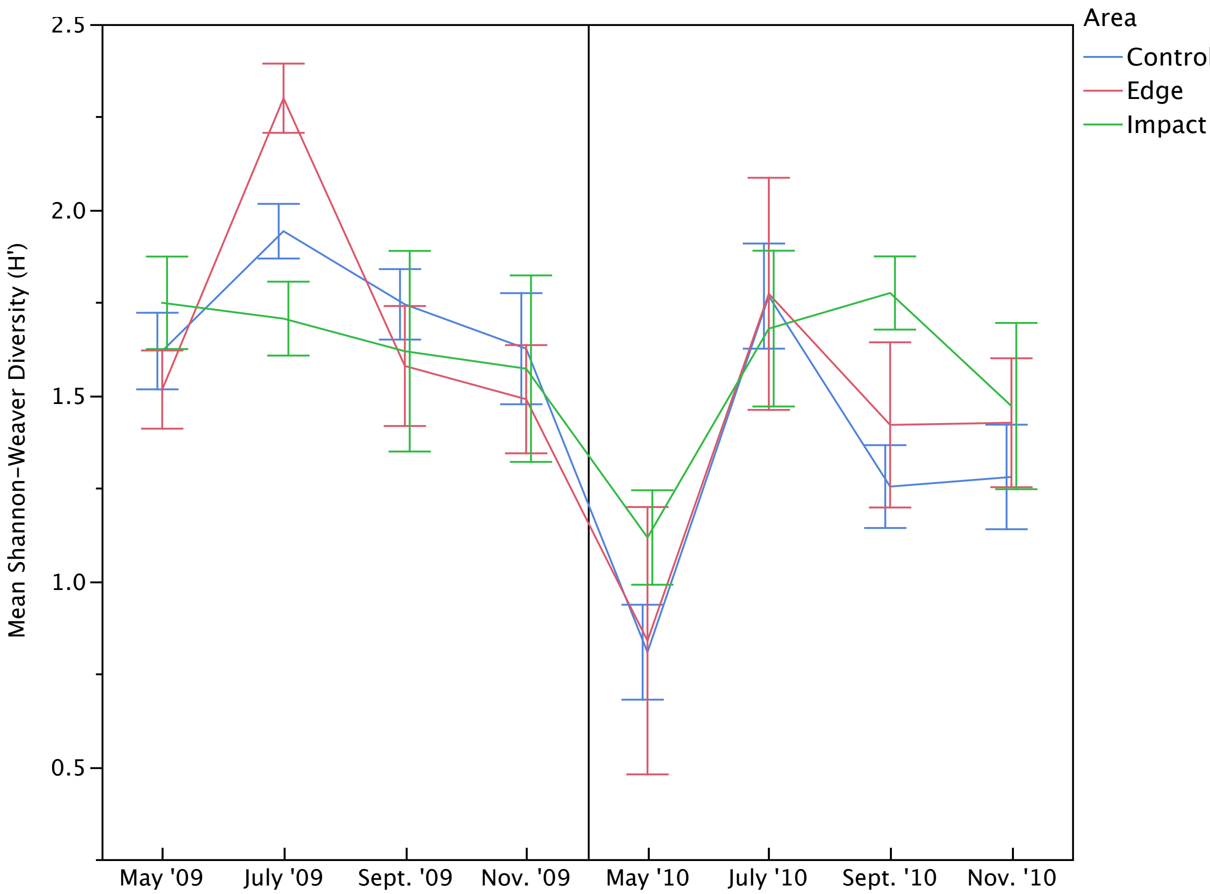

Figure 3.9. Monthly mean Shannon-Weaver diversity (H') collected by purse seine at control (blue), marsh edge (red), and impact (green) areas. Vertical line indicates time of artificial reef addition.

3.7 Community Abundance Distributions

3.7.1 Fyke Nets

Analysis of fyke net abundance distributions (N/hour) showed no significant differences between areas before and after reef addition (PERMANOVA; Period*Area p=0.16; Table 3.3).

3.7.2 Purse Seine

Analysis of purse seine abundance distributions (N/m^2) showed a significance in the Period*Area interaction term (PERMANOVA; p<0.01) (Table 3.4). ANOSIM pairwise comparisons of the term Interaction showed before-control (BC) sites were significantly different from after-edge (AE), before-edge (BE), and after-control (AC) sites (p=0.01%), and before-impact (BI) sites were significantly different from AE sites (p=0.01%). However, the comparison of interest between before-impact (BI) and after-impact (AI) sites was not significant (p=36.8%).

Table 3.3. PERMANOVA output of log(n+1) transformed nekton abundance distributions per hour from fyke net samples (α=0.01).

Factor	df	SS	MS	Pseudo-F	P-value
Period	1	9369	9369	1.2522	0.0718
Month	3	92821	30940	9.8331	0.0001
Pond	3	15710	5236.7	1.642	0.1432
Area (Pond)	6	7767.5	1294.6	0.91592	0.5739
Period*Month	3	25204	8401.3	8.2751	0.0001
Period*Pond	3	5379.5	1793.2	1.7662	0.0256
Month*Pond	9	28703	3189.2	3.1413	0.0001
Period*Area(Pond)	6	7472.1	1245.3	1.2266	0.1609
Month*Area(Pond)	18	25442	1413.4	1.3922	0.0103

Table 3.4. PERMANOVA output of log(n+1) transformed nekton abundance distributions per m^2 from purse seine samples (α=0.01).

Factor	df	SS	MS	Pseudo-F	P-value
Period	1	10189	10189	0.89105	0.1275
Month	3	76062	25354	6.7531	0.0001
Pond	3	39556	13185	3.4653	0.0013
Area (Pond)	6	33707	5617.9	2.9562	0.0001
Period*Month	3	36969	12323	10.556	0.0001
Period*Pond	3	9699.2	3233.1	2.7693	0.0001
Month*Pond	9	34245	3805	3.2592	0.0001
Period*Area(Pond)	6	11636	1939.4	1.6612	0.0026
Month*Area(Pond)	18	34207	1900.4	1.6278	0.0001

3.8 Community Biomass Distributions

3.8.1 Fyke Nets

Analysis of fyke net biomass distributions (g/hour) showed a significant difference between areas before and after reef addition (PERMANOVA; Period*Area $p<0.01$; Table 3.5). ANOSIM pairwise comparisons of the term Interaction showed significant differences in biomass distributions between BC and AE sites (p=0.01%), BE and AE sites (p=0.1%), and BC and AC sites (p=0.03%). The comparison of interest between BI and AI sites was not significantly different (p=35.3%).

Table 3.5. PERMANOVA output of log(n+1) transformed nekton biomass per hour from fyke net samples ($\alpha=0.01$).

Factor	df	SS	MS	Pseudo-F	P-value
Period	1	11034	11034	1.2791	0.034
Month	3	63281	21094	8.448	0.0001
Pond	3	17734	5911.4	2.3442	0.0189
Area (Pond)	6	10103	1683.8	0.96949	0.5115
Period*Month	3	27693	9231	7.3525	0.0001
Period*Pond	3	7357.1	2452.4	1.9533	0.0055
Month*Pond	9	22696	2521.7	2.0086	0.0001
Period*Area(Pond)	6	12302	2050.3	1.6331	0.0058
Month*Area(Pond)	18	31262	1736.8	1.3833	0.0039

3.8.2 Purse Seine

Analysis of purse seine species biomass distributions (g/m^2) showed no significant difference in the Period*Area interaction term (PERMANOVA; p=0.22) (Table 3.6).

3.9 SIMPER Analysis

3.9.1 Fyke Nets

SIMPER analysis of fyke net abundance distributions identified 13 species as contributing over 90% to the dissimilarities between impact areas before and after

Table 3.6. PERMANOVA output of log(n+1) transformed nekton biomass distributions per m^2 from purse seine samples (α=0.01).

Factor	df	SS	MS	Pseudo-F	P-value
Period	1	9266.1	9266.1	1.1544	0.0488
Month	3	60859	20286	5.7294	0.0001
Pond	3	43987	14662	4.093	0.0002
Area (Pond)	6	44602	7433.7	3.6627	0.0001
Period*Month	3	25483	8494.4	5.9972	0.0001
Period*Pond	3	7850.2	2616.7	1.8474	0.005
Month*Pond	9	32241	3582.3	2.5291	0.0001
Period*Area(Pond)	6	9698.5	1616.4	1.1412	0.215
Month*Area(Pond)	18	36533	2029.6	1.4329	0.0003

artificial reef addition (Table 3.7). Three species contributed over 50% to the dissimilarity between BI and AI samples; white shrimp (*Litopenaeus setiferus,* 29.76%), brown shrimp (*Farfantepenaeus aztecus*, 16.57%), and blue crab (*Callinectes sapidus*, 8.12%). SIMPER analysis of fyke net biomass distributions showed that 14 species contributed over 90% of

Table 3.7. SIMPER output of the species that explain >90% of the dissimilarity in fyke net community abundance distributions (N/hour) at impact areas before and after artificial reef addition.

Species	Before Mean CPUE (N/hour)	After Mean CPUE (N/hour)	% contribution to dissimilarity	% cumulative contribution
White shrimp (*L. setiferus*)	0.78	0.61	29.76	29.76
Brown shrimp (*F. aztecus*)	0.24	0.44	16.57	46.33
Blue crab (*C. sapidus*)	0.23	0.19	8.12	54.45
Spot (*L. xanthurus*)	0.09	0.15	6.20	60.65
Pinfish (*L. rhomboides*)	0.05	0.14	5.32	65.98
Silver perch (*B. chrysoura*)	0.05	0.07	4.46	70.44
Gulf menhaden (*B. patronus*)	0.00	0.15	4.02	74.45
Sand seatrout (*C. arenarius*)	0.07	0.04	3.69	78.14
Gulf killifish (*F. grandis*)	0.02	0.05	2.94	81.07
Atlantic croaker (*M. undulatus*)	0.02	0.06	2.85	83.93
Grass shrimp (*P. pugio*)	0.04	0.03	2.65	86.58
Striped mullet (*M. cephalus*)	0.03	0.03	2.30	88.88
Highfin goby (*G. oceanicus*)	0.04	0.01	2.21	91.09

the dissimilarities between impact areas before and after artificial reef addition (Table 3.8). Blue crab contributed the most to this dissimilarity (17.63%), followed by white shrimp (10.96%), silver perch (*Bairdiella chrysoura,* 9.02%), and brown shrimp (8.01%).

Table 3.8. SIMPER output of the species that explain >90% of the dissimilarity in fyke net community biomass distributions (g/hour) at impact areas before and after artificial reef addition.

Species	Before Mean CPUE (g/hour)	After Mean CPUE (g/hour)	% contribution to dissimilarity	% cumulative contribution
Blue crab (*C. sapidus*)	2.20	1.89	17.63	17.63
White shrimp (*L. setiferus*)	1.43	0.89	10.96	28.59
Silver perch (*B. chrysoura*)	0.51	0.60	9.02	37.61
Brown shrimp (*F. aztecus*)	0.44	0.67	8.01	45.62
Pinfish (*L. rhomboides*)	0.30	0.65	7.25	52.87
Atlantic croaker (*M. undulatus*)	0.34	0.49	6.88	59.75
Spot (*L. xanthurus*)	0.36	0.54	6.24	65.99
Striped mullet (*M. cephalus*)	0.40	0.23	5.22	71.21
Highfin goby (*G. oceanicus*)	0.42	0.12	4.80	76.01
Southern flounder (*P. lethostigma*)	0.14	0.36	3.80	79.81
Spotted seatrout (*C. nebulosus*)	0.13	0.21	2.92	82.73
Sand seatrout (*C. arenarius*)	0.28	0.07	2.92	85.65
Gulf killifish (*F. grandis*)	0.17	0.13	2.62	88.27
Hardhead catfish (*A. felis*)	0.18	0.05	2.55	90.82

3.9.2 Purse Seine

SIMPER analysis of purse seine abundance distributions identified 10 species as contributing over 90% to the dissimilarities at impact areas between the before period and the after period (Table 3.9). Brown shrimp contributed the most to these dissimilarities (16.34%), followed by bay anchovy (*Anchoa mitchilli*, 14.74%), white shrimp (14.30%), and Gulf menhaden (*Brevoortia patronus*, 10.43%). SIMPER analysis of purse seine biomass distributions identified 13 species as contributing more than 90% to the

Table 3.9. SIMPER output of the species that explain >90% of the dissimilarity in purse seine community abundance distributions (N/m^2) at impact areas before and after artificial reef addition.

Species	Before Mean Density (N/m^2)	After Mean Density (N/m^2)	% contribution to dissimilarity	% cumulative contribution
Brown shrimp (*F. aztecus*)	0.05	0.11	16.34	16.34
Bay anchovy (*A. mitchilli*)	0.03	0.10	14.74	31.07
White shrimp (*L. setiferus*)	0.07	0.05	14.30	45.38
Gulf menhaden (*B. patronus*)	0.04	0.04	10.43	55.81
Spot (*L. xanthurus*)	0.04	0.02	9.78	65.58
Atlantic croaker (*M. undulatus*)	0.02	0.07	9.44	75.02
Bay whiff (*C. spilopterus*)	0.03	0.02	5.87	80.89
Sand seatrout (*C. arenarius*)	0.01	0.02	4.10	84.99
Pinfish (*L. rhomboides*)	0.00	0.02	3.24	88.23
Hardhead catfish (*A. felis*)	0.00	0.01	2.00	90.23

dissimilarities between BI and AI samples (Table 3.10). The three species that contributed the most to the dissimilarities in biomass distributions were striped mullet (*Mugil cephalus*, 14.36%), Atlantic croaker (*Micropogonias undulatus*, 12.56%), and spot (*Leiostomus xanthurus*, 11.24%).

3.10 Individual Species: Fyke Nets

SIMPER analyses of fyke net samples identified 11 species as contributing to differences in both community abundance distributions (N/hour) and community biomass distributions (g/hour) of impact areas between the before period and after period: Atlantic croaker (*Micropogonias undulatus*), blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), Gulf killifish (*Fundulus grandis*), highfin goby (*Gobionellus oceanicus*), pinfish (*Lagodon rhomboides*), sand seatrout (*Cynoscion arenarius*), silver perch

(*Bairdiella chrysoura*), spot (*Leiostomus xanthurus*), striped mullet (*Mugil cephalus*), and white shrimp (*Litopenaeus setiferus*).

Table 3.10. SIMPER output of the species that explain >90% of the dissimilarity in purse seine community biomass distributions (g/m^2) at impact areas before and after artificial reef addition.

Species	Before Mean Density (g/m^2)	After Mean Density (g/m^2)	% contribution to dissimilarity	% cumulative contribution
Striped mullet (*M. cephalus*)	0.17	0.13	14.36	14.36
Atlantic croaker (*M. undulatus*)	0.06	0.23	12.56	26.91
Spot (*L. xanthurus*)	0.18	0.09	11.24	38.15
Gulf menhaden (*B. patronus*)	0.07	0.06	7.17	45.32
Brown shrimp (*F. aztecus*)	0.06	0.11	7.05	52.37
Blue crab (*C. sapidus*)	0.14	0.01	6.92	59.29
Pinfish (*L. rhomboides*)	0.01	0.10	6.47	65.76
Hardhead catfish (*A. felis*)	0.06	0.06	5.87	71.63
Bay anchovy (*A. mitchilli*)	0.03	0.08	5.15	76.78
White shrimp (*L. setiferus*)	0.08	0.05	4.95	81.73
Bay whiff (*C. spilopterus*)	0.05	0.04	4.07	85.80
Red drum (*S. ocellatus*)	0.00	0.08	3.58	89.38
Highfin goby (*G. oceanicus*)	0.01	0.02	1.96	91.34

3.10.1. Atlantic croaker (*Micropogonias undulatus*)

Overall, 141 Atlantic croaker were collected by fyke nets during this study (Table 3.1). Atlantic croaker increased in mean abundance CPUE (N/hour) by ~4-fold and mean biomass CPUE (g/hour) by ~2-fold from the before period to the after period, while average weight and average standard length (SL) per individual decreased (Table 3.11). At impact areas, average weight and average SL of Atlantic croaker also decreased between periods, while mean CPUE (N/hour and g/hour) increased (Figure 3.10). At control areas, Atlantic croaker increased in mean abundance and biomass CPUE, however decreased slightly in average weight and average SL between the before and after periods. Atlantic

Table 3.11. Atlantic croaker (*Micropogonias undulatus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.02 (±0.01)	0.81 (±0.36)	34.91 (±10.68)	93.15 (±10.56)
After	0.11 (±0.03)	1.66 (±0.34)	14.57 (±2.60)	73.64 (±3.07)
BI	0.02 (±0.01)	1.94 (±1.53)	105.30 (±39.52)	155.00 (±35.85)
AI	0.07 (±0.04)	2.04 (±1.23)	26.83 (±12.89)	86.20 (±10.63)
BC	0.03 (±0.01)	0.45 (±0.19)	14.99 (±4.50)	76.05 (±7.42)
AC	0.12 (±0.04)	1.51 (±0.33)	13.22 (±2.52)	75.02 (±3.68)
BE	<0.01	0.77	171.60	205.00
AE	0.15 (±0.06)	1.70 (±0.71)	11.59 (±4.86)	64.14 (±5.78)

croaker collected at marsh edge areas increased drastically in mean abundance per hour and mean biomass per hour after artificial reef addition, while average weight and average SL decreased (Figure 3.10). These dramatic changes at edge areas are a result of only one individual being collected at edge areas before reef construction. ANOSIM results show a significant difference in Period*Area interactions for Atlantic croaker mean abundance per hour (p=0.2%) and mean biomass per hour (p=0.1%). Pairwise comparisons show significant differences in Atlantic croaker mean abundance per hour between BC and AC sites (p=0.1%), BE and AC sites (p=0.06%), and BE and AE sites (p=0.3%). No significant difference was found between the contrast of interest, BI versus AI sites (p=43.8%). Pairwise comparisons of Atlantic croaker mean biomass per hour also show significant differences between BC and AC sites (p=0.05%), BE and AC sites (p=0.04%), and BE and AE sites (p=0.3%), as well as between BI and AC sites (p=0.6%). No significant difference was found between BI and AI sites (p=23.6%). In the after period, no significant differences were found between habitat types in Atlantic croaker mean abundance per hour (p=34%)

or mean biomass per hour (p=28.8%). ANOSIM results showed no significant differences between Period*Area interactions in Atlantic croaker mean individual weight (p=10.7%) or mean SL (p=4.5%). In the after period, no significant difference was found between habitat types in Atlantic croaker average weight (p=25.5%) or average SL (p=22.4%).

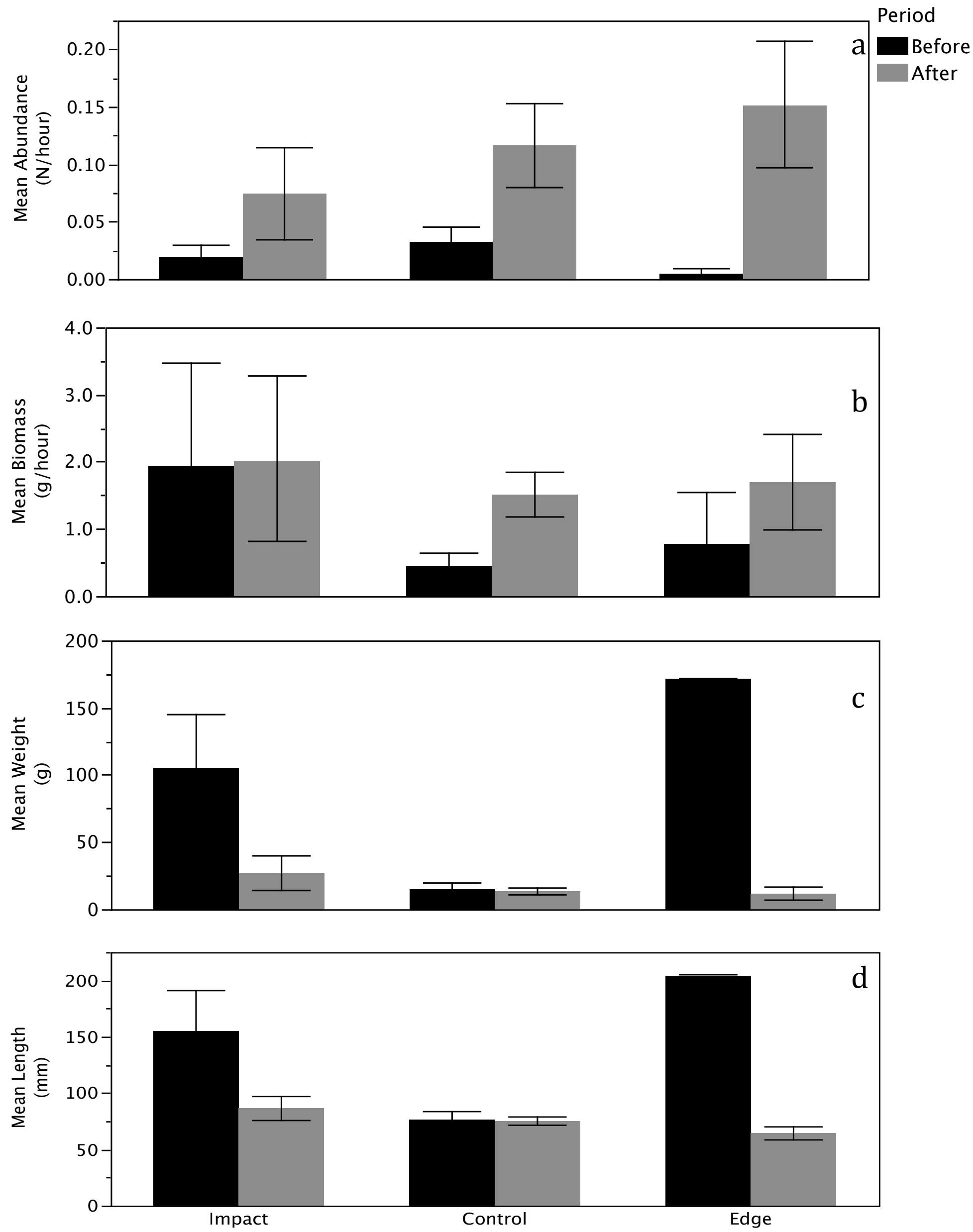

Figure 3.10. Fyke net catches of Atlantic croaker (*Micropogonias undulatus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.2 Blue crab (*Callinectes sapidus*)

A total of 552 blue crab were collected by fyke nets during this study (Table 3.1). Overall, blue crab mean abundance per hour, mean biomass per hour, average weight, and average carapace width decreased (Table 3.12). This pattern of decrease was also seen at impact, control, and edge areas when compared separately (Figure 3.11). Mean abundance and biomass per hour of blue crab were highest at edge areas and lowest at impact areas throughout the study. ANOSIM results showed no significant difference in Period*Area interactions for blue crab mean abundance per hour (p=1.3%), mean biomass per hour (p=13.8%), average weight (p=18.4%), and average carapace width (p=13.1%). There were also no significant differences in blue crab mean abundance CPUE (p=48.5%), mean biomass CPUE (p=41.7%), average weight (p=55.7%), and average carapace width (p=56.8%) between habitat types during the after period.

Table 3.12. Blue crab (*Callinectes sapidus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g) , and mean individual carapace width (mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean Carapace Width mm (±SE)
Before	0.30 (±0.03)	28.16 (±3.35)	93.14 (±3.98)	91.84 (±2.56)
After	0.23 (±0.03)	12.64 (±1.99)	56.02 (±4.10)	78.37 (±3.07)
BI	0.27 (±0.06)	23.22 (±7.66)	84.97 (±10.94)	89.05 (±6.46)
AI	0.22 (±0.05)	13.89 (±4.62)	60.39 (±8.40)	86.55 (±6.71)
BC	0.30 (±0.04)	27.73 (±4.38)	93.64 (±5.15)	92.91 (±3.32)
AC	0.25 (±0.04)	14.73 (±2.83)	60.80 (±5.37)	80.86 (±3.87)
BE	0.35 (±0.06)	34.40 (±7.16)	98.05 (±7.34)	91.28 (±5.12)
AE	0.17 (±0.06)	5.25 (±1.85)	30.35 (±8.10)	57.41 (±6.68)

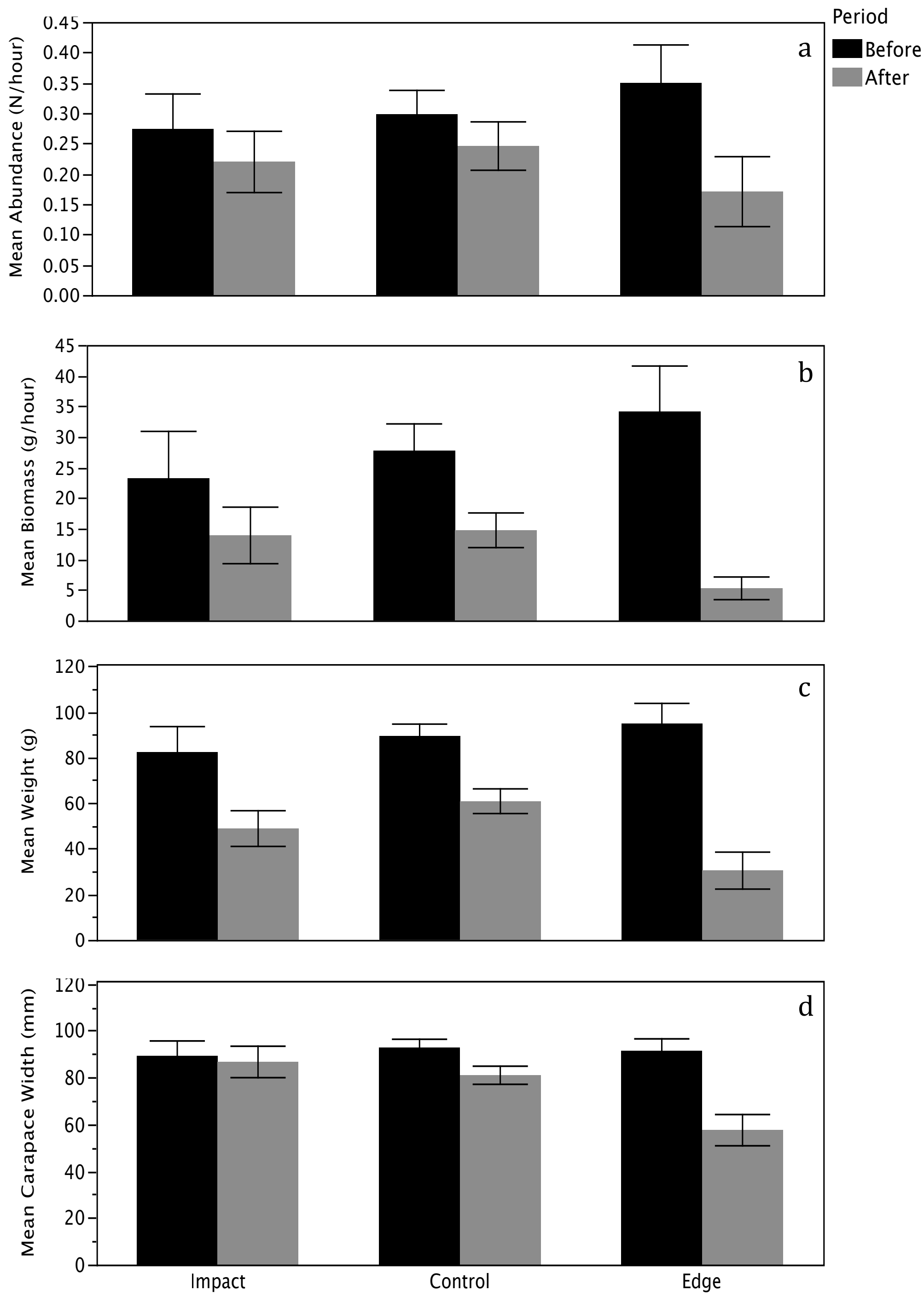

Figure 3.11. Fyke net catches of blue crab (*Callinectes sapidus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean carapace width (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.3 Brown shrimp (*Farfantepenaeus aztecus*)

Overall, 2,577 brown shrimp were collected by fyke nets during this study (Table 3.1). Brown shrimp increased in mean abundance per hour by ~3-fold and mean biomass per hour by ~2-fold after artificial reef construction, but average weight and average rostrum length decreased (Table 3.13). When comparing the different areas individually, impact areas increased in brown shrimp mean abundance CPUE by ~2-fold and mean biomass CPUE more than doubled (Figure 3.12). Average weight and average rostrum length of brown shrimp decreased at impact areas between periods. At control areas, brown shrimp mean abundance per hour increased ~3-fold, mean biomass per hour increased more than 2-fold, and average rostrum length slightly increased. Average weight of brown shrimp at control areas decreased. Edge areas showed >2-fold increases in mean abundance per hour and mean biomass per hour of brown shrimp, while average weight and average rostrum length slightly decreased (Figure 3.12). No significant differences were found between Period*Area interactions of brown shrimp mean abundance per hour

Table 3.13. Brown shrimp (*Farfantepenaeus aztecus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual rostrum length (mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean Rostrum Length mm (±SE)
Before	0.54 (±0.14)	1.55 (±0.43)	2.85 (±0.05)	26.70 (±0.20)
After	2.12 (±0.50)	5.06 (±1.24)	2.39 (±0.02)	26.42 (±0.12)
BI	0.40 (±0.19)	1.21 (±0.62)	3.05 (±0.13)	27.81 (±0.51)
AI	1.25 (±0.68)	2.55 (±1.29)	2.04 (±0.08)	25.19 (±0.32)
BC	0.56 (±0.21)	1.65 (±0.65)	2.93 (±0.06)	26.98 (±0.25)
AC	2.31 (±0.70)	5.72 (±1.78)	2.48 (±0.03)	27.09 (±0.15)
BE	0.63 (±0.26)	1.58 (±0.66)	2.50 (±0.10)	25.28 (±0.38)
AE	2.45 (±1.24)	5.65 (±2.92)	2.31 (±0.05)	25.24 (±0.26)

(p=16.8%), mean biomass per hour (p=28.7%), mean weight (p=83.3%), or mean rostrum length (p=86%). During the after period, there were no significant differences in brown shrimp mean CPUE or mean sizes between habitat types.

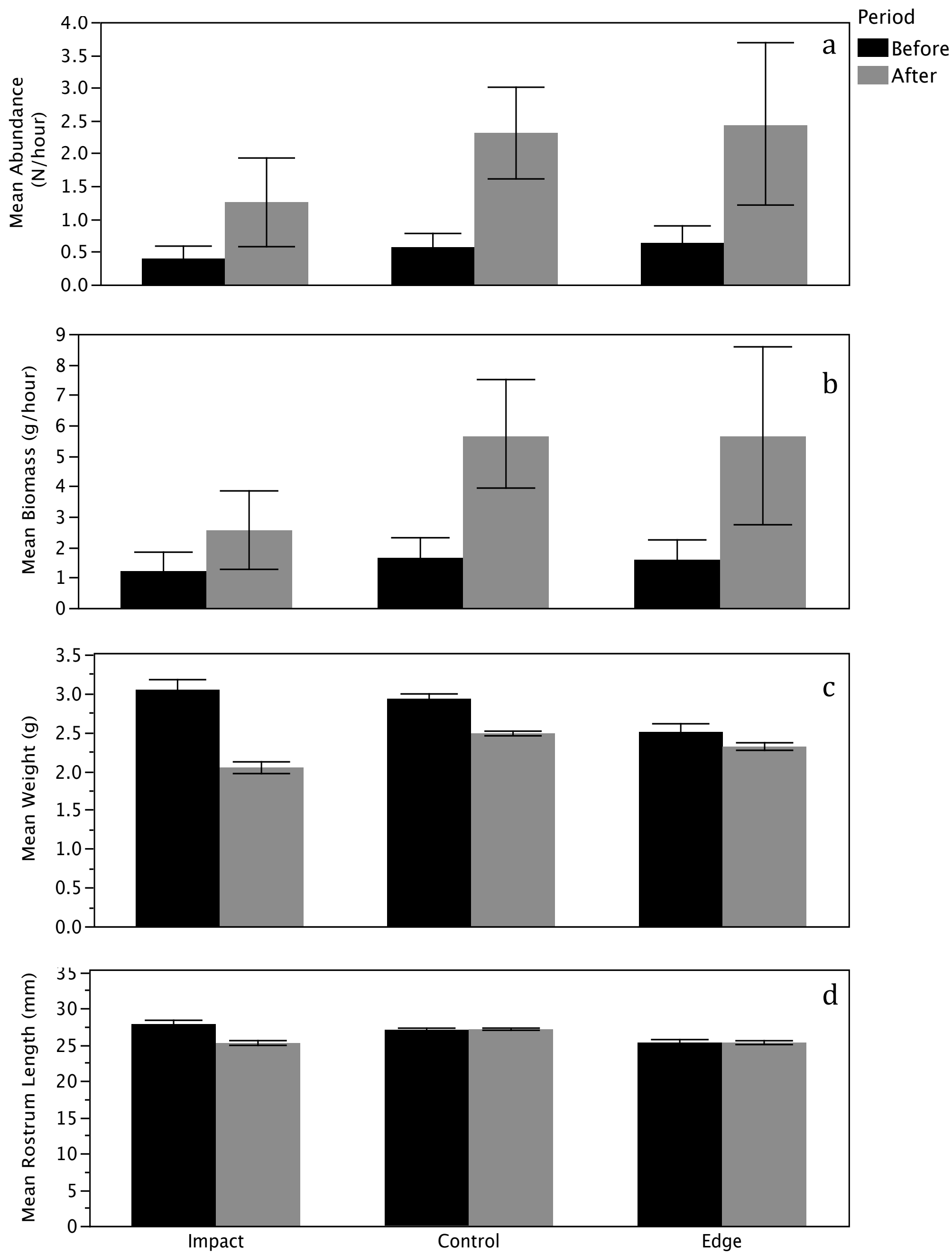

Figure 3.12. Fyke net catches of brown shrimp (*Farfantepenaeus aztecus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean rostrum length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.4 Gulf killifish (*Fundulus grandis*)

Overall, 93 Gulf killifish were collected by fyke nets during this study (Table 3.1). From the before period to the after period, Gulf killifish increased in mean abundance per hour and mean biomass per hour, but decreased in average weight and average SL (Table 3.14). At impact areas, mean abundance per hour of Gulf killifish increased 2-fold, while mean biomass per hour, mean weight, and mean SL decreased (Figure 3.13). At control areas, Gulf killifish mean abundance per hour and mean biomass per hour decreased by approximately half after reef construction and average individual size also decreased. Edge areas displayed increases in mean abundance per hour and mean biomass per hour with decreases in average weight and average SL of Gulf killifish between periods (Figure 3.13). ANOSIM results showed no significant difference in Period*Area interactions for Gulf killifish mean abundance per hour (p=53.2%), mean biomass per hour (p=55.8%), mean weight (p=71.5%), and mean SL (p=80.1%). There were also no significant differences between habitat types during the after period.

Table 3.14. Gulf killifish (*Fundulus grandis*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.03 (±0.01)	0.31 (±0.13)	9.12 (±1.14)	69.28 (±2.98)
After	0.06 (±0.03)	0.37 (±0.19)	6.34 (±0.73)	61.53 (±2.14)
BI	0.02 (±0.01)	0.28 (±0.15)	12.24 (±4.97)	76.00 (±10.76)
AI	0.07 (±0.05)	0.22 (±0.16)	3.24 (±0.32)	52.58 (±1.75)
BC	0.01 (±<0.01)	0.10 (±0.05)	10.10 (±3.16)	72.67 (±8.04)
AC	0.01 (±0.00)	0.04 (±0.03)	7.87 (±2.52)	71.67 (±6.39)
BE	0.11 (±0.06)	1.00 (±0.58)	8.35 (±1.18)	67.36 (±3.36)
AE	0.20 (±0.11)	1.50 (±0.87)	7.28 (±0.96)	63.79 (±2.78)

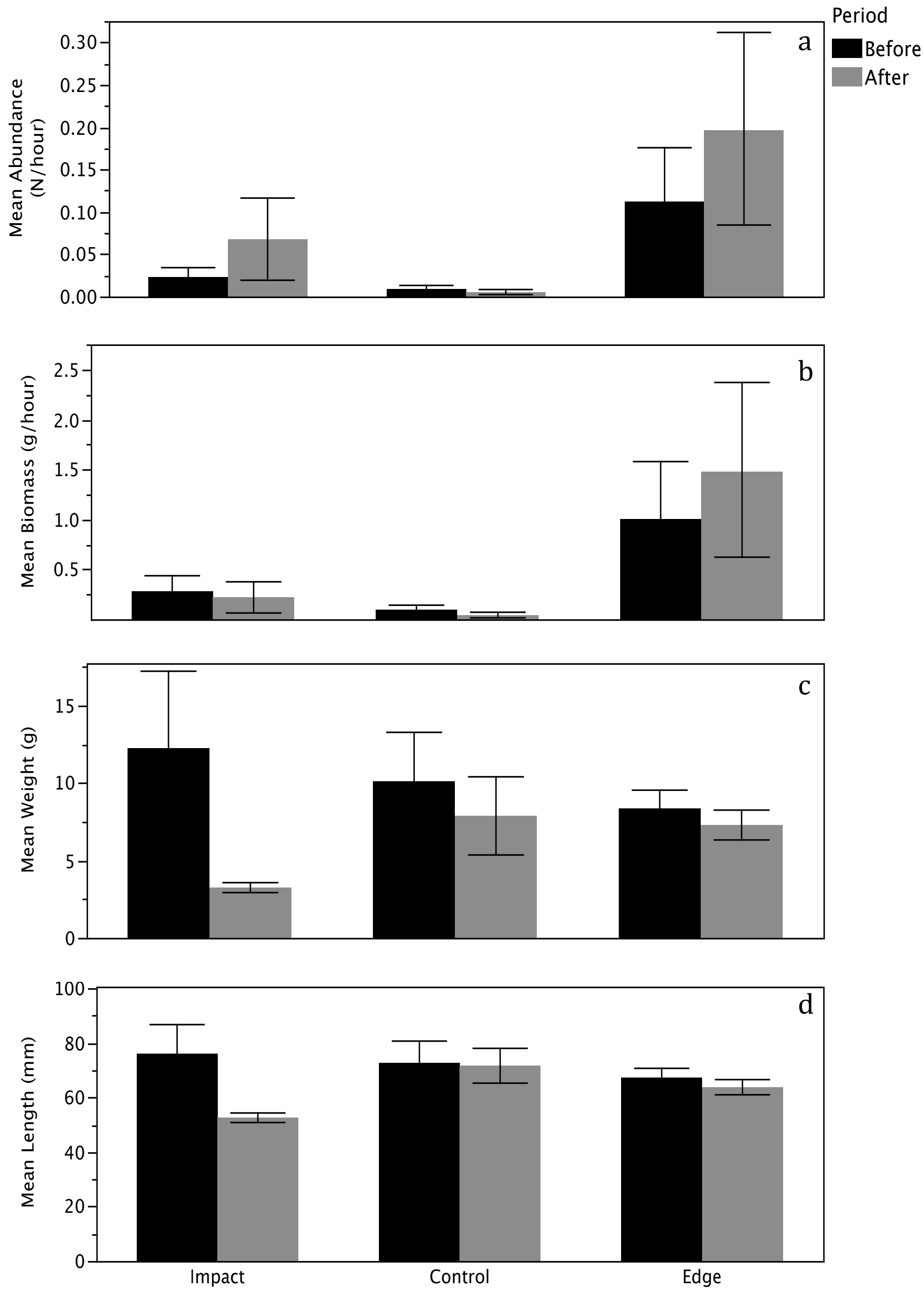

Figure 3.13. Fyke net catches of Gulf killifish (*Fundulus grandis*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour,) c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.5 Highfin goby (*Gobionellus oceanicus*)

Overall, 95 highfin goby were collected by fyke nets during this study (Table 3.1). Highfin goby decreased in mean abundance per hour, mean biomass per hour, average weight, and average SL after artificial reef construction (Table 3.15). This pattern of decrease was also seen at impact, control, and edge areas when compared individually (Figure 3.14). Highfin goby mean abundance per hour and mean biomass per hour was highest at control areas throughout the study. Impact areas decreased the most in highfin goby mean CPUE after reef construction. Largest individuals were found at impact areas and smallest individuals were found at edge areas during both periods (Figure 3.14).

Table 3.15. Highfin goby (*Gobionellus oceanicus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.06 (±0.01)	0.84 (±0.20)	14.44 (±0.93)	109.25 (±2.76)
After	0.03 (±0.01)	0.42 (±0.16)	12.82 (±0.99)	104.97 (±2.68)
BI	0.05 (±0.02)	0.82 (±0.32)	17.42 (±2.19)	119.16 (±6.28)
AI	0.01 (±0.01)	0.23 (±0.18)	14.83 (±2.81)	116.33 (±12.20)
BC	0.07 (±0.02)	0.98 (±0.31)	13.93 (±1.10)	107.42 (±3.35)
AC	0.04 (±0.02)	0.53 (±0.25)	13.50 (±1.28)	105.59 (±3.25)
BE	0.03 (±0.02)	0.43 (±0.22)	13.14 (±2.90)	105.71 (±6.74)
AE	0.03 (±0.02)	0.29 (±0.18)	9.35 (±0.69)	97.00 (±2.03)

ANOSIM results showed no significant differences in Period*Area interactions for highfin goby mean abundance per hour (p=36.4%), mean biomass per hour (p=33.9%), mean weight (p=45.8%), and mean SL (p=52.1%). There were also no significant differences between habitat types during the after period.

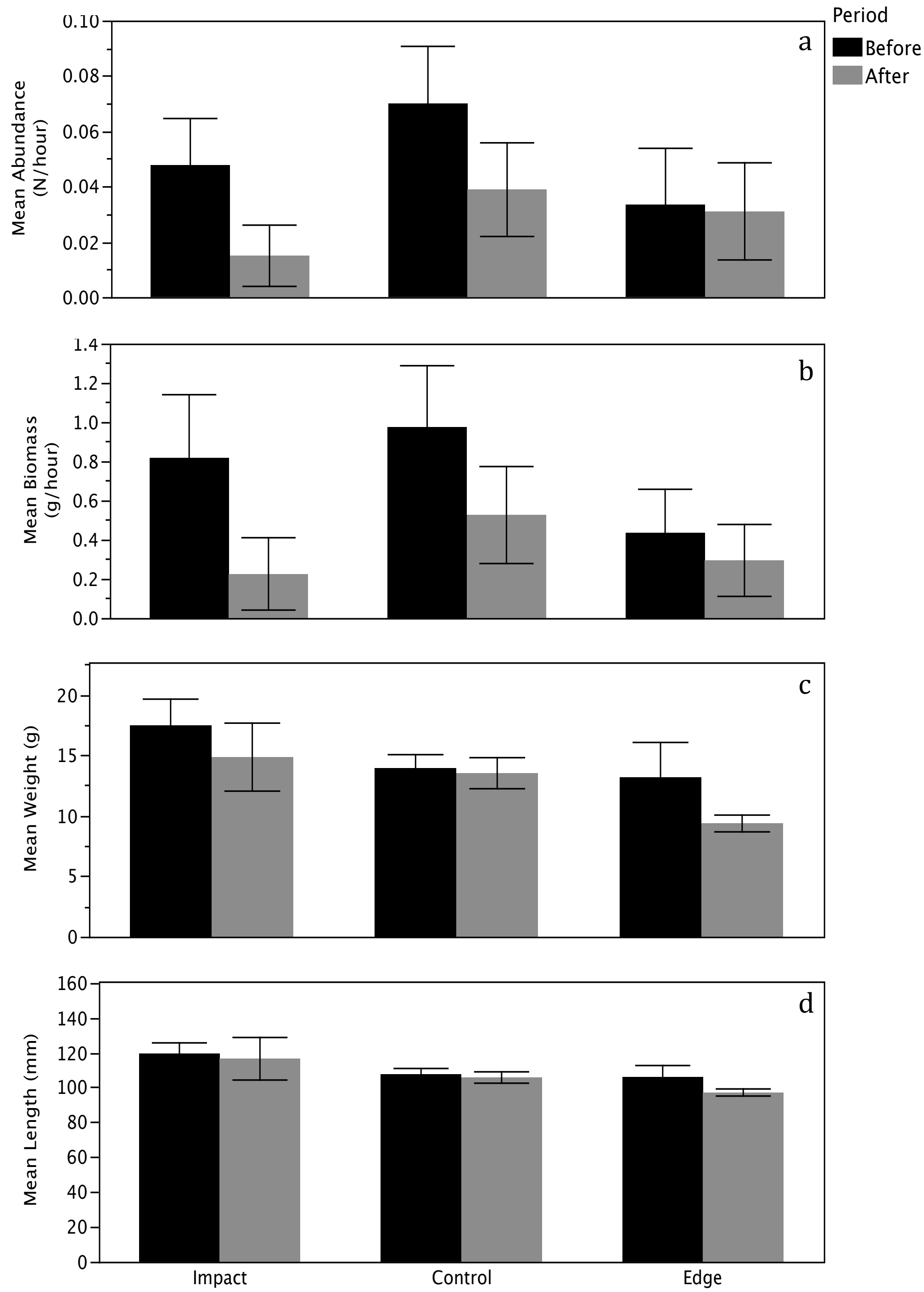

Figure 3.14. Fyke net catches of highfin goby (*Gobionellus oceanicus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.6 Pinfish (*Lagodon rhomboides*)

Overall, 276 pinfish were collected by fyke nets during this study (Table 3.1). Pinfish increased in mean abundance per hour (>3-fold) and mean biomass per hour after artificial reef construction, and decreased in average weight and average SL (Table 3.16). This trend of increasing CPUE and decreasing size was also seen at impact, control, and edge areas individually. Pinfish mean abundance per hour increased more than 2-fold at impact areas, more than 3-fold at control areas, and more than doubled at edge areas (Figure 3.15a). Mean pinfish weight after reef construction was approximately half of the mean weight before reef construction at all areas (Figure 3.15c). ANOSIM results showed

Table 3.16. Pinfish (*Lagodon rhomboides*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.06 (±0.02)	1.40 (±0.52)	25.41 (±2.04)	88.73 (±2.76)
After	0.23 (±0.06)	2.26 (±0.61)	9.90 (±0.55)	64.75 (±1.18)
BI	0.05 (±0.03)	1.33 (±1.13)	26.02 (±4.97)	85.08 (±7.53)
AI	0.18 (±0.08)	1.46 (±0.51)	8.18 (±1.53)	58.08 (±3.26)
BC	0.06 (±0.03)	1.57 (±0.78)	26.15 (±2.58)	90.83 (±3.29)
AC	0.28 (±0.10)	2.79 (±1.00)	10.01 (±0.61)	65.71 (±1.31)
BE	0.05 (±0.01)	0.98 (±0.39)	21.72 (±4.61)	84.70 (±6.67)
AE	0.13 (±0.03)	1.50 (±0.49)	11.51 (±1.76)	67.56 (±3.68)

no significant differences in Period*Area interactions for pinfish mean abundance per hour (p=6.4%), mean biomass per hour (p=6.8%), mean weight (p=85.6%), and mean SL (p=71.3%). There were also no significant differences between habitat types during the after period.

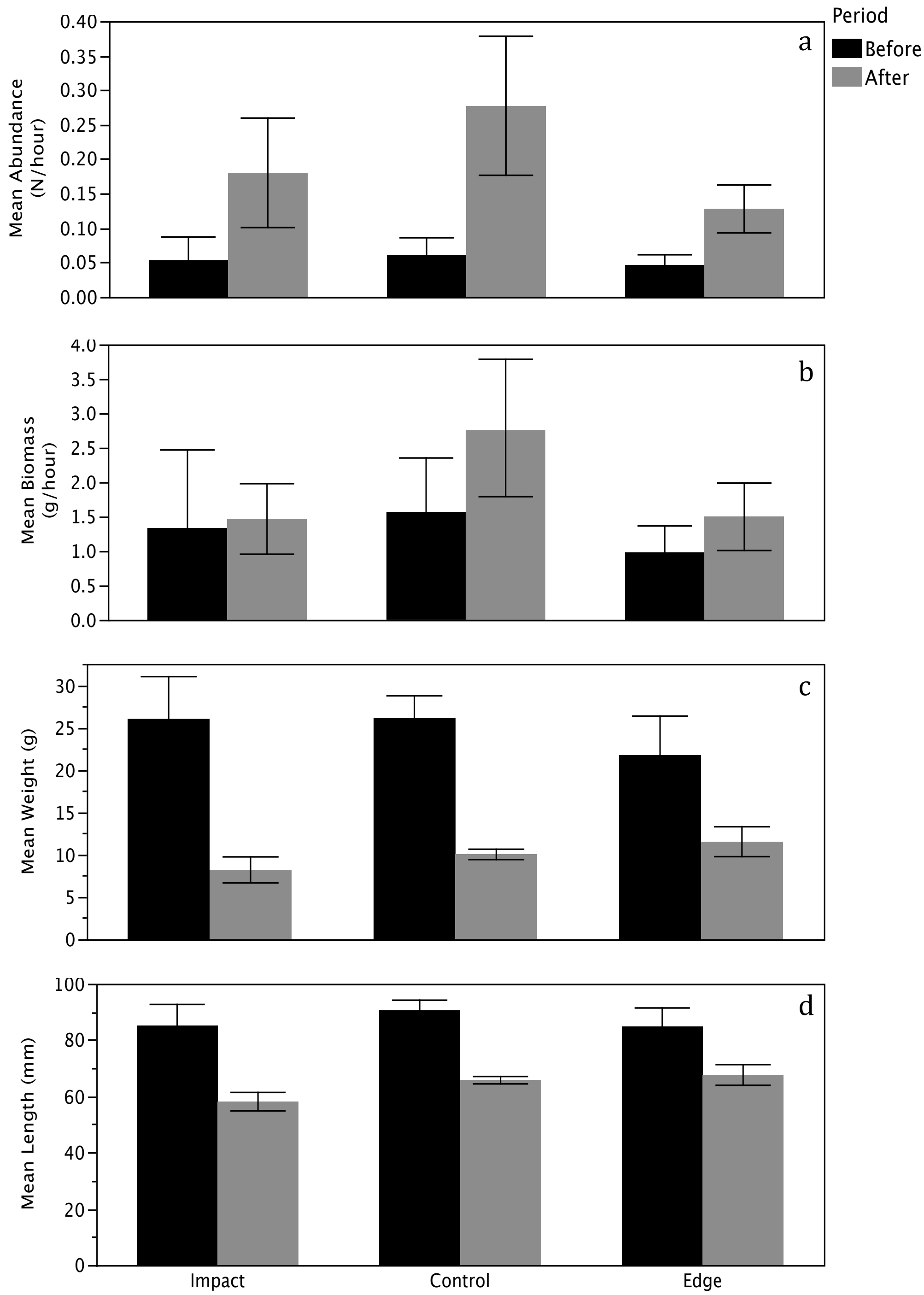

Figure 3.15. Fyke net catches of pinfish (*Lagodon rhomboides*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.7 Sand seatrout (*Cynoscion arenarius*)

Overall, 209 sand seatrout were collected by fyke nets during this study (Table 3.1). Sand seatrout decreased in mean abundance per hour, mean biomass per hour, average individual weight, and average individual SL after artificial reef construction (Table 3.17). Impact areas and edge areas also decreased in sand seatrout mean abundance CPUE, mean biomass CPUE, average weight, and average SL between periods (Figure 3.16). At control areas, sand seatrout mean abundance per hour and mean biomass per hour increased,

Table 3.17. Sand seatrout (*Cynoscion arenarius*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.77 (±0.25)	0.77 (±0.25)	13.77 (±3.62)	74.31 (±5.38)
After	0.63 (±0.18)	0.63 (±0.18)	4.26 (±0.80)	57.93 (±1.33)
BI	0.41 (±0.13)	0.41 (±0.13)	5.10 (±0.98)	68.94 (±8.80)
AI	0.08 (±0.04)	0.08 (±0.04)	1.61 (±0.31)	43.55 (±2.84)
BC	0.52 (±0.23)	0.52 (±0.23)	9.80 (±3.85)	66.76 (±5.42)
AC	0.74 (±0.25)	0.74 (±0.25)	5.08 (±1.31)	60.05 (±2.00)
BE	1.90 (±0.99)	1.90 (±0.99)	37.63 (±14.12)	103.96 (±18.96)
AE	0.87 (±0.50)	0.87 (±0.50)	3.32 (±0.26)	57.10 (±1.29)

while average weight and average SL decreased. ANOSIM results showed no significant differences in Period*Area interactions for sand seatrout mean abundance per hour (p=44.7%), mean biomass per hour (p=44.8%), mean weight (p=17.5%), and mean SL (p=27.1%). There was also no significant difference between mud, reef, or edge habitat types during the after period.

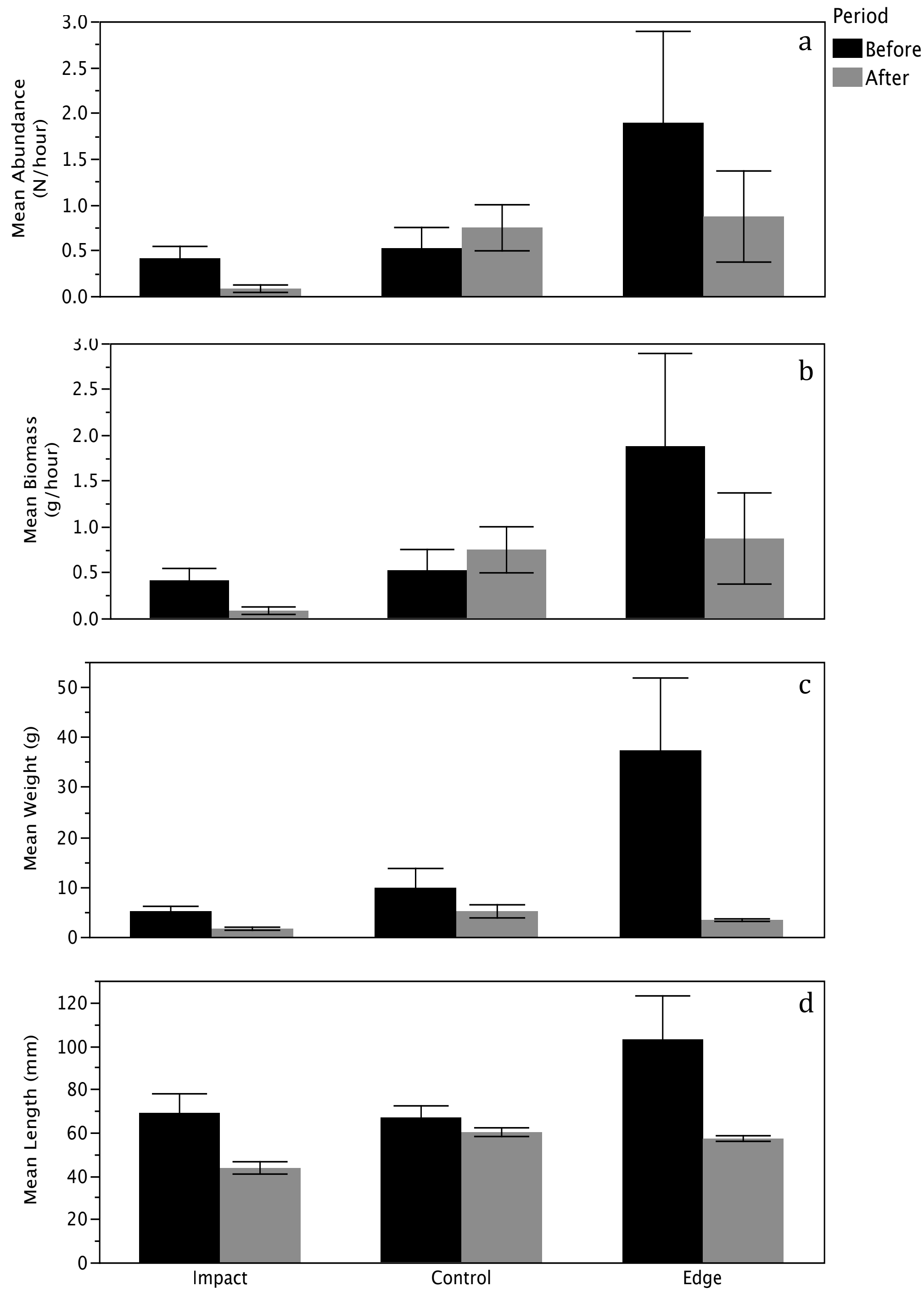

Figure 3.16. Fyke net catches of sand seatrout (*Cynoscion arenarius*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.8 Silver perch (*Bairdiella chrysoura*)

A total of 201 silver perch were collected by fyke nets during this study (Table 3.1). Overall, silver perch increased in mean abundance per hour and mean biomass per hour between periods, and decreased in average weight and average SL (Table 3.18). This pattern of increased mean CPUE and decreased mean size of silver perch was also seen at impact and control areas (Figure 3.17). Edge areas showed decreases in silver perch mean

Table 3.18. Silver perch (*Bairdiella chrysoura*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.07 (±0.01)	1.63 (±0.36)	23.75 (±2.43)	94.23 (±3.65)
After	0.12 (±0.03)	1.66 (±0.36)	14.51 (±1.68)	76.96 (±2.49)
BI	0.06 (±0.04)	1.98 (±1.11)	33.38 (±7.24)	106.00 (±8.97)
AI	0.08 (±0.04)	2.03 (±1.04)	26.63 (±7.88)	88.44 (±9.95)
BC	0.07 (±0.02)	1.23 (±0.32)	17.97 (±2.67)	85.52 (±4.54)
AC	0.17 (±0.06)	1.90 (±0.48)	12.03 (±1.46)	74.03 (±2.42)
BE	0.08 (±0.03)	2.47 (±1.05)	31.37 (±4.99)	107.81 (±6.73)
AE	0.03 (±0.01)	0.58 (±0.38)	21.19 (±5.04)	92.83 (±9.36)

abundance per hour and mean biomass per hour, in addition to decreases in mean weight and mean SL after reef construction. ANOSIM results showed no significant difference in interaction terms for sand seatrout mean abundance CPUE (p=22.6%), mean biomass CPUE (p=17.6%), mean weight (p=73.4%), and mean SL (p=69.2%). During the after period, ANOSIM results again showed no significant differences in sand seatrout mean CPUE or size between reef, soft-bottom, and edge habitat types.

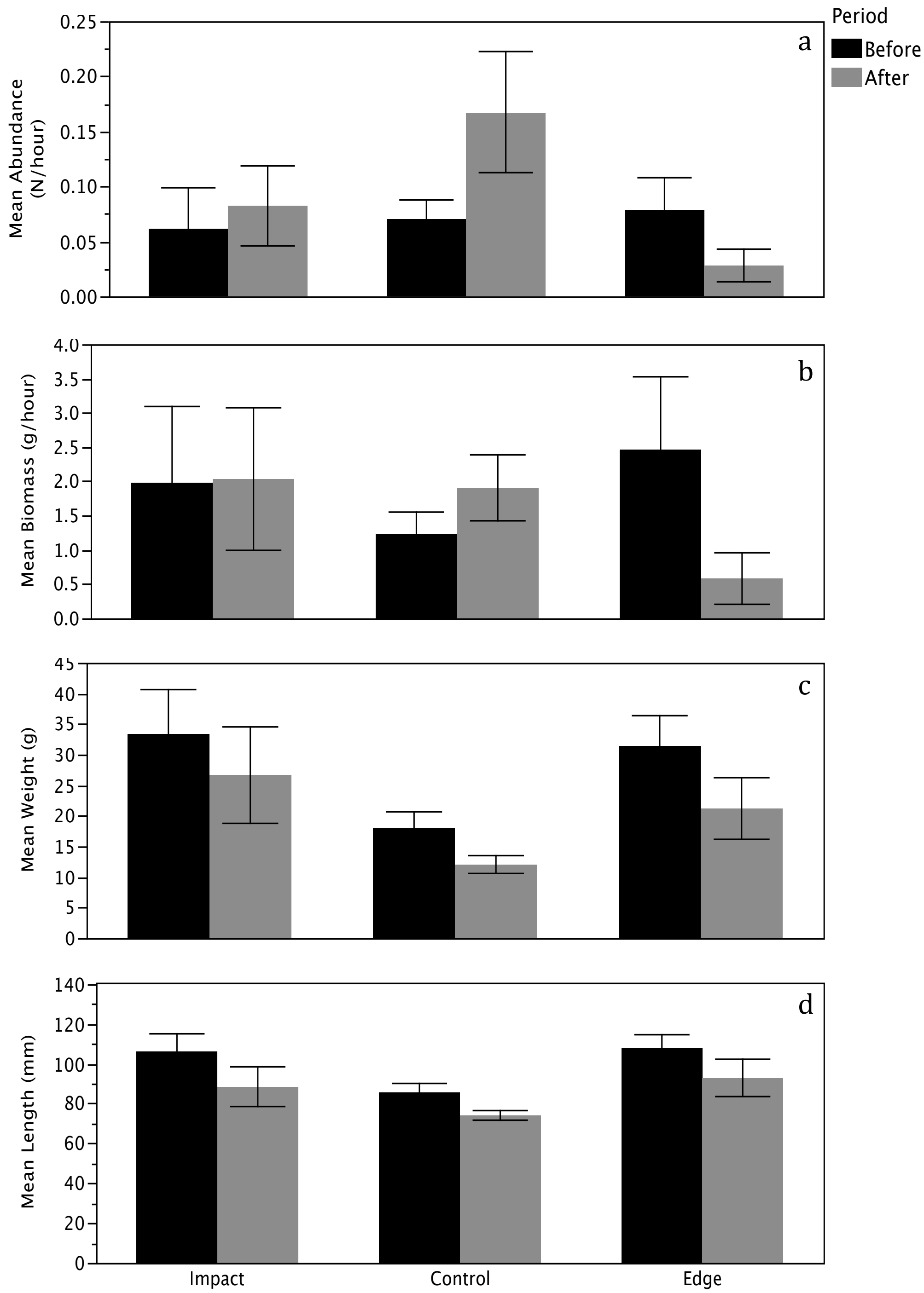

Figure 3.17. Fyke net catches of silver perch (*Bairdiella chrysoura*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.9 Spot (*Leiostomus xanthurus*)

Overall, 357 spot were collected by fyke nets during this study (Table 3.1). Spot increased in mean abundance per hour, mean biomass per hour, and mean individual weight, but decreased in mean individual SL after artificial reef construction (Table 3.19). Spot mean abundance per hour doubled at impact areas while slightly increasing at control and edge areas (Figure 3.18a). Spot mean biomass per hour more than doubled at impact and edge areas while control areas decreased in spot mean biomass per hour (Figure 3.18b). Similarly, mean weight of spot nearly doubled at impact and edge areas while decreasing at control areas (Figure 3.18c). Mean SL of spot decreased at impact and control areas, and increased at edge areas (Figure 3.18d). ANOSIM results showed no significant difference in Period*Area interactions for spot mean abundance per hour (p=66%), mean biomass per hour (p=62.7%), mean weight (p=71.3%), and mean SL (p=56.4%). During the after period, there were also no significant differences in spot mean CPUE or mean size between habitat types.

Table 3.19. Spot (*Leiostomus xanthurus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.16 (±0.03)	1.06 (±0.21)	6.98 (±0.41)	63.76 (±0.99)
After	0.20 (±0.03)	1.48 (±0.35)	7.94 (±1.23)	60.82 (±1.46)
BI	0.10 (±0.04)	0.67 (±0.31)	6.53 (±0.89)	61.78 (±2.51)
AI	0.20 (±0.09)	1.90 (±1.27)	11.31 (±4.58)	58.66 (±4.83)
BC	0.18 (±0.04)	1.25 (±0.32)	7.23 (±0.55)	64.10 (±1.26)
AC	0.21 (±0.04)	1.17 (±0.25)	5.88 (±0.88)	59.72 (±1.20)
BE	0.14 (±0.05)	0.91 (±0.29)	6.38 (±0.61)	63.95 (±1.91)
AE	0.16 (±0.06)	2.00 (±1.00)	12.00 (±3.79)	67.88 (±4.93)

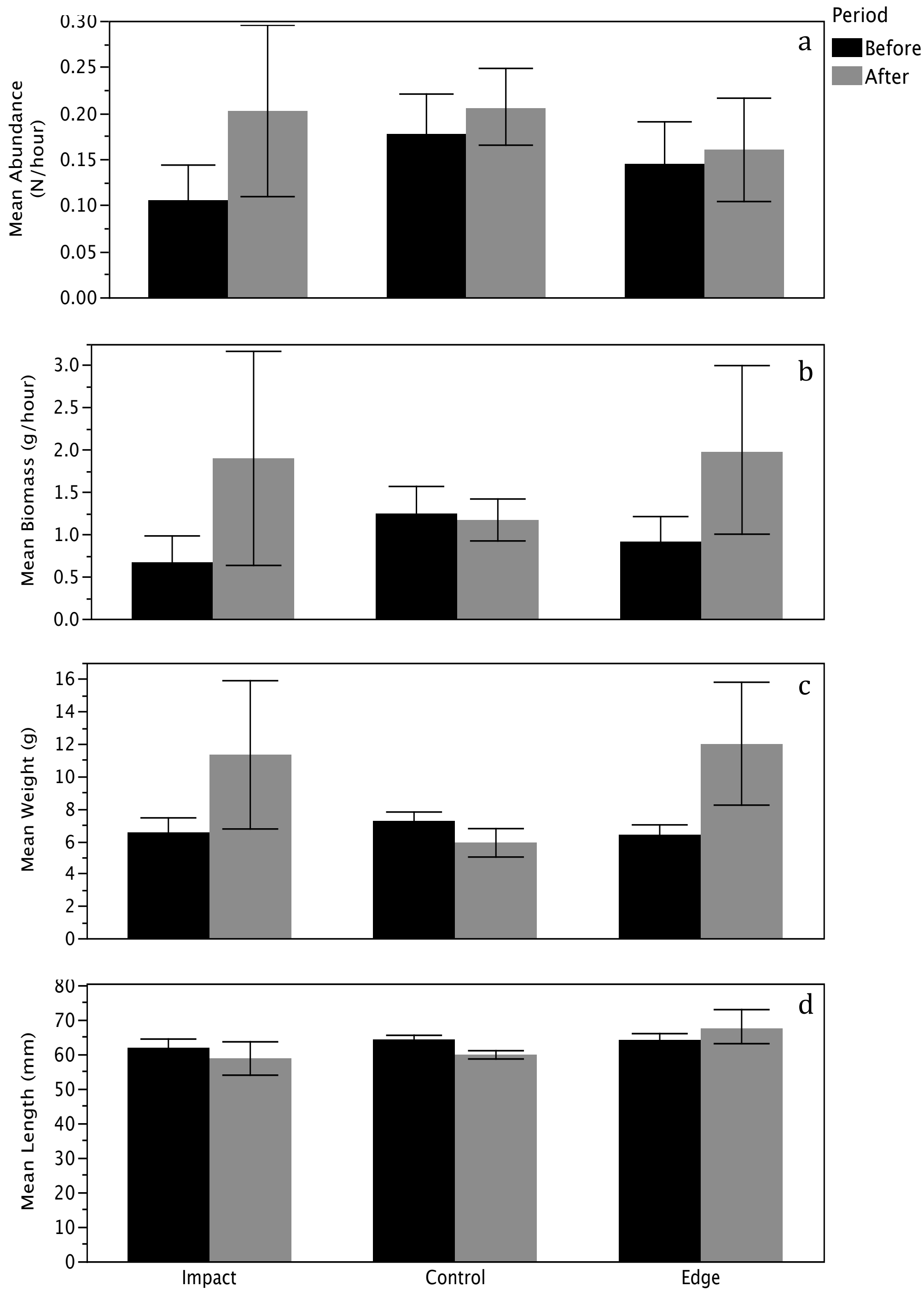

Figure 3.18. Fyke net catches of spot (*Leiostomus xanthurus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.10 Striped mullet (*Mugil cephalus*)

Overall, 40 striped mullet were collected by fyke nets during this study (Table 3.1). Striped mullet decreased in mean abundance per hour, mean biomass per hour, average weight per individual, and average SL per individual after artificial reef construction (Table 3.20). At control areas, striped mullet mean abundance CPUE, mean biomass CPUE, average weight, and average SL also decreased (Figure 3.19). At impact areas, the mean abundance per hour of striped mullet increased between periods, while mean biomass per hour, average weight, and average SL decreased. Edge areas displayed decreases in striped mullet mean abundance and biomass per hour, with increases in average individual weight and average SL between periods (Figure 3.19). ANOSIM results showed no significant difference in interaction terms for striped mullet mean abundance per hour (p=60.4%), mean biomass per hour (p=58.7%), average weight (p=16.7%), and average SL (p=23.7%). During the after period, there were no significant differences between reef, mud, and edge habitat types.

Table 3.20. Striped mullet (*Mugil cephalus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.03 (±0.01)	0.87 (±0.32)	31.74 (±7.34)	104.83 (±5.46)
After	0.01 (±0.01)	0.22 (±0.17)	23.06 (±18.00)	72.10 (±15.35)
BI	0.04 (±0.03)	1.64 (±1.02)	46.57 (±25.12)	114.00 (±16.69)
AI	0.04 (±0.04)	0.96 (±0.83)	25.80 (±22.67)	68.50 (±19.16)
BC	0.03 (±0.02)	0.82 (±0.40)	29.00 (±5.22)	105.17 (±5.04)
AC	<0.01	0.01	6.66	79
BE	0.02 (±0.01)	0.26 (±0.18)	14.43 (±2.62)	85.00 (±4.83)
AE	0.01	0.1	17.5	94

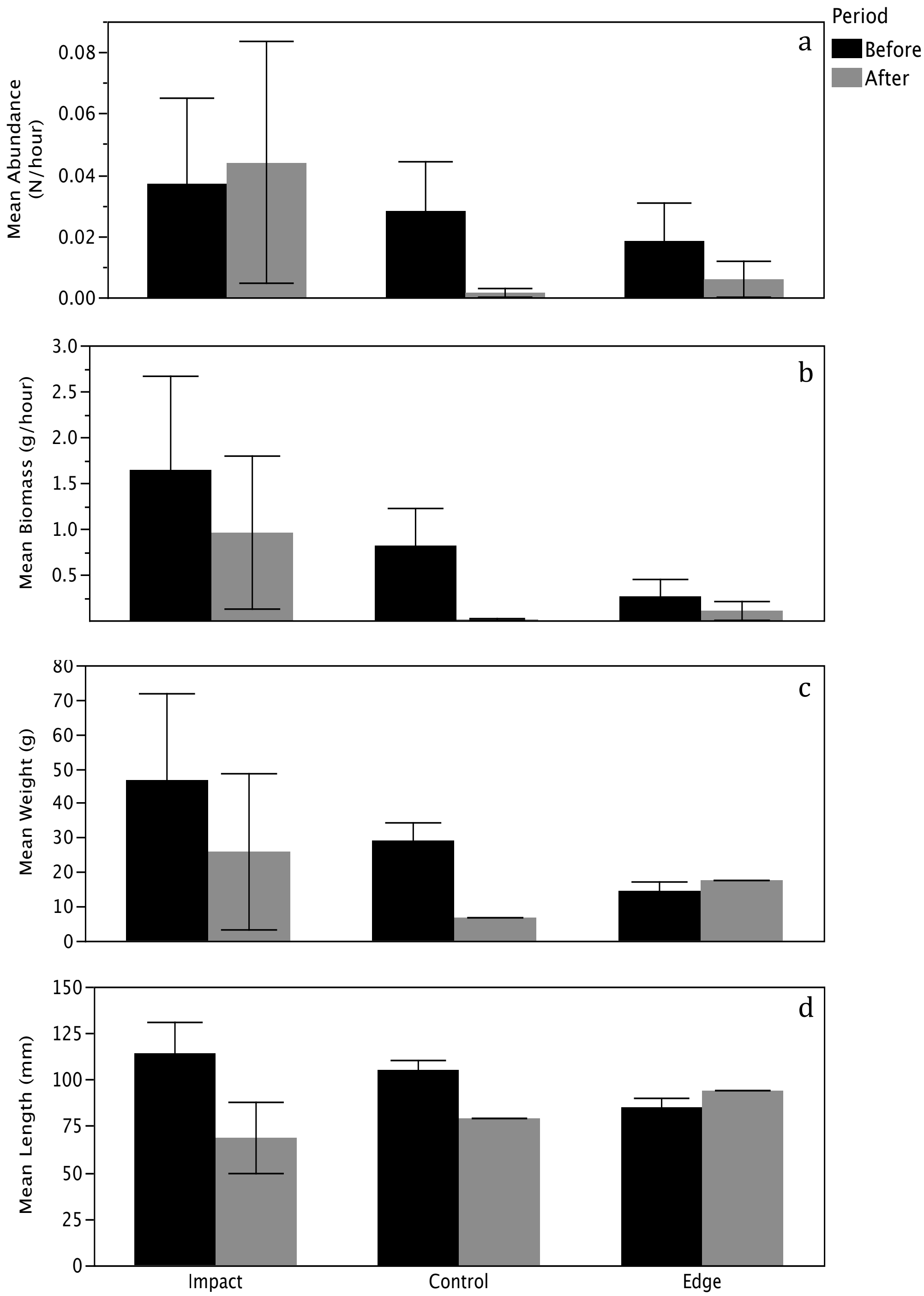

Figure 3.19. Fyke net catches of striped mullet (*Mugil cephalus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.10.11 White shrimp (*Litopenaeus setiferus*)

Overall, 5,058 white shrimp individuals were collected by fyke nets during this study (Table 3.1). White shrimp decreased in mean abundance per hour and mean biomass per hour, but increased in average individual weight and average rostrum length after artificial reef construction (Table 3.21). Decreases in white shrimp mean CPUE and increases in white shrimp mean size was also observed at control areas after reef addition (Figure 3.20). Impact areas showed decreases in white shrimp mean abundance per hour, mean biomass per hour, mean weight, and mean rostrum length between periods. At edge

Table 3.21. White shrimp (*Litopenaeus setiferus*) mean abundance CPUE (N/hour), mean biomass CPUE (g/hour), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by fyke nets before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean CPUE N/hour (±SE)	Mean CPUE g/hour (±SE)	Mean Weight g (±SE)	Mean Rostrum Length mm (±SE)
Before	2.39 (±0.41)	7.60 (±1.00)	2.99 (±0.08)	26.09 (±0.23)
After	2.29 (±0.40)	6.96 (±1.49)	3.10 (±0.06)	27.45 (±0.19)
BI	1.71 (±0.67)	5.45 (±1.53)	2.97 (±0.23)	25.90 (±0.61)
AI	1.36 (±0.46)	2.30 (±0.67)	1.73 (±0.10)	23.55 (±0.39)
BC	2.41 (±0.40)	7.41 (±1.09)	2.88 (±0.11)	25.54 (±0.29)
AC	2.34 (±0.40)	7.29 (±1.25)	3.16 (±0.08)	28.03 (±0.25)
BE	3.01 (±1.52)	10.32 (±3.43)	3.26 (±0.17)	27.92 (±0.51)
AE	3.06 (±1.52)	10.65 (±6.34)	3.54 (±0.09)	28.10 (±0.41)

areas, white shrimp mean abundance per hour, mean biomass per hour, average weight, and average rostrum length increased between periods (Figure 3.20). ANOSIM results showed no significant differences in Period*Area interactions for white shrimp mean abundance per hour (p=2.8%), mean weight (p=21.7%), and mean rostrum length (p=32.8%). ANOSIM results show a significant difference in white shrimp mean biomass

per hour (p=0.9%). Pairwise comparisons show significant differences between BC and AE sites (p=0.3%) and between BC and AI sites (p=0.2%). No significant difference between BI and AI sites was found (p=9.2%). During the after period, white shrimp showed no significant differences between habitat types.

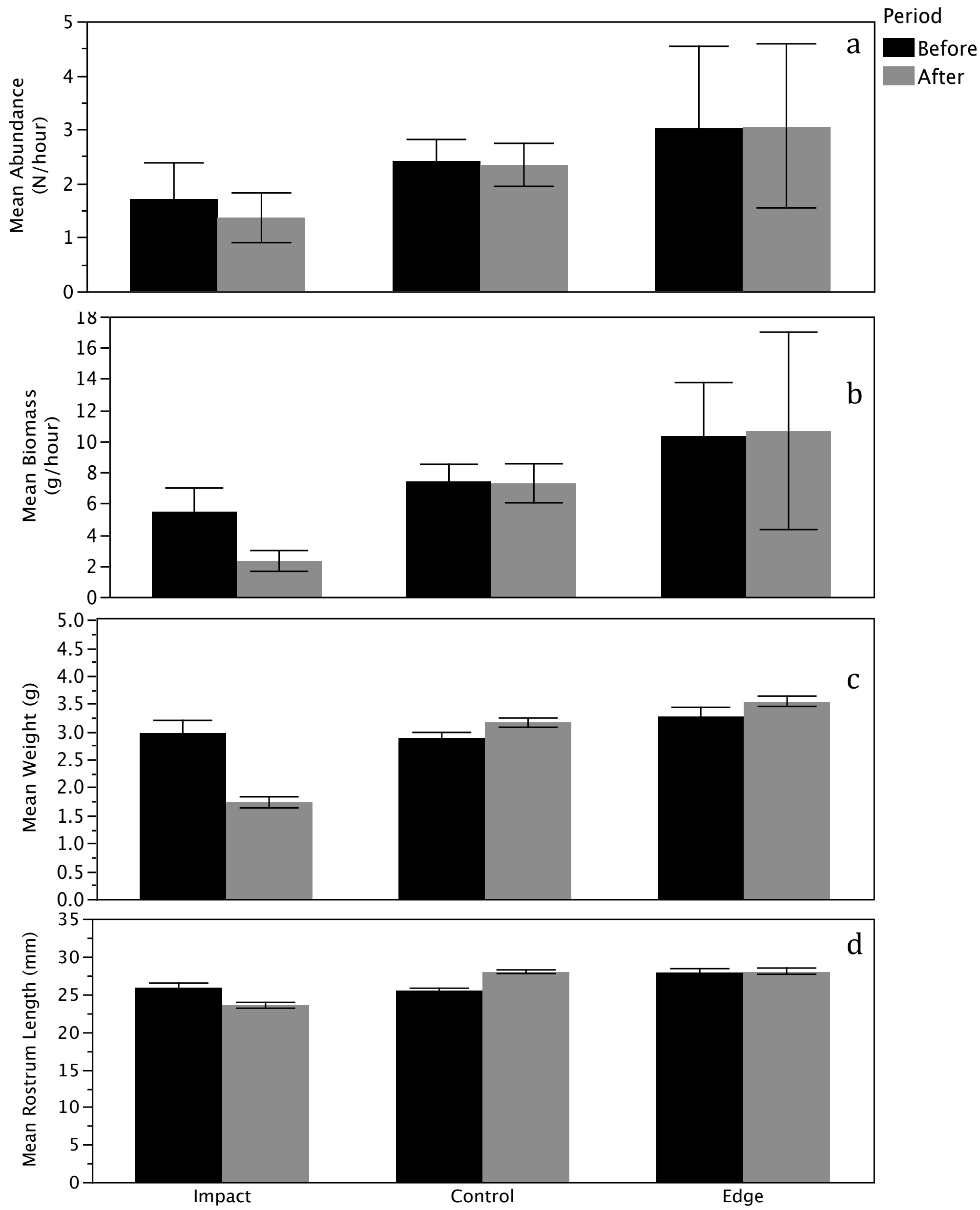

Figure 3.20. Fyke net catches of white shrimp (*Litopenaeus setiferus*) a) mean abundance CPUE (N/hour), b) mean biomass CPUE (g/hour), c) mean weight (g), and d) mean rostrum length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11 Individual Species: Purse Seine

Nine species were identified by SIMPER analyses of purse seine abundance and biomass data as contributing to changes at impact areas: Atlantic croaker (*M. undulatus*), bay anchovy (*Anchoa mitchilli*), bay whiff (*Citharichthys spilopterus*), brown shrimp (*F. aztecus*), Gulf menhaden (*Brevoortia patronus*), hardhead catfish (*Ariopsis felis*), pinfish (*L. rhomboides*), spot (*L. xanthurus*), and white shrimp (*L. setiferus*).

3.11.1 Atlantic croaker (*Micropogonias undulatus*)

Overall, 3,101 Atlantic croaker were collected by purse seine (Table 3.1). Atlantic croaker increased in mean abundance per m^2 (>3-fold), mean biomass per m^2 (>2-fold), and average SL after artificial reef construction, yet average weight decreased (Table 3.22). Control and edge areas also increased in Atlantic croaker mean abundance per m^2, mean

Table 3.22. Atlantic croaker (*Micropogonias undulatus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.03 (±0.04)	0.12 (±0.02)	4.19 (±0.24)	54.46 (±0.88)
After	0.10 (±0.19)	0.41 (±0.07)	3.74 (±0.06)	56.63 (±0.23)
BI	0.02 (±0.02)	0.07 (±0.03)	3.91 (±0.53)	51.19 (±2.26)
AI	0.08 (±0.14)	0.31 (±0.10)	3.58 (±0.14)	55.33 (±0.57)
BC	0.03 (±0.03)	0.12 (±0.02)	4.20 (±0.31)	54.85 (±1.08)
AC	0.08 (±0.13)	0.30 (±0.06)	3.71 (±0.07)	56.80 (±0.29)
BE	0.04 (±0.05)	0.17 (±0.06)	4.44 (±0.52)	55.92 (±1.96)
AE	0.20 (±0.33)	0.84 (±0.26)	3.96 (±0.15)	57.31 (±0.54)

biomass per m^2, and average SL and decreased in average weight after reef addition (Figure 3.21). At impact areas, Atlantic croaker mean abundance and biomass densities increased more than 3-fold. Average SL increased and average weight decreased at impact areas

after reef construction. ANOSIM results showed no significant differences in Period*Area interaction terms of Atlantic croaker mean abundance per m² (p=31.4%), mean biomass per m² (p=29.8%), mean weight (p=20.4%), and mean SL (p=16.7%). During the after period, Atlantic croaker showed no significant differences between habitat types.

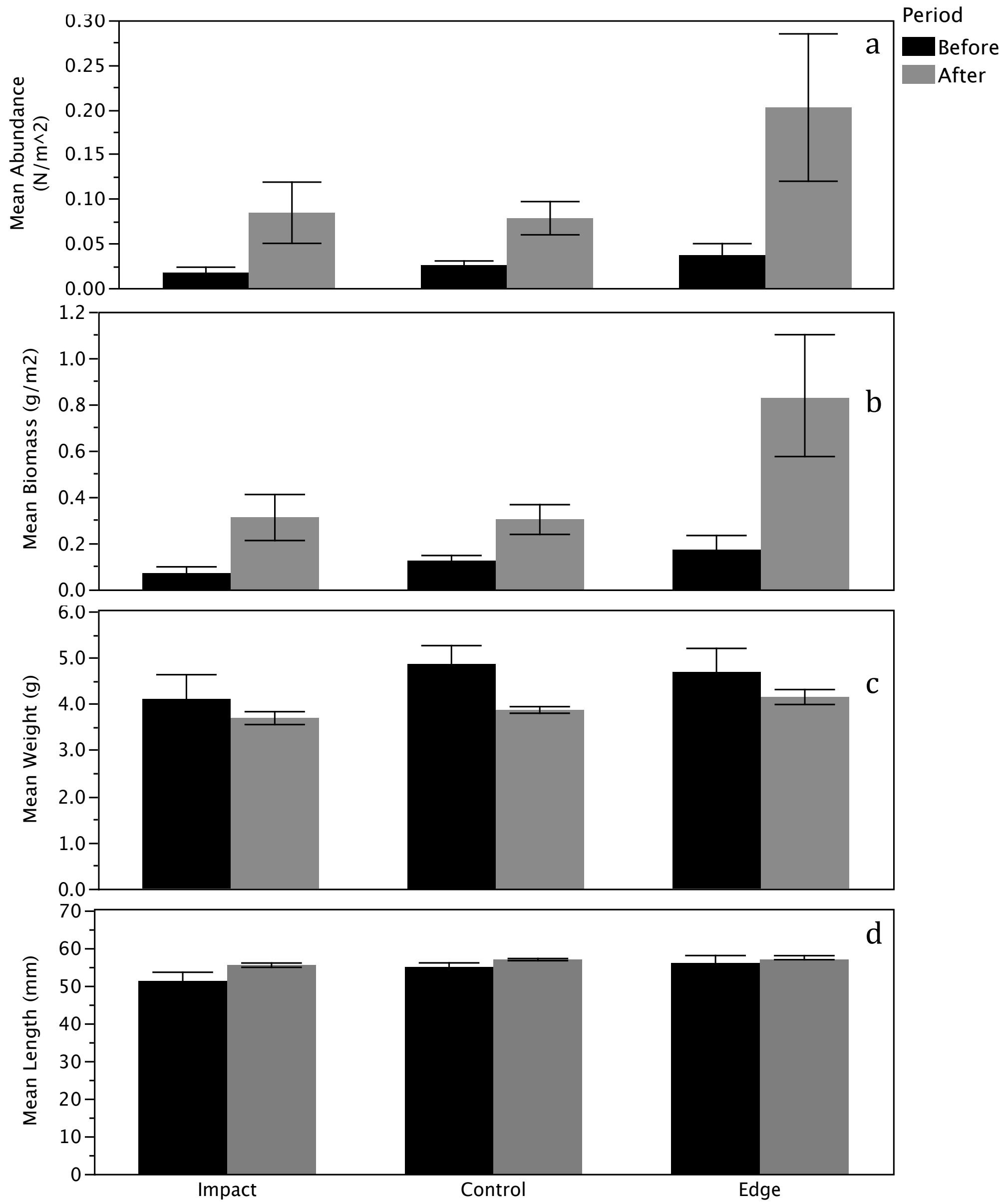

Figure 3.21. Purse seine catches of Atlantic croaker (*Micropogonias undulatus*) a) mean abundance density (N/m²), b) mean biomass density (g/m²), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11.2 Bay anchovy (*Anchoa mitchilli*)

A total of 6,515 bay anchovy were collected by purse seine during this study (Table 3.1). Bay anchovy increased in mean abundance per m^2 and mean biomass per m^2 after artificial reef construction, while average weight and average SL per individual decreased (Table 3.23). This pattern of increasing mean densities and decreasing mean sizes of bay

Table 3.23. Bay anchovy (*Anchoa mitchilli*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.10 (±0.01)	0.09 (±0.01)	0.95 (±0.01)	41.78 (±0.12)
After	0.17 (±0.03)	0.14 (±0.02)	0.84 (±0.01)	40.04 (±0.11)
BI	0.03 (±0.01)	0.03 (±0.01)	0.88 (±0.03)	40.78 (±0.45)
AI	0.11 (±0.05)	0.09 (±0.04)	0.82 (±0.02)	39.39 (±0.31)
BC	0.10 (±0.02)	0.09 (±0.02)	0.96 (±0.01)	41.63 (±0.15)
AC	0.16 (±0.03)	0.14 (±0.03)	0.86 (±0.01)	40.42 (±0.13)
BE	0.16 (±0.05)	0.15 (±0.05)	0.95 (±0.02)	42.74 (±0.20)
AE	0.24 (±0.09)	0.19 (±0.07)	0.78 (±0.02)	39.15 (±0.26)

anchovy was also seen at impact, control, and edge areas individually (Figure 3.22). Despite bay anchovy mean densities increasing more than 2-fold at impact areas, these areas had the lowest mean densities of bay anchovy throughout the study. No significant differences were found between Period*Area interactions in bay anchovy mean abundance per m^2 (p=8.5%), mean biomass per m^2 (p=11.8%), mean weight (p=23.5%), and mean SL (p=11.7%). During the after period, bay anchovy showed no significant differences between habitat types.

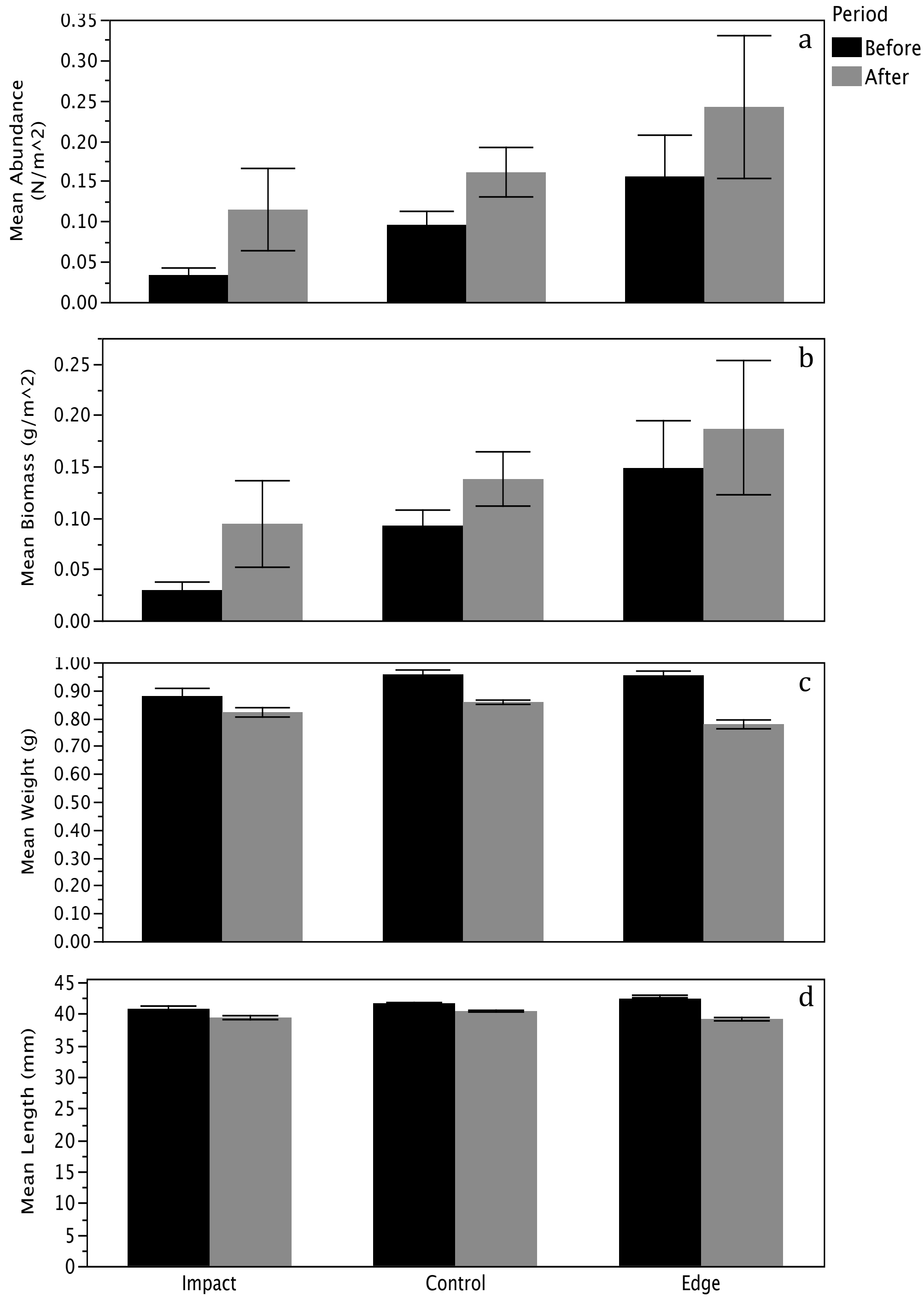

Figure 3.22. Purse seine catches of bay anchovy (*Anchoa mitchilli*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11.3 Bay whiff (*Citharichthys spilopterus*)

Overall, 1,047 bay whiff were collected by purse seine during this study (Table 3.1). Bay whiff decreased in mean abundance per m^2 and mean biomass per m^2 after artificial reef construction, while the average weight per individual and average SL increased (Table 3.24). This pattern of decreased mean densities and increased mean sizes of bay whiff was also seen at control areas (Figure 3.23). At impact areas, bay whiff decreased in mean abundance per m^2 and increased in average weight and average SL after reef addition, while mean biomass per m^2 showed no change. Bay whiff decreased in mean abundance per m^2, mean biomass per m^2, average weight, and average SL at edge areas between periods (Figure 3.23). ANOSIM results showed no significant differences between Period*Area interactions of bay whiff mean abundance per m^2 (p=1.3%), mean biomass per m^2 (p=9.8%), mean weight (p=70.5%), or mean SL (p=65%). In the after period, bay whiff mean densities and mean sizes showed no significant differences between habitat types.

Table 3.24. Bay whiff (*Citharichthys spilopterus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.02 (±<0.01)	0.06 (±0.01)	2.56 (±0.10)	49.78 (±0.70)
After	0.02 (±<0.01)	0.05 (±0.01)	2.74 (±0.11)	52.10 (±0.73)
BI	0.03 (±0.01)	0.05 (±0.01)	1.74 (±0.17)	43.22 (±1.24)
AI	0.02 (±0.01)	0.05 (±0.03)	2.18 (±0.14)	49.37 (±1.25)
BC	0.02 (±<0.01)	0.05 (±0.01)	2.92 (±0.15)	52.65 (±0.97)
AC	0.01 (±<0.01)	0.04 (±0.01)	3.17 (±0.19)	54.50 (±1.11)
BE	0.04 (±0.01)	0.11 (±0.03)	2.73 (±0.22)	51.18 (±1.52)
AE	0.04 (±0.02)	0.10 (±0.04)	2.58 (±0.21)	50.84 (±1.42)

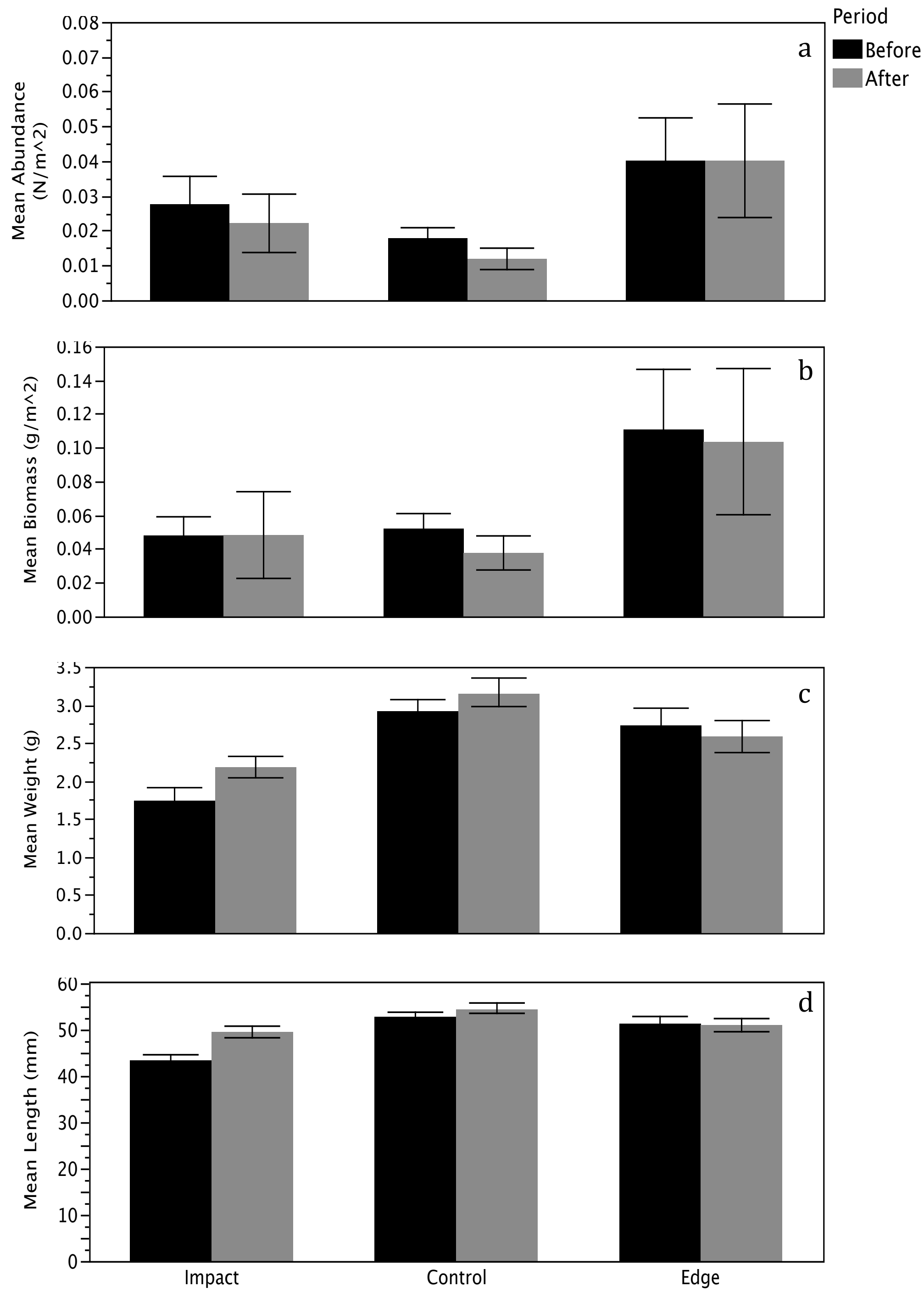

Figure 3.23. Purse seine catches of bay whiff (*Citharichthys spilopterus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11.4 Brown shrimp (*Farfantepenaeus aztecus*)

A total of 6,542 brown shrimp were collected by purse seine during this study (Table 3.1). Brown shrimp increased in mean abundance per m^2 2-fold and mean biomass per m^2 doubled between periods, however average weight and average rostrum length per individual decreased (Table 3.25). This pattern of increased densities and decreased sizes was also seen at impact and edge areas (Figure 3.24). Control areas displayed increased mean densities of brown shrimp and average rostrum length between periods with decreased average weight. No significant differences were found between Period*Area

Table 3.25. Brown shrimp (*Farfantepenaeus aztecus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual rostrum length (mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean Rostrum Length mm (±SE)
Before	0.08 (±0.03)	0.13 (±0.06)	1.51 (±0.03)	19.62 (±0.17)
After	0.23 (±0.07)	0.25 (±0.07)	1.10 (±0.02)	19.48 (±0.10)
BI	0.05 (±0.02)	0.07 (±0.03)	1.40 (±0.08)	20.19 (±0.37)
AI	0.14 (±0.07)	0.14 (±0.06)	0.98 (±0.03)	18.92 (±0.23)
BC	0.04 (±0.01)	0.05 (±0.01)	1.32 (±0.05)	19.34 (±0.24)
AC	0.12 (±0.03)	0.15 (±0.04)	1.24 (±0.03)	19.68 (±0.16)
BE	0.22 (±0.13)	0.39 (±0.30)	1.77 (±0.04)	19.72 (±0.32)
AE	0.66 (±0.34)	0.66 (±0.32)	0.99 (±0.02)	19.47 (±0.15)

interactions in brown shrimp mean abundance per m^2 (p=4.6%), mean biomass per m^2 (p=10%), mean weight (p=7.1%), and mean rostrum length (p=2.9%). The after period displayed no significant differences in brown shrimp mean abundance per m^2 (p=55.6%), mean biomass per m^2 (p=62.3%), mean weight (p=31.6%), and mean rostrum length (p=56.7%) between soft-bottom, reef, and marsh edge habitats.

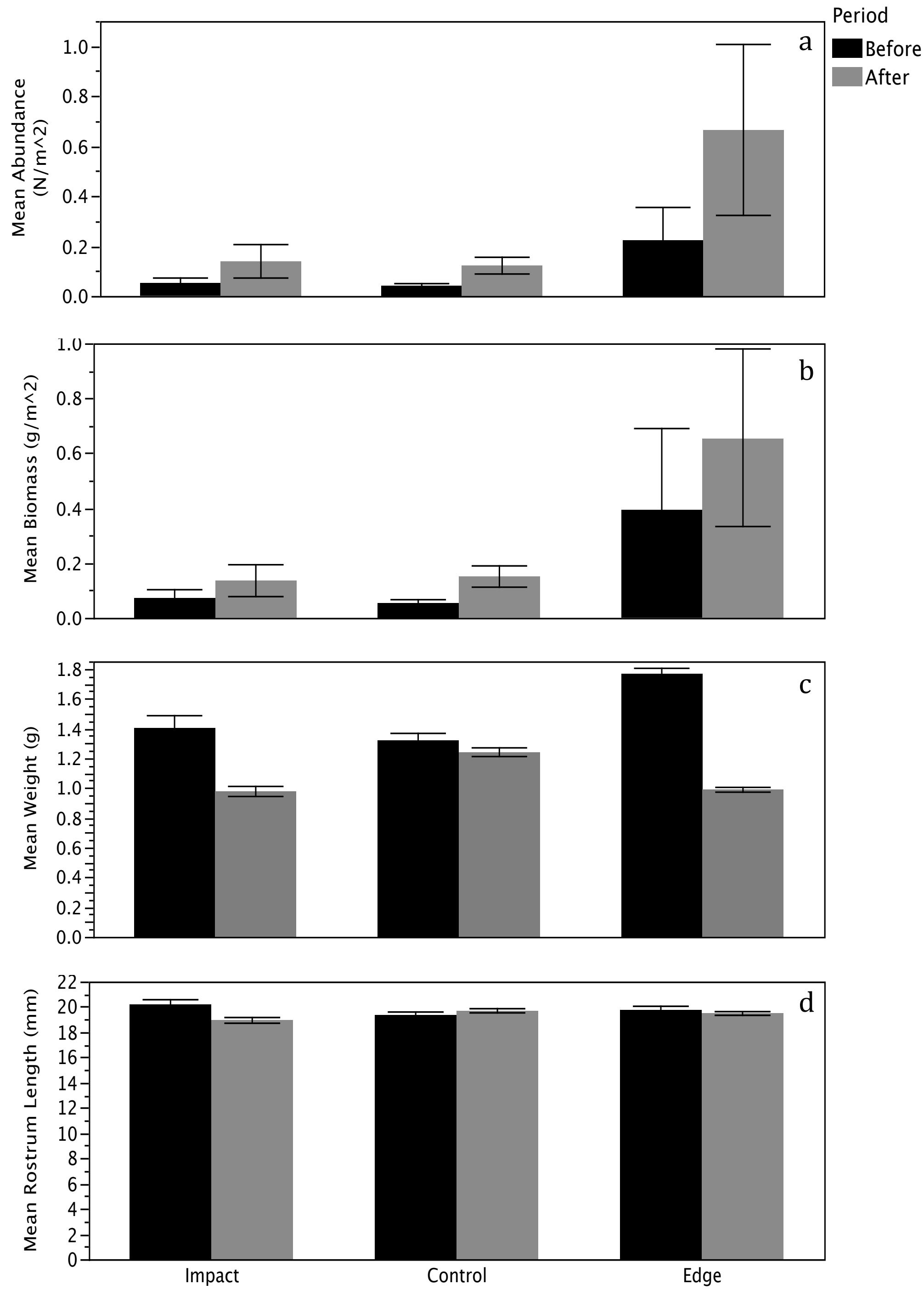

Figure 3.24. Purse seine catches of brown shrimp (*Farfantepenaeus aztecus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean rostrum length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11.5 Gulf menhaden (*Brevoortia patronus*)

A total of 73,856 Gulf menhaden were collected by purse seine during this study (Table 3.1). From the before to the after period, Gulf menhaden mean abundance per m^2 increased ~25-fold and mean biomass per m^2 increased >3-fold, as average weight and average SL per individual decreased (Table 3.26). This pattern was also seen at control and edge areas where abundance per m^2 increased ~53-fold and ~14-fold, respectively, and mean biomass per m^2 increased more than 3-fold at both areas (Figure 3.25). At impact

Table 3.26. Gulf menhaden (*Brevoortia patronus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.11 (±0.04)	0.38 (±0.14)	4.23 (±0.19)	53.05 (±0.52)
After	2.95 (±1.08)	1.74 (±0.55)	0.62 (±<0.01)	33.68 (±0.16)
BI	0.04 (±0.03)	0.09 (±0.05)	2.00 (±0.10)	46.07 (±0.80)
AI	0.05 (±0.03)	0.07 (±0.02)	1.47 (±0.12)	39.12 (±0.87)
BC	0.06 (±0.02)	0.43 (±0.21)	7.27 (±0.40)	60.26 (±0.74)
AC	3.24 (±1.27)	2.12 (±0.74)	0.66 (±<0.01)	34.57 (±0.20)
BE	0.33 (±0.21)	0.50 (±0.31)	1.53 (±0.03)	41.00 (±0.48)
AE	5.01 (±3.81)	2.25 (±1.63)	0.45 (±<0.01)	30.05 (±0.25)

areas, Gulf menhaden increased slightly in mean abundance per m^2, but decreased in biomass per m^2, average weight, and average SL. Gulf menhaden mean abundance per m^2 ANOSIM results of Period*Area interaction terms were slightly non-significant (p=1.1%), with pairwise comparisons showing significant differences between BI and AI sites (p=0.3%), as well as BC and AC sites (p=0.2%). ANOSIM results of Gulf menhaden mean biomass per m^2 showed a significant difference between Interaction terms (p=0.8%). Pairwise comparisons showed a significant difference between BI and AI sites (p=0.1%) as

well as BC and AC sites (p=0.2%). ANOSIM results of Gulf menhaden average weight and average SL showed no significant differences between interaction terms (p=62.3% and p=70%, respectively). After artificial reef construction, mean densities and mean sizes of Gulf menhaden showed no significant differences between habitat types.

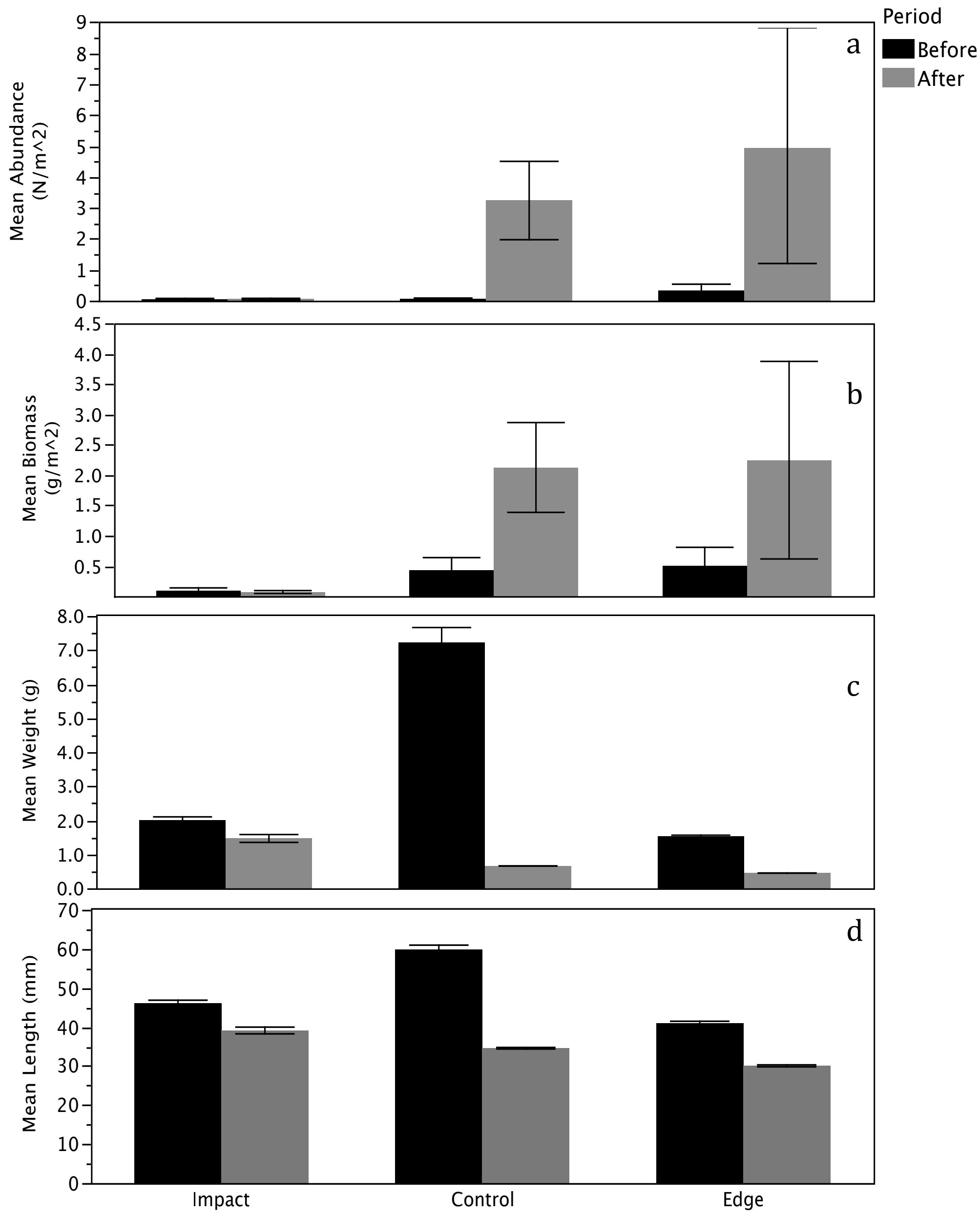

Figure 3.25. Purse seine catches of Gulf menhaden (*Brevoortia patronus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11.6 Hardhead catfish (*Ariopsis felis*)

A total of 304 hardhead catfish were collected by purse seine during this study (Table 3.1). Overall, hardhead catfish increased in mean abundance per m^2 and decreased in mean biomass per m^2, average weight, and average SL after artificial reef construction (Table 3.27). At impact areas, hardhead catfish mean abundance and biomass per m^2 increased as average weight and average SL decreased (Figure 3.26). Control areas also followed this pattern of increased mean densities and decreased mean sizes of hardhead catfish. Edge areas increased in hardhead catfish mean abundance per m^2, but decreased in mean biomass per m^2, mean weight, and mean SL between periods (Figure 3.26). No significant differences were found between Period*Area interactions in hardhead catfish mean abundance per m^2 (p=20.5%), mean biomass per m^2 (p=22.9%), mean weight (p=6.4%), or mean SL (p=3.6%). In the after period, no significant differences were found in hardhead catfish mean abundance per m^2 (p=10.5%), mean biomass per m^2 (p=14.5%), average weight (p=60.4%), or average SL (p=55.3%) between habitat types.

Table 3.27. Hardhead catfish (*Ariopsis felis*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	<0.01 (±<0.01)	0.10 (±0.03)	23.26 (±3.93)	100.52 (±4.22)
After	0.01 (±<0.01)	0.10 (±0.02)	11.74 (±1.49)	80.34 (±1.99)
BI	<0.01 (±<0.01)	0.07 (±0.03)	16.14 (±2.89)	91.88 (±4.82)
AI	0.01 (±<0.01)	0.07 (±0.03)	7.92 (±1.56)	74.44 (±2.05)
BC	<0.01 (±<0.01)	0.05 (±0.01)	16.40 (±2.38)	92.22 (±3.55)
AC	0.01 (±<0.01)	0.09 (±0.03)	12.11 (±1.78)	81.05 (±2.46)
BE	<0.01 (±<0.01)	0.27 (±0.16)	80.19 (±27.87)	168.60 (±21.29)
AE	0.01 (±<0.01)	0.14 (±0.06)	18.19 (±7.92)	89.43 (±9.82)

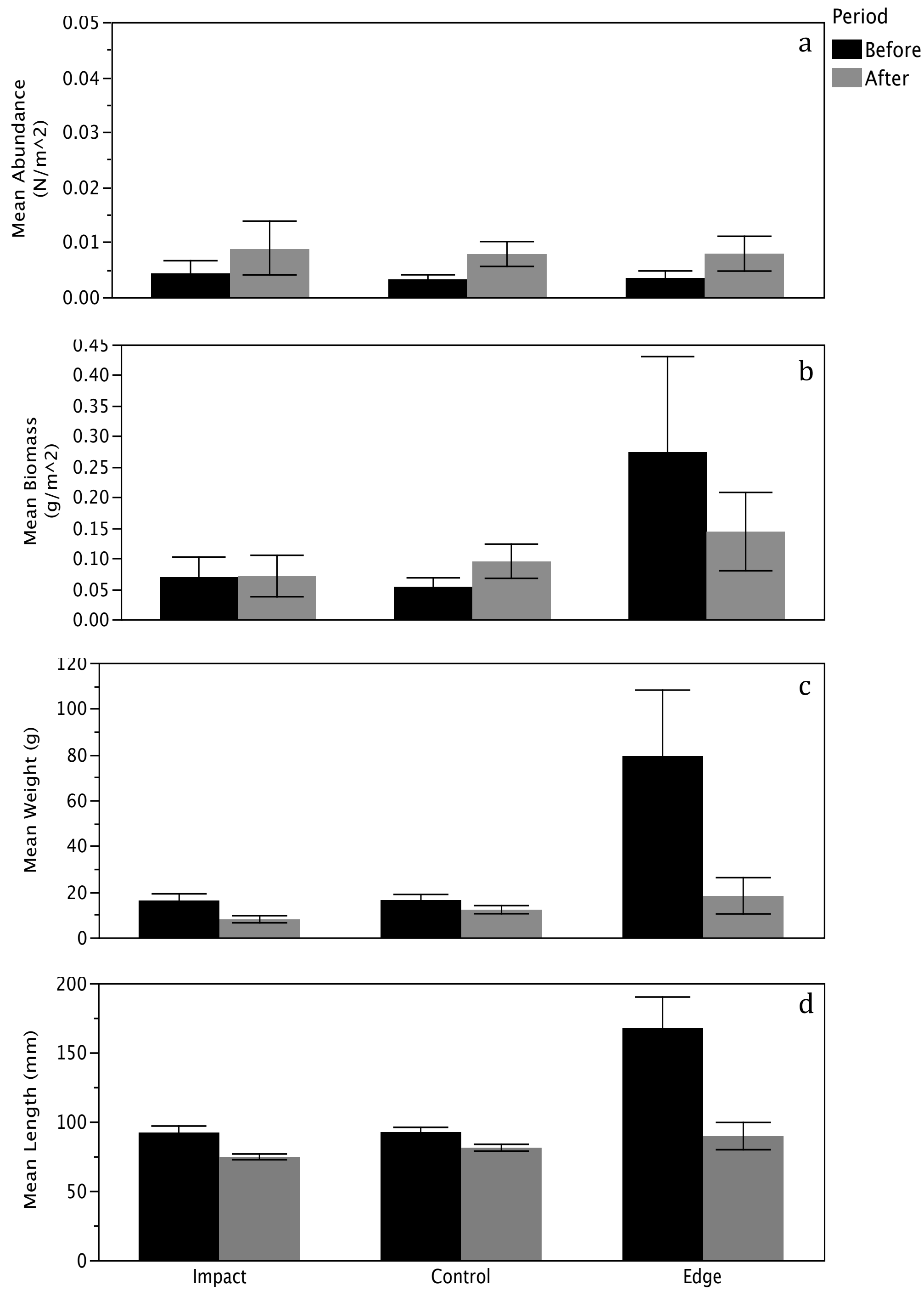

Figure 3.26. Purse seine catches of hardhead catfish (*Ariopsis felis*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11.7 Pinfish (*Lagodon rhomboides*)

Overall, 594 pinfish were collected by purse seine during this study (Table 3.1). Pinfish increased in mean abundance per m^2 (>5-fold) and mean biomass per m^2 (>2-fold) between periods, however average weight decreased in half and average SL also decreased (Table 3.28). This pattern of increased pinfish densities and smaller average sizes was also seen at impact, control, and edge areas when analyzed separately (Figure 3.27). ANOSIM

Table 3.28. Pinfish (*Lagodon rhomboides*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.00 (±<0.01)	0.07 (±0.02)	17.06 (±1.54)	75.35 (±2.28)
After	0.03 (±0.01)	0.23 (±0.06)	8.34 (±0.26)	60.97 (±0.66)
BI	<0.01 (±<0.01)	0.01 (±0.01)	10.24 (±2.59)	66.17 (±5.08)
AI	0.02 (±0.01)	0.12 (±0.03)	5.35 (±0.50)	51.66 (±1.27)
BC	<0.01 (±<0.01)	0.02 (±0.01)	22.02 (±2.21)	84.73 (±2.87)
AC	0.01 (±<0.01)	0.08 (±0.02)	10.30 (±0.37)	67.25 (±0.90)
BE	0.02 (±<0.01)	0.27 (±0.10)	16.36 (±2.02)	73.56 (±2.97)
AE	0.09 (±0.02)	0.80 (±0.23)	8.81 (±0.38)	62.33 (±0.95)

analyses of Period*Area interactions on pinfish mean abundance per m^2 were slightly non-significant (p=1.2%). Pairwise comparisons showed significant differences between BI and AE sites (p=0.01%), BC and AE sites (p=0.2%), and between BC and AC sites (p=0.1%). The pairwise comparison between BI and AI sites was slightly non-significant (p=1.3%). ANOSIM results of pinfish mean biomass per m^2 also showed a slightly non-significant difference between Interaction terms (p=1.8%). Pairwise comparisons showed a significant difference between BI and AI sites (p=0.6%), BC and AE sites (p=0.2%), BE and AI sites (p=0.4%), as well as BC and AC sites (p=0.3%). ANOSIM results of pinfish average

weight and average SL showed no significant differences between interaction terms (p=29.2% and p=18.1%, respectively). ANOSIM analysis of the after period showed no significant differences in pinfish mean densities or mean sizes between habitat types.

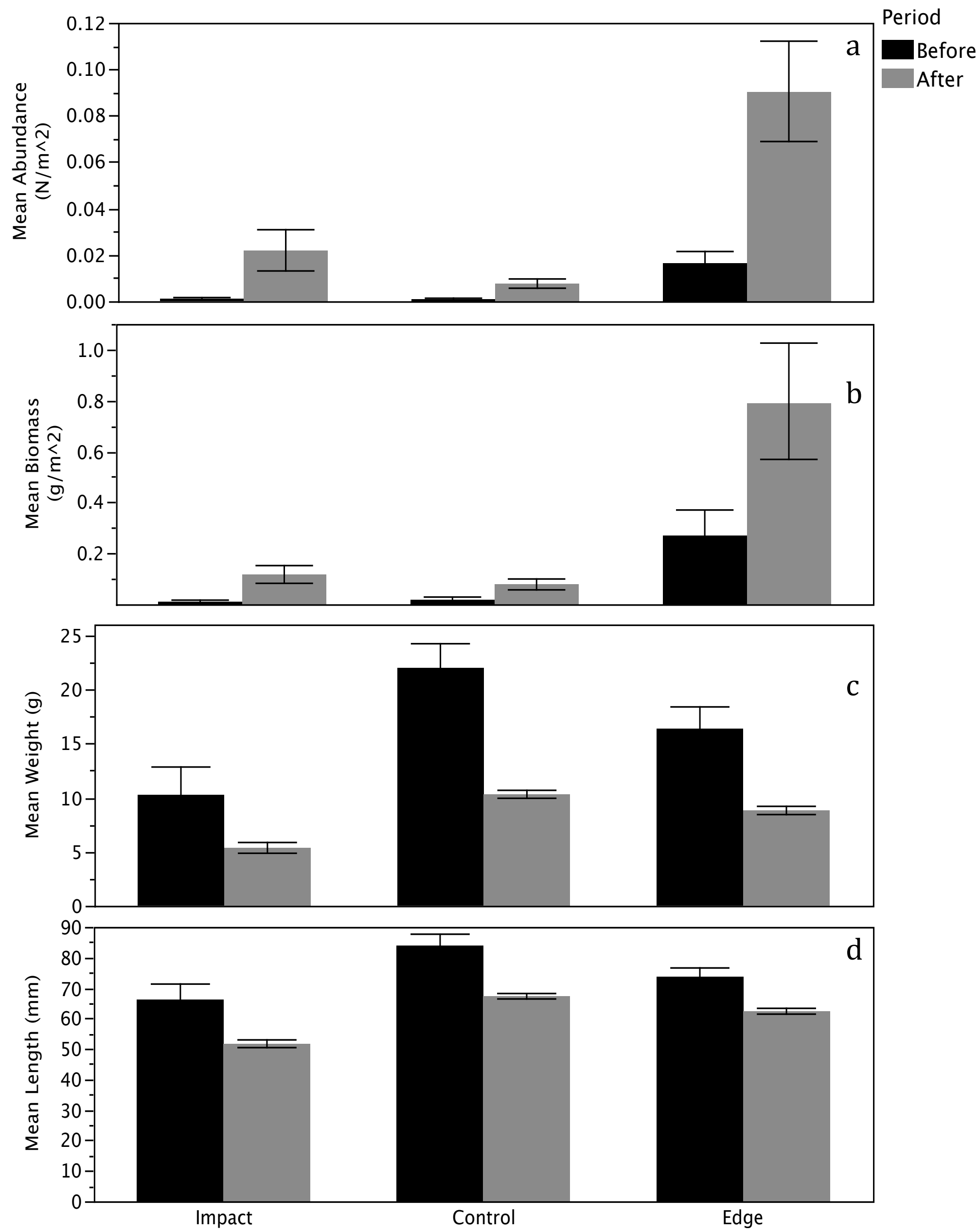

Figure 3.27. Purse seine catches of pinfish (*Lagodon rhomboides*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11.8 Spot (*Leiostomus xanthurus*)

A total of 1,919 spot were collected by purse seine during this study (Table 3.1). Overall, spot decreased in mean abundance per m^2, mean biomass per m^2, mean weight per individual, and mean SL per individual after artificial reef construction (Table 3.29). This pattern of decreases was also seen at impact and control areas (Figure 3.28). Edge areas displayed a slight increase in average spot SL (<1%) with decreases in spot mean abundance per m^2, mean biomass per m^2, and mean individual weight between periods (Figure 3.28). ANOSIM results showed no significant difference in Period*Area interactions of spot mean abundance per m^2 (p=55.4%), mean biomass per m^2 (p=54.7%), average weight per individual (p=8.5%), and average SL per individual (p=5.1%). During the after period, there were no significant differences in spot mean densities or mean weight between habitat types, however mean SL showed a significant difference between habitat types (p=1%). Pairwise comparisons showed mean SL of spot on reef habitats was significantly smaller on than soft-bottom habitats (p=0.2%) during the after period.

Table 3.29. Spot (*Leiostomus xanthurus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual standard length (SL, mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean SL mm (±SE)
Before	0.05 (±0.01)	0.43 (±0.06)	8.42 (±0.24)	65.47 (±0.47)
After	0.03 (±0.01)	0.25 (±0.06)	7.05 (±0.20)	63.52 (±0.45)
BI	0.04 (±0.02)	0.24 (±0.09)	5.66 (±0.27)	58.95 (±0.68)
AI	0.02 (±0.01)	0.10 (±0.03)	4.76 (±0.33)	54.41 (±1.02)
BC	0.04 (±0.01)	0.35 (±0.07)	9.45 (±0.35)	68.00 (±0.69)
AC	0.02 (±<0.01)	0.14 (±0.03)	7.10 (±0.17)	65.29 (±0.42)
BE	0.10 (±0.04)	0.87 (±0.21)	8.41 (±0.51)	65.30 (±0.94)
AE	0.09 (±0.02)	0.72 (±0.24)	8.05 (±0.47)	65.51 (±0.90)

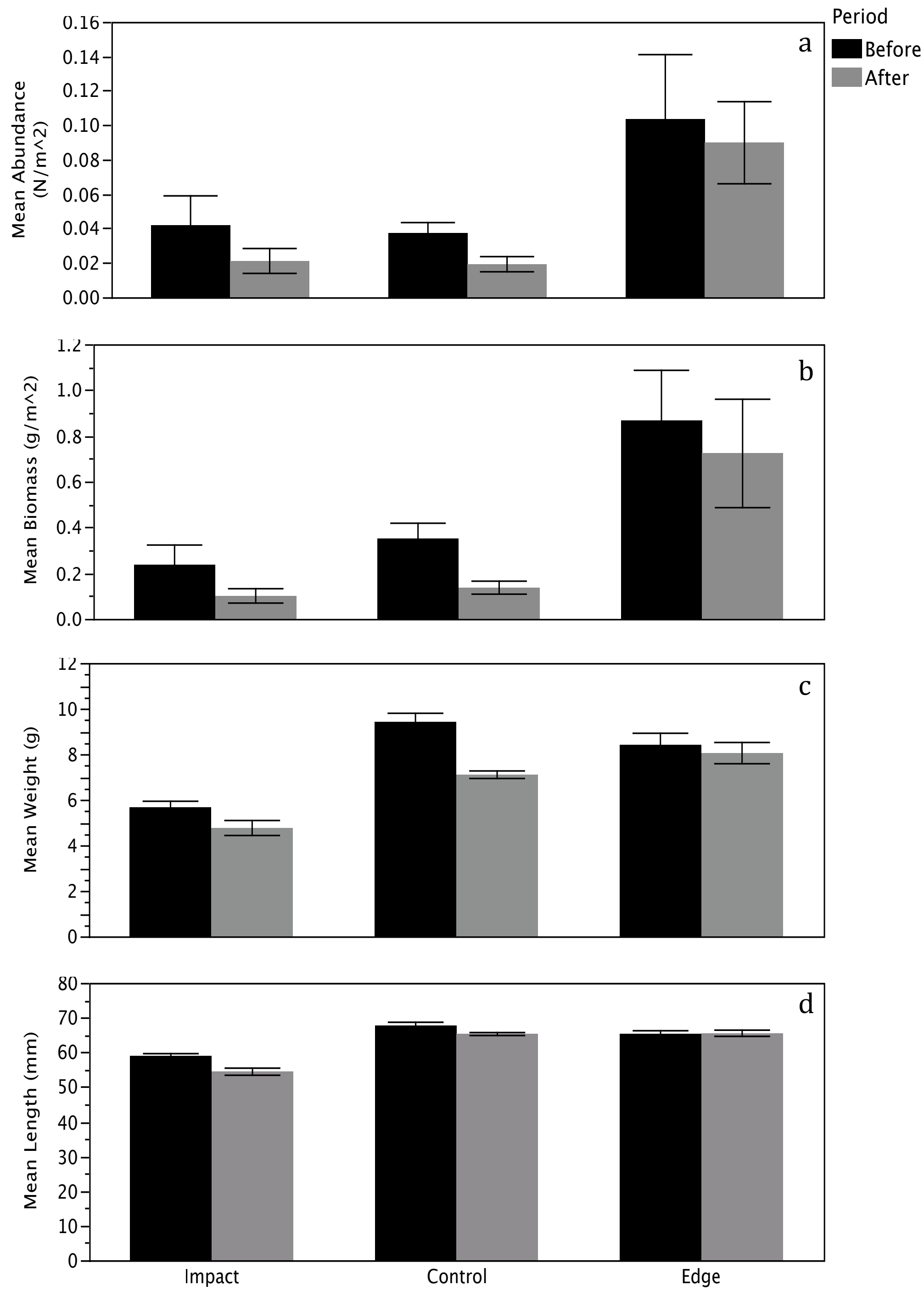

Figure 3.28. Purse seine catches of spot (*Leiostomus xanthurus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean standard length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

3.11.9 White shrimp (*Litopenaeus setiferus*)

A total of 3,989 white shrimp were collected by purse seine during this study (Table 3.1). Overall, white shrimp decreased in mean abundance per m^2, mean biomass per m^2, average weight, and average rostrum length after artificial reef construction (Table 3.30). At impact areas, white shrimp mean densities decreased as well as mean weight while average rostrum length slightly increased between periods (Figure 3.29). At control areas, white shrimp increased in mean abundance per m^2 and mean biomass per m^2, and decreased in average weight and average rostrum length between periods. White shrimp

Table 3.30. White shrimp (*Litopenaeus setiferus*) mean abundance density (N/m^2), mean biomass density (g/m^2), mean individual weight (g), and mean individual rostrum length (mm) ± standard error (SE) caught by purse seine before and after artificial reef construction and at before-impact (BI), after-impact (AI), before-control (BC), after-control (AC), before-edge (BE), and after-edge (AE) sites.

	Mean Density N/m^2 (±SE)	Mean Density g/m^2 (±SE)	Mean Weight g (±SE)	Mean Rostrum Length mm (±SE)
Before	0.10 (±0.03)	0.12 (±0.02)	1.26 (±0.06)	18.83 (±0.17)
After	0.08 (±0.02)	0.11 (±0.03)	1.25 (±0.05)	18.68 (±0.21)
BI	0.08 (±0.03)	0.08 (±0.02)	1.03 (±0.10)	17.90 (±0.32)
AI	0.06 (±0.02)	0.06 (±0.01)	1.00 (±0.09)	18.10 (±0.44)
BC	0.04 (±0.01)	0.07 (±0.01)	1.53 (±0.12)	19.24 (±0.32)
AC	0.06 (±0.01)	0.07 (±0.01)	1.12 (±0.07)	17.75 (±0.27)
BE	0.30 (±0.12)	0.35 (±0.08)	1.14 (±0.08)	19.01 (±0.26)
AE	0.17 (±0.06)	0.29 (±0.15)	1.71 (±0.10)	20.88 (±0.42)

at edge areas decreased in mean abundance per m^2 and mean biomass per m^2, while average weight and average rostrum length increased (Figure 3.29). ANOSIM results of white shrimp mean abundance per m^2 showed a significant difference between Period*Area interactions (p=0.9%), with pairwise comparisons showing significant differences between BC and BE sites (p=0.3%) as well as between BC and AC sites

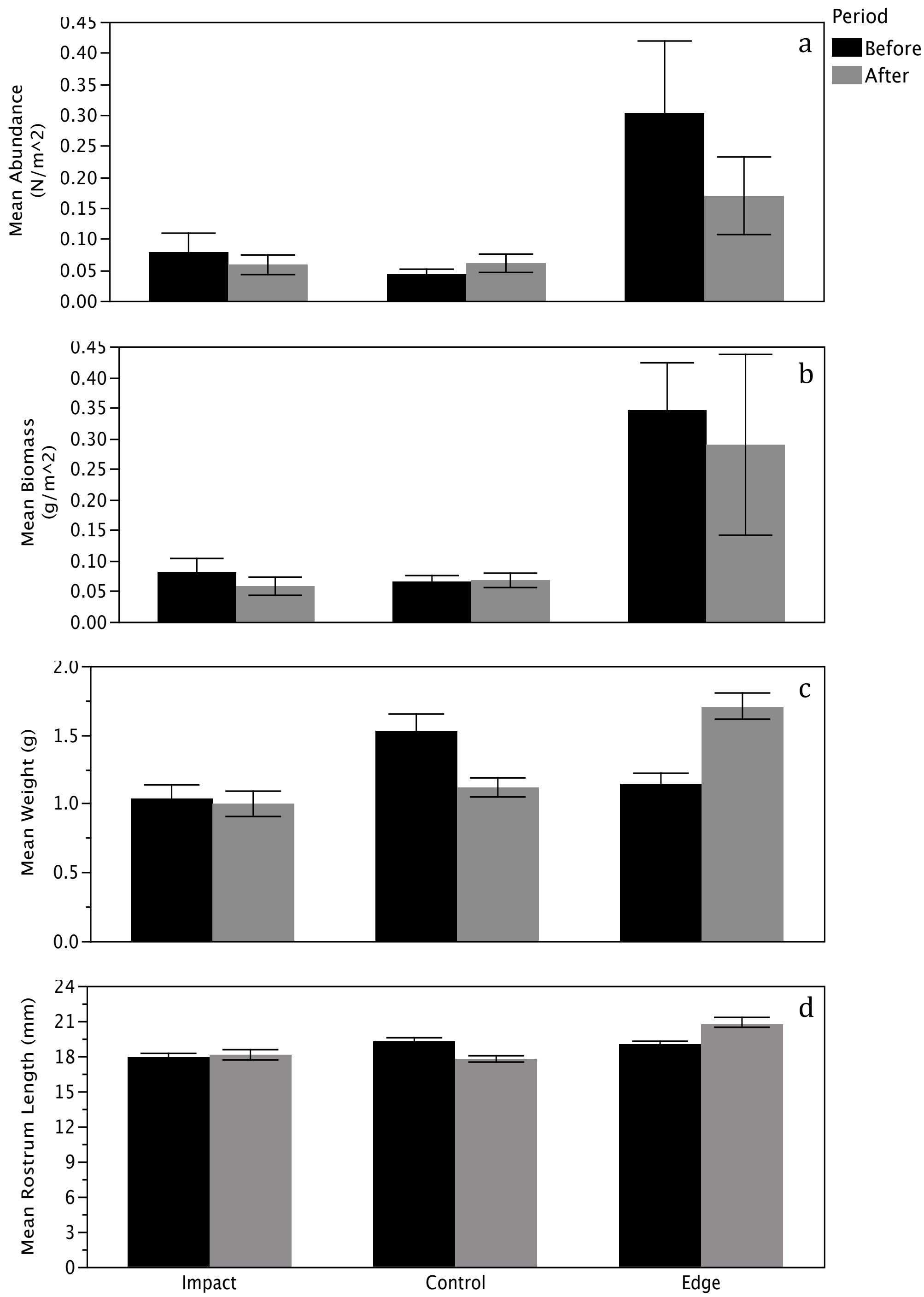

Figure 3.29. Purse seine catches of white shrimp (*Litopenaeus setiferus*) a) mean abundance density (N/m^2), b) mean biomass density (g/m^2), c) mean weight (g), and d) mean rostrum length (mm) at impact, control, and edge areas before (black) and after (gray) artificial reef addition. Error bars show +/- standard error.

(p=0.3%). There was no significant difference between BI and AI sites (p=93.4%). During the after period, white shrimp mean abundance per m^2 showed no significant difference between habitat types (p=31.9%). ANOSIM results of white shrimp mean biomass per m^2 also showed a significant difference between interaction terms (p=0.7%). Pairwise comparisons showed a significant difference between BE and BC sites (p=0.4%), BI and BE sites (p=0.3%), BE and AI sites (p=0.1%), and BC and AC sites (p=0.8%). The comparison between BI and AI sites was not significant (p=48.1%). In the after period, ANOSIM results of white shrimp mean biomass per m^2 showed no significant difference between habitat types (p=25.1%). ANOSIM results of white shrimp mean weight and mean rostrum length showed no significant differences between Period*Area interactions (p=90.2% and p=87%, respectively). ANOSIM analysis of habitats types in the after period showed no significant differences in white shrimp mean weight (p=76.9%) or mean rostrum length (p=91.5%).

CHAPTER 4: DISCUSSION

4.1 Sampling Design and Statistical Inference

Potential limitations and concerns regarding the use of Before-After-Control-Impact (BACI) experimental designs for impact assessment have been identified by previous literature and thus addressed in this study. Major concerns involve the ability of the design to account for natural variance, autocorrelation, type I errors, difficulty in interpretation, and assumption violations of statistical analyses (Hewitt et al., 2001; Hurlburt, 1984; Schwarz, 2011; Stewart-Oaten et al., 1986; Stewart-Oaten and Bence, 2001). Natural variation is accounted for in this study by not employing a simple BACI design with only one time factor and one space factor, rather multiple months within each time period were sampled as well as multiple space factors both larger (ponds) and smaller (sites) than the scale of impact. Analyses such as PERMANOVA and ANOSIM compare factors and their levels using Bray-Curtis dissimilarity matrices, which utilize differences between temporal and spatial factors simultaneously to control autocorrelation. The possibility of type I errors was reduced by collecting multiple explanatory variables (i.e. species) and including them in a single analysis (PERMANOVA). Most concerns over statistical assumptions apply to parametric tests such as ANOVA, but do not apply to semi-parametric and non-parametric analyses such as ANOSIM and PERMANOVA.

The tests of environmental factors were conducted with the goal of comparing the four experimental ponds to ensure nekton experienced similar conditions in all ponds. Measurements were taken every 5 minutes for approximately 12 hours per day of sampling creating extremely large sample sizes. While the statistical tests of each environmental factor showed significance differences, I believe this to be a result of such large sample

sizes. Mean values show small differences between ponds that I do not believe are biologically significant. The experimental ponds were close enough in proximity to experience similar physical conditions yet far enough apart to avoid pseudoreplication.

It is important to note that the reefs constructed during this study, while intended to mimic oyster reefs, did not consist of oyster shells. Oyster reefs are established by the settlement, growth, and subsequent layering of oysters creating a highly complex structure that may not be entirely comparable to this study's limestone cobble reefs. It is possible for limestone cobble reefs to increase in complexity and develop into fully functional oyster reefs, however this typically occurs over multiple years. After only one year of deployment, it is likely that the structural complexity and subsequent community complexity of this study's reefs are less than that of an established oyster reef.

All sampling during this study occurred surrounding high tide because that was the only time the ponds were accessible by boat. At low tide, the water depth in the ponds decreased to extremely low levels and ponds completely drained at low tide during winter months, especially after passage of cold fronts. This routine of daily drainage at low tide may have limited reef availability for nekton and thus reef utilization. It may also have acted as a daily disturbance inhibiting reef colonization, which would limit the expected benefit of increased benthic-pelagic coupling.

4.2 Results

The species collected in this study are typical of Louisiana estuaries with dominant species similar to previous studies (Rozas and Reed 1993; Day et al. 2009; De Mutsert 2010; Simonsen and Cowan 2013). This study collected 57 species, 33 of which were

collected on the artificial reefs. A similar study in Barataria Bay found 43 species associated with high-relief artificial oyster reefs (Simonsen et al. 2013), while as many as 80 species have been identified as associating with natural oyster reefs (Coen et al. 1999). Transient species dominated this study's catches. Coen et al. (1999) described seven fish species as reef-dependent residents of oyster reefs, however this study only collected two such species and each was extremely rare. These resident species are small cryptic fishes and the gear types used in this study may not have been able to collect them effectively. The fyke nets require fish to swim into them and the described reef residents are benthic species that often remain on the hard substrate of the reef and do not frequently swim in the water column. The purse seine sweeps across the benthic surface possibly allowing small benthic species to avoid capture in the interstitial spaces of the reef.

During the before period, when all control and impact areas were soft-bottom (mud) habitats, impact areas had the lowest mean abundance and biomass of both gear types. This is likely related to the physical location of impact areas within the ponds. Impact areas were the northern and eastern sites within each experimental pond, both of which had channel entrances at the southern end of the pond. It is possible that northern sites, which were farthest from the connecting channel, were utilized less by nekton.

Overall, the addition of the artificial reef did not significantly impact the species richness, species diversity, nekton density, or composition of the nekton community. Previous studies have also found no difference in nekton abundance or species richness between reef and soft-bottom habitats (Plunket and LaPeyre 2005; MacRae 2006; Simonsen and Cowan 2013). Large diverse communities of estuarine nekton are frequently

observed in the vicinity of oyster reefs despite little evidence of site-specific linkages based on habitat (Coen et al. 1999; Harding and Mann 2001; Coen and Grizzle 2007). This is generally seen as evidence of the highly mobile and opportunistic nature of the species comprising estuarine communities (Coen et al. 1999; Harding and Mann 2001; Simonsen et al. 2013).

While analyses of the nekton community as a whole showed no impact from reef addition, some individual species did display significant changes. Purse seine catches of pinfish (*Lagodon rhomboides*) significantly increased at impact areas as well as control areas after reef addition. While pinfish densities at impact and control areas were similar before reef construction, impact areas increased more considerably than control areas after reef construction. Highest densities of pinfish were found at marsh edge habitats throughout the study. This is similar to previous studies that show pinfish are frequently found on a wide variety of habitats, but usually in higher densities on more structurally complex habitats (Coen et al. 1999; Baltz et al. 1993; Coen and Grizzle 2007). Pinfish mouth morphology and ontogenetic shifts in prey preferences may allow juveniles to successfully exploit prey resources both on the reef and in the interstitial spaces (Cutwa and Turingan 2000, Garner 2012).

In contrast to pinfish, sand seatrout (*Cynoscion arenarius*) mouth morphology is not well suited to grazing on reefs and juveniles show diet preferences for invertebrates at soft-bottom habitats before shifting to a more piscivorous diet (Ditty and Bourgeois 1991; Hein 1999, Garner 2012). While significant changes were not observed, sand seatrout abundance and biomass only increased at control areas (soft-bottom habitats). Reef

addition may negatively affect juvenile sand seatrout by reducing availability of their preferred soft-bottom habitat.

During the after period when reef habitats were available, the average standard length of spot (*Leiostomus xanthurus*) caught by purse seine was significantly higher on soft-bottom habitats than reef habitats. The smallest individuals were also caught at impact sites before reef construction when impact areas consisted of soft-bottom habitat. This is likely a result of impact site locations within the ponds rather than a negative impact from artificial reef presence. Density and individual size of spot decreased at all habitats after reef addition indicating that declines are likely driven by natural variances in recruitment rather than habitat preference. Numerous previous studies have shown spot utilization of oyster reefs with increasing densities as reef complexity increases (Breitburg 1999; Coen et al. 1999; Harding and Mann 2001; Lenhert and Allen 2002).

White shrimp (*Litopenaeus setiferus*) biomass caught by fyke nets was significantly lower at after-impact (AI) sites than before-control (BC) sites, which only differed from impact areas in location before reef construction. White shrimp CPUE was lowest at AI sites, which also had the smallest average individual size. This could mean that white shrimp were negatively affected by the addition of the artificial reefs, however BC sites may not be entirely comparable to before-impact (BI) sites, and the contrast of BI versus AI sites showed no significant difference. Impact areas had the lowest CPUE of white shrimp before reef construction when such areas had the same soft-bottom habitat as control areas. This is more likely a result of impact area locations within each pond rather than an effect of the reefs. Previous studies of white shrimp also show variable habitat selection

and omnivorous feeding behavior (Minello and Zimmerman 1991; Shervette and Gelwick 2008).

Purse seine catches of Gulf menhaden (*Brevoortia patronus*) showed statistically significant changes in density at impact areas. However, I believe this is an error as mean values showed little difference. It is likely a result of patchy assemblages making sample replicates highly variable. Impact areas had much smaller catches of Gulf menhaden than control and edge areas throughout the study. This is more likely an effect of impact area locations within the experimental ponds than a habitat driven effect. While catches of Gulf menhaden increased only slightly at impact areas, mean abundance at edge areas increased 15-fold; control areas increased 50-fold. These drastic increases are due to a few large samples from May 2010 when over 94% of all Gulf menhaden were caught. The majority of these large samples during the May 2010 sampling trip were from the two control ponds that did not receive habitat enhancement. Gulf menhaden is a pelagic, schooling species that has been found in high densities on oyster reefs, but is typically found in open water with non-vegetated bottoms (Reintjes 1970). The schooling, pelagic nature of Gulf menhaden is more likely the driver of Gulf menhaden distribution rather than habitat type.

Fyke net catches of Atlantic croaker (*Micropogonias undulatus*) showed significant increases at control areas and edge areas after reef addition while impact areas also increased, though not significantly. This is likely evidence of natural variations in the Atlantic croaker recruitment as well as the opportunistic nature of the species. Previous studies report that high densities of Atlantic croaker are consistently collected over various

habitat types with habitat-specific linkages showing conflicting results (Petrik et al. 1999; Harding and Mann 2001; Coen and Grizzle 2007; Simonsen and Cowan 2013).

4.3 Deepwater Horizon Oil Spill

In April 2010 during the transition from the before period to the after period, the Deepwater Horizon oil rig exploded off the southeastern coast of Louisiana causing oil to be released into the Gulf of Mexico. While currents, winds, and other meteorological and oceanographic factors spread the oil into coastal waterways and shorelines, the study area examined here was not directly impacted by oil. While it is possible that the oil spill affected the results in this study, to say so would be pure speculation. This study was not intended to test for oil spill effects and water samples were not collected. I believe the potential for oil spill impacts on this study is small because the oil did not enter the study area. Another reason I think the chance of oil spill effects is small is due to the timing of the spill in association with estuarine species life cycles. Most species collected during this study move into the coastal estuaries during the fall and winter and were most likely already in the ponds and adjacent areas before the oil release and dispersal began.

4.4 Conclusions

The goal of this study was to assess the impacts of artificial reef creation on estuarine nekton by examining 1) changes in species richness, species diversity, nekton abundance, and nekton biomass, 2) changes in nekton community abundance and biomass distributions, and 3) changes in individual species' abundance, biomass, and size. Overall, the addition of artificial reefs had no significant effect on the nekton community while some individual species may be more affected than the community as a whole. Previous

studies of estuarine nekton species show that select life-stages may be positively or negatively affected by reef presence depending on ontogenetic shifts in prey and habitat selection of each species (Cutwa and Turingan 2000; Garner 2012; Simonsen et al. 2013). The artificial reefs constructed in this study seem to have positively affected pinfish (*L. rhomboides*) densities, likely by enhancing pinfish feeding success. Despite little evidence of habitat-specific linkages, large, diverse nekton communities are consistently observed in the vicinity of oyster reefs (Coen and Grizzle 2007). I believe in the absence of natural oyster reefs that the artificial reefs constructed in this study can act as quality nekton habitat once colonization and maturation of the reefs occur. The addition of movement data from a concurrent tagging study may shed more light on the habitat preferences and niche partitioning of nekton species. Future research on the effects of artificial reef addition should extend the monitoring period of this study to follow the evolution of limestone cobble reefs into colonized oyster reefs. Also, the placement and size of such reefs need to be selected carefully. Equal access and availability of all habitats is important for accurate comparisons.

4.5 Literature Cited

Baltz, D., C. Rakocinski and J. Fleeger. 1993. Microhabitat se by marsh-edge fishes in a Louisiana estuary. Environmental Biology of Fishes 36: 109-126.

Breitburg, D. 1999. Are three-dimensional structure and healthy oyster populations the keys to an ecologically interesting and important fish community? In: Luckenbach, M., Mann, R., Wessen, J. (eds) Oyster reef habitat restoration: a synopsis of approaches. Virginia Institute of Marine Science Press, Williamsburg, Virginia, p. 239-250.

Clarke, K. and R. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E: Plymouth.

Coen, L., M. Luckenbach and D. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. American Fisheries Society Symposium 22: 438-454.

Coen, L. and R. 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 109p.

Cutwa, M. and R. Turingan. 2000. Intralocality variation in feeding biomechanics and prey use in *Archosargus probatocephalus* (Teleostei, Sparidae), with implications for the ecomorphology of fishes. Environmental Biology of Fishes 59: S356-S362.

Day Jr., J., J. Cable, J. Cowan Jr., R. DeLaune, K. de Mutsert, B. Fry, H. Mashriqui, D. Justic, P. Kemp, R. Lane, J. Rick, S. Rick, L. Rozas, G. Snedden, E. Swenson, R. Twilley and B. Wissel. 2009. The impacts of pulsed reintroduction of river water on a Mississippi Delta coastal basin. Journal of Coastal Research 54: 225-243.

De Mutsert, K. 2010. The effects of a freshwater diversion on nekton species biomass distributions, food web pathways, and community structure in a Louisiana estuary. Doctoral Dissertation 188p. Louisiana State University.

Ditty, J. and M. Bourgeois. 1991. Life history and ecology of sand seatrout, *Cynoscion arenarius* Ginsburg, in the northern Gulf of Mexico: a review. Northeast Gulf Science 12(1): 35-47.

Garner, S. 2012. Effects of mimic artificial oyster reefs on the ecology of juvenile fishes in marsh ponds: a before-after-control-impact analysis. Master's Thesis 200p. Louisiana State University.

Harding, J. and R. Mann. 2001. Oyster reefs as fish habitat: opportunistic use of the restored reefs by transient fishes. Journal of Shellfish Research 20(3): 951-959.

Hein, S. 1999. Species profile of sand seatrout. Louisiana Department of Wildlife and Fisheries. 120p.

Hewitt, J., S. Thrush and V. Cummings. 2001. Assessing environmental impacts: effects of spatial and temporal variability at likely impact scales. Ecological Applications 11(5): 1502-1516.

Hurlburt, S. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54: 187-311.

Lehnert, R. and D. Allen. 2002. Nekton use of subtidal oyster shell habitat in a southeastern US estuary. Estuaries 25: 1015-1024.

MacRae, P. 2006. A community approach to identifying essential fish habitat of spotted seatrout, *Cynoscion nebulosus*, in Barataria Bay, Louisiana. Doctoral Dissertation 161p. Louisiana State University.

Minello, T. and R. Zimmerman. 1991. The role of estuarine habitats in regulating growth and survival of juvenile penaeid shrimp. Developments in Aquaculture and Fisheries Science 22: 1-16.

Petrik, R., P. Levin, G. 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.

Plunket, J. and M. LaPeyre. 2005. Oyster beds as fish and macroinvertebrate habitat in Barataria Bay, Louisiana. Bulletin of Marine Science 77(1): 155-164.

Reintjes, J. 1970. The gulf menhaden and our changing estuaries. Proceedings of the Gulf and Caribbean Fisheries Institute 22: 87-90.

Rozas, L. and D. Reed. 1993. Nekton use of marsh-surface habitats in Louisiana (USA) deltaic salt marshes undergoing submergence. Marine Ecology Progress Series. 96: 147-157.

Schwarz. C. 2011. Sampling, regression, experimental design and analysis for environmental scientists, biologists, and resource managers. Department of Statistics and Actuarial Science, Simon Fraser University.

Shervette, V. and F. Gelwick. 2008. Relative nursery function of oyster, vegetated marsh edge, and nonvegetated bottom habitats for juvenile white shrimp *Litopenaeus setiferus*. Wetlands Ecology and Management 16(5): 405-419.

Simonsen, K. and J. Cowan, Jr. 2013. Effect of an inshore artificial reef on the trophic dynamics of three species of estuarine fish. Bulletin of Marine Science 89(3): 657-676.

Simonsen, K., J. Cowan, Jr. and A. Fischer. 2013. Examination of an estuarine fish assemblage over an inshore artificial reef. Open Fish Science Journal 6: 48-57.

Stewart-Oaten, A., W. Murdoch and K. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? Ecology 67(4): 929-940.

Stewart-Oaten, A. and J. Bence. 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monographs 71(2): 305-339.

Stuntz, G., T. Minello and L. Rozas. 2010. Relative value of oyster reef as habitat for estuarine nekton in Galveston Bay, Texas. Marine Ecology Progress Series 406: 147-159.

THE VITA

Kari Klotzbach was born in March 1985 in New Orleans, Louisiana and has been a life-long resident of southeastern Louisiana. Raised in Chalmette, Louisiana, Kari graduated with honors from St. Mary's Dominican High School in New Orleans in August 2003. From 2003 to 2007, Kari attended Louisiana State University where she earned a Bachelor of Science degree in Biological Sciences with a concentration in Marine Biology in May 2007. In August 2008, Kari returned to Louisiana State University as a graduate student under Dr. James Cowan, Jr. Since then she has been a research assistant in the Department of Oceanography and Coastal Sciences and is currently a candidate for the degree of Master's of Science.