2007

Disturbance effects on nekton communities of seagrasses and bare substrates in Biloxi Marsh, Louisiana

Jamie Lynn Maiaro
Louisiana State University and Agricultural and Mechanical College

DISTURBANCE EFFECTS ON NEKTON COMMUNITIES OF SEAGRASSES AND BARE SUBSTRATES IN BILOXI MARSH, LOUISIANA

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

in

The Department of Oceanography and Coastal Sciences

by
Jamie Lynn Maiaro
B.S, Louisiana State University, 2004
August 2007

ACKNOWLEDGEMENTS

I would like to give my sincerest thanks to my major professor, Dr. Donald M. Baltz for his patience, kindness, and support throughout my years as a master's student. I especially appreciate his perseverance through the grueling field work when I needed an extra hand.

I would also like to thank my committee members, both past and present. I am grateful for the late Dr. E. Barry Moser's input on statistical analyses as well as the input and suggestions of my current committee members: Dr. Robert P. Gambrell, Dr. James P. Geaghan, and Dr. Nan D. Walker.

There are many individuals who have made this project possible. I am forever indebted to several local fishermen: my brother, Jason Cutrer, his friend, Bobby "Düt" Lovell, and the Campo family. Without them, I never would have found the seagrass beds in Biloxi Marsh. I am also grateful for Düt's willingness to get seagrass samples for me when I could not get them myself. I also appreciate the willingness of Christie, Düt's wife, to store those dirty samples in her refrigerator until I could pick them up.

I would like to thank Arie Roth for her field assistance, friendship, and input. I am also grateful to Pablo Granados-Dieselldorf and Stephanie Cogburn for their friendship and field assistance. I know the field work was trying at times, especially when the lightning storms and marsh fires surrounded us, but my field crew persevered through the troubles. Additionally, I thank Dr. Michael Kaller for his input on statistical analysis.

Lastly, I would like to thank my family for their support and encouragement. I am grateful for my husband, Bradley Crowe. His love, patience, and encouragement as I

worked toward my degree go unmatched. While every member of my family has helped me to achieve this goal in some way, my parents, Albert and Debbie Maiaro, were particularly helpful. I appreciate their willingness to listen, words of encouragement, and enthusiasm for my work. I also have to thank them for moving out of their FEMA trailer for a week so that I could stay in it with my field help during the aftermath of Hurricane Katrina.

This project was funded by NASA and the Center for Coastal Zone Assessment and Remote Sensing at Southern University.

TABLE OF CONTENTS

ABSTRACT

With marshes deteriorating rapidly across the Louisiana coast, the role of seagrasses in sustaining fisheries has come into question. Seagrasses are known to shelter small fish from larger predators. Seagrasses also act as a foraging ground for commercially important species, including spotted seatrout. Thirty samples, fifteen from seagrass habitats and fifteen from bare substrate habitats, were collected inside Biloxi Marsh using a drop sampler in May 2005. After the passage of Hurricanes Cindy and Katrina on July 6, 2005 and August 29, 2005, respectively, the seagrasses in Biloxi Marsh were either uprooted, buried, or both. The May 2005 sites were re-sampled in August 2005 and May 2006 for comparison of pre- and post-hurricane communities.

Multidimensional Scaling (MDS) analysis, followed by MANOVA was used to assess overall community structure and species composition, whereas canonical correlation was used to assess the influence of environmental variables on communities. Results show differences in seagrass and bare substrate communities prior to hurricane passage in May 2005. However, post-Cindy, the sites with remaining seagrass resembled the seagrass sites of May 2005, while those without seagrass resembled the bare sites of May 2005. After Cindy, canonical correlation analysis showed that the variables of bottom type, habitat type, month, salinity, turbidity, dry weight of seagrasses, *Farfantepenaeus aztecus, Lucania parva, Palaemonetes pugio* and *Syngnathus scovelli* loaded heavily on the first canonical variable, while habitat type, month, substrate, and *Sphoeroides parvus* loaded heavily on the second.

Post-Katrina, all sites were bare, and thus resembled the bare substrate sites of May 2005. Post-Katrina canonical correlation revealed heavy loadings of bottom type,

habitat type, year, salinity, dissolved oxygen, turbidity, dry weight, *Anchoa mitchilli, Lucania parva*, *Mysidopsis* spp., *Palaemonetes pugio*, and *Syngnathus scovelli*.

Changes in community structure and species composition observed after the passage of Cindy and Katrina occurred only in seagrass stations that suffered either removal of seagrasses, influx of salt water from storm surges, or both. Additionally, dry weight of seagrasses and/or habitat type were the variables that loaded most heavily on the canonical variables, indicating that presence of seagrasses was the main factor leading to observed changes in community.

GENERAL INTRODUCTION

Seagrasses occur worldwide in shallow, estuarine habitats (Rozas and Minello 1997), particularly in temperate and tropical regions (Short and Wyllie-Escheverria 1996). Named for their ability to thrive in salt water, seagrasses also require the water and ocean currents for reproductive purposes (Short and Wyllie-Escheverria 1996). Locations of seagrass meadows are influenced by many factors including water clarity, salinity, and depth (Sheridan and Minello 2003) as seagrasses need near-optimal conditions to survive.

Seagrasses are an important habitat to many nekton, providing excellent nursery habitat, food, and shelter for many organisms (Hemminga and Nieuwenhuize 1990). The complex structure of seagrass stems and leaves provides hiding places for smaller nekton to avoid predators (Bell and Westoby 1986, Wilson et al. 1990, Heck et al. 2003, Woodley and Peterson 2003) as well as surfaces for epibenthic species to attach (Connolly 1997). Seagrasses also provide an excellent food source for nekton (Rozas and Odum 1988). Leaves of seagrasses can serve as food directly for herbivores, while detritus from decomposing plants can serve as food for detritivores. Increased productivity in seagrass beds results in a large abundance of plankton and small crustaceans, which are preyed upon by fishes (Bell and Pollard 1989).

Seagrasses also alter the physics and chemistry of the water column, which contributes to the habitat value of seagrass beds. Seagrasses play an important role in nutrient cycling, which increases the productivity of seagrass beds and surrounding areas (Jenkins et al. 1997). While photosynthesis carried out by seagrasses increases the dissolved oxygen available in the water column (Levinton 2001), the complex plant

structure reduces water current speed and increases sedimentation and water clarity (Orth and von Montfrans 1990, Heise and Bartone 1999, Bologna and Heck 2002).

Enhanced predator protection and prey availability make seagrass beds attractive for juvenile nekton. Due to the utilization of seagrass beds by many species at some stage of their life history, seagrasses are often referred to as nursery habitats (Bell and Pollard 1989, Thomas et al. 1990, Rozas and Reed 1994, Castellanos and Rozas 2001, Epifanio et al. 2003). In many cases, fish and invertebrates are more abundant and diverse in seagrass habitats (Rozas and Odum 1988, Bell and Pollard 1989, Jenkins et al. 1997, Rozas and Minello 1998, Minello et al. 2003).

Due to sensitivity to environmental changes, seagrasses are often considered an indicator species as they promptly show signs of stress or mortality after a disturbance (Orth and Moore 1983). There are many disturbances that affect seagrasses, including human disturbances (e.g., propeller scarring, industrial pollution), geological disturbances (e.g., erosion, subsidence), biological disturbances (e.g., grazing, bioturbation), and meteorological disturbances (e.g., ice formation and retreat, frontal passages, and hurricanes) (Short and Wyllie-Escheverria 1996).

This paper focuses on hurricane disturbances. Hurricanes can have a number of effects on seagrass beds. Winds and waves can uproot the seagrasses and deposit them on nearby land (Hemminga and Nieuwenhuize 1990, Pulich and White 1991, Short and Wyllie-Escheverria 1996, Greenwood et al. 2006). Storm surge can bring in sediment from the ocean and bury the grasses (Wanless et al. 1988). Winds create waves that beat along marsh edges, causing erosion. These eroded sediments, as well as sediment input from increased runoff or stirred up from the bottom by wave action, remain suspended in

the water column, increasing turbidity. Increased nutrient influxes from runoff can result in phytoplankton blooms, which increase turbidity. With increasingly turbid waters, seagrasses may no longer receive enough light, and thus die (Short and Wyllie-Escheverria 1996, Steward et al. 2006).

Seagrasses may experience substantial salinity fluctuations after hurricanes. Storm surges bring in saltier oceanic water, which needs to be flushed out of the system, whereas rainfall in inland areas causes increased runoff, which decreases salinity (Tabb and Jones 1962, Greenwood et al. 2006, Paperno et al. 2006, Steward et al. 2006, Switzer et al. 2006). In both cases, seagrasses may be able to tolerate salinity changes for a short time; however, if the salinity regime is altered for an extended time, seagrasses may die or suffer reductions if they cannot acclimate to the change.

This paper focuses on seagrass and bare substrate habitat types in a Louisiana estuary. They were impacted by two hurricanes in the span of three months. To evaluate nekton community structure in the following chapters, only the most frequently occurring species were considered. Seventeen taxa were included in analyses (Table I.1)

In chapter one, the seagrass and bare substrate habitat types are analyzed in terms of nekton community structure pre- and post- Hurricane Cindy, a category one storm. Hurricane Cindy damaged the study area, but did little damage to infrastructures, ports, and waterways. In Chapter 2, the focus is on Hurricane disturbance effects across the two habitat types. While chapter 2 emphasizes the effects of Hurricane Katrina, a category three storm that heavily damaged infrastructure, ports, and waterways, it is also explores the intermediate effects caused by Hurricane Cindy.

Table I.1. Frequency of taxa occurrence in fifteen seagrass (S) and fifteen bare substrate (B) stations across the three sampling events in the Goose Flat study area. Common and scientific fish and invertebrate names follow International Taxonomic Information System (ITIS 2006).

Species Frequency									
Taxa	**Common Name**	**May 05**		**Aug 05**		**May 06**		**Overall**	
		S	**B**	**S**	**B**	**S**	**B**	**Total**	**%**
Family Xanthidae	mud crab	14	10	4	11	11	10	60	66.7
Gobiosoma bosc	naked goby	5	8	8	13	9	8	51	56.7
Farfantepenaeus aztecus	brown shrimp	11	4	4	7	11	13	50	55.6
Callinectes sapidus	blue crab	10	5	1	3	6	10	35	38.9
Anchoa mitchilli	bay anchovy	0	2	5	7	10	6	30	33.3
Myrophis punctatus	speckled worm eel	6	4	0	6	4	3	23	25.6
Mysidopsis	mysid shrimp	9	2	7	2	0	0	20	22.2
Lucania parva	rainwater killifish	14	2	2	0	0	0	18	20.0
Palaemonetes pugio	grass shrimp	11	2	2	0	1	1	17	18.9
Microgobius gulosus	clown goby	3	1	3	5	0	1	13	14.4
Ctenogobius boleosoma	darter goby	4	4	0	2	0	0	10	11.1
Syngnathus scovelli	Gulf pipefish	6	0	3	1	0	0	10	11.1
Sphoeroides parvus	least puffer	1	0	0	5	1	2	9	10.0
Symphurus plagiusa	blackcheek tonguefish	0	0	4	2	0	0	6	6.7
Gobiesox Strumosus	skilletfish	0	2	0	0	0	4	6	6.7
Citharichthys spilopterus	bay whiff	0	0	0	0	4	2	6	6.7
Cynoscion nebulosus	spotted seatrout	1	0	1	1	1	1	5	5.6
Cyprinodon variegatus	sheepshead minnow	2	0	1	0	0	0	3	3.3
Dormitator maculatus	fat sleeper	1	2	0	0	0	0	3	3.3
Elops saurus	ladyfish	3	0	0	0	0	0	3	3.3
Gobiidae spp.	goby	0	1	1	1	0	0	3	3.3
Strongylura marina	Atlantic needlefish	1	1	0	0	0	0	2	2.2
Anchoa hepsetus	striped anchovy	0	0	0	0	1	1	2	2.2
Heterandria formosa	least killifish	2	0	0	0	0	0	2	2.2
Callinectes spp.	swimming crab	0	0	1	1	0	0	2	2.2
Scartella cristata	molly miller	0	1	0	0	0	0	1	1.1
Fundulus grandis	Gulf killifish	1	0	0	0	0	0	1	1.1
Lutjanus griseus	gray snapper	1	0	0	0	0	0	1	1.1
Callinectes similis	lesser blue crab	0	0	0	1	0	0	1	1.1
Leiostomus xanthurus	spot	0	1	0	0	0	0	1	1.1
Squilla empusa	mantis shrimp	0	1	0	0	0	0	1	1.1
Synodus foetens	inshore lizardfish	0	1	0	0	0	0	1	1.1
Poecilia latipinna	sailfin molly	0	0	1	0	0	0	1	1.1
Unidentified Invert	unidentifiable invertebrate	1	0	0	0	0	0	1	1.1
Brevoortia patronus	gulf menhaden	0	0	0	0	1	0	1	1.1
Alpheus heterochaelis	bigclaw snapping shrimp	0	0	0	0	0	1	1	1.1
Bairdiella chrysoura	silver perch	0	0	0	0	0	1	1	1.1
Micropogonias undulatus	Atlantic croaker	0	0	0	0	1	0	1	1.1
TOTALS		107	54	48	68	61	64	402	

LITERATURE CITED

Bell, J. D. and D. A. Pollard. 1989. Ecology of fish assemblages and fisheries associated with seagrasses, p. 565-611. *In* A.W.D. Larkum, A. J. McComb, and S. A. Shepard (eds.), Biology of Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region. Elsevier, Amsterdam.

Bell, J. D. and M. Westoby. 1986. Importance of local changes in leaf height and density to fish and decapods associated with seagrasses. *Journal of Experimental Marine Biology and Ecology* 104:249-274.

Bologna, P. A. X. and K. L. Heck, Jr. 2002. Impact of habitat edges on density and secondary production of seagrass-associated fauna. *Estuaries* 25:1033-1044.

Castellanos, D. L. and L. P. Rozas. 2001. Nekton use of submerged aquatic vegetation, marsh, and shallow unvegetated bottom in the Atchafalaya River Delta, a Louisiana tidal freshwater system. *Estuaries* 24:184-197.

Connolly, R. M. 1997. Differences in composition of small, motile invertebrate assemblages from seagrass and unvegetated habitats in a southern Australian estuary. *Hydrobiologia* 346:137-148.

Epifanio, C. E., A. I. Dittel, R. A. Rodriguez, and T. E. Targett. 2003. The role of macroalgal beds as nursery habitat for juvenile blue crabs, *Callinectes sapidus. Journal of Shellfish Research* 22:881-886.

Greenwood, M. F. D., P. W. Stevens, and R. E. Matheson, Jr. 2006. Effects of the 2004 hurricanes on the fish assemblages in two proximate southwest Florida estuaries: change in the context of interannual variability. *Estuaries and Coasts* 29:985-996.

Heck, Jr., K. L., G. Hays, and R. J. Orth. 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series* 253:123-136.

Heise, R. J. and S. A. Bortone. 1999. Estuarine artificial reefs to enhance seagrass planting and provide fish habitat. *Gulf of Mexico Science* 2:59-74.

Hemminga, M. A. and J. Nieuwenhuize. 1990. Seagrass wrack-induced dune formation on a tropical coast (Banc-Darguin, Mauritania). *Estuarine, Coastal and Shelf Science* 31:499-502.

Integrated Taxonomic Information System (ITIS). Retrieved May 1, 2007. www.itis.gov.

Jenkins, G. P., H. M. A. May, M. J. Wheatley, and M.G. Holloway. 1997. Comparison of fish assemblages associated with seagrass and adjacent unvegetated habitats of Port Phillip Bay and Corner Inlet, Victoria, Australia, with emphasis on commercial species. *Estuarine, Coastal and Shelf Science* 44:569-588.

Levinton, J. S. 2001. Marine Biology Function, Biodiversity, Ecology, 2nd edition. Oxford University Press, Incorporated, New York, New York.

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

Orth, R. J. and K. A. Moore. 1983. Chesapeake Bay: an unprecedented decline in submerged aquatic vegetation. *Science* 222:51-53.

Orth, R. J. and J. van Montfrans. 1990. Utilization of marsh and seagrass habitats by early stages of *Callinectes sapidus*: a latitudinal perspective. *Bulletin of Marine Science* 46:126-144.

Paperno, R., D. M. Tremain, D. H. Adams, A. P. Sebastian, J. T. Sauer, and J. Dutka-Gianelli. 2006. The disruption and recovery of fish communities in the Indian River Lagoon, Florida, following two hurricanes in 2004. *Estuaries and Coasts* 29:1004-1010.

Pulich, W. M., and W. A. White. 1991. Decline of submerged vegetation in the Galveston Bay system: Chronology and relationships to physical processes. *Journal of Coastal Research* 7:1125-1138.

Rozas, L. P. and T. J. Minello. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: a review of sampling design with focus on gear selection. *Estuaries* 20:199-213.

Rozas, L. P. and T. J. Minello. 1998. Nekton use of salt marsh, seagrass, and nonvegetated habitats in a south Texas (USA) estuary. *Bulletin of Marine Science* 63:481-501.

Rozas, L. P. and W. E. Odum. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. *Oecologia* 77:101-106.

Rozas, L. P. and D. J. Reed. 1994. Comparing nekton assemblages of subtidal habitats in pipeline canals traversing brackish and saline marshes in coastal Louisiana. *Wetlands* 14: 262-275.

Sheridan, P. and T. J. Minello. 2003. Nekton use of different habitat types in seagrass beds of lower Laguna Madre, Texas. *Bulletin of Marine Science* 72:37-61.

Short, F. T. and S. Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* 23:17-27.

Steward, J. E., R. W. Virnstein, M. A. Lasi, L. J. Morris, J. D. Miller, L. M. Hall, and W. A. Tweedale. 2006. The impacts of the 2004 hurricanes on hydrology, water quality, and seagrass in the central Indian River Lagoon, Florida. *Estuaries and Coasts* 29:954-965.

Switzer, T. S., B. L. Winner, N. M. Dunham, J. A. Whittington, and M. Thomas. 2006. Influence of sequential hurricanes on nekton communities in a southeast Florida estuary: short-term effects in the context of historical variations in freshwater inflow. *Estuaries and Coasts* 29:1011-1018.

Tabb, D. C. and A. C. Jones. 1962. Effect of Hurricane Donna on the aquatic fauna of north Florida Bay. *Transactions of the American Fisheries Society* 91:375-378.

Thomas, J. L., R. J. Zimmerman, and T. J. Minello. 1990. Abundance patterns of juvenile blue crabs (*Callinectes sapidus)* in nursery habitats of two Texas bays. *Bulletin of Marine Science* 46:115-125.

Wanlass, H. R., L. P. Tedesco, and K. M. Tyrrell. 1988. Production of subtidal tubular and surficial tempestites by Hurricane Kate, Caicos platform, British West Indies. *Journal of Sedimentary Petrology* 58:739-750.

Wilson, K. A., K. W. Able, and K. L. Heck, Jr. 1990. Predation rates on juvenile blue crabs in estuarine nursery habitats: evidence for the importance of macroalgae (*Ulva lactuca)*. *Marine Ecology Progress Series* 58:243-251.

Woodley, C. M. and M. S. Peterson. 2003. Measuring responses to simulated predation threat using behavioral and physiological metrics: the role of aquatic vegetation. *Oecologia* 136:155-160.

CHAPTER 1. INFLUENCES OF SEAGRASS PRESENCE AND ABSENCE ON NEKTON COMMUNITIES PRE- AND POST-HURRICANE CINDY IN BILOXI MARSH, LOUISIANA

INTRODUCTION

Seagrasses typically occur in shallow estuarine and marine waters with muddy, sandy, or rocky bottoms in temperate and tropical climates (Godfrey and Wooten 1979, Hemminga and Nieuwenhuize 1990, Short and Wyllie-Echeverria 1996, Rozas and Minello 1997). Among the most highly productive habitats in the world, seagrass beds are important to many assemblages of animals in aquatic ecosystems (Hemminga and Nieuwenhuize 1990, Rozas and Minello 1998, Heise and Bortone 1999, Deegan 2002, Orth et al. 2002). The high productivity of seagrasses provides a direct and indirect food source for many fishes and invertebrates. Several herbivorous fishes and invertebrates feed upon the leaves of seagrasses, while decaying leaves act as food for detritivores, or enrich nearby sediments to fuel food production for fishes (Dawes 1998, Heise and Bortone 1999, Orth et al. 2002, Epifanio et al. 2003).

In addition to food, the stems and leaves of seagrasses provide structures that serve as a hiding place or attachment substrate for small fish and invertebrate prey (Bell and Westoby 1986b, Howard et al.1989, Castellanos and Rozas 2001, Heck et al. 2003, Woodley and Peterson 2003). Plants with larger, thicker leaves provide more protection than those with finer, threadlike leaves (Heck and Orth 1980). Predation rates are often lower in vegetated habitats when compared to unvegetated habitats (Heck and Thoman 1981, Bell and Westoby 1986a, Rozas and Odum 1988, Wilson et al. 1990b, Heise and Bortone 1999). This combination of structure, food availability, and lower predation rates often yields comparatively higher abundances and diversities of fishes and

invertebrates in seagrass beds (Summerson and Peterson 1984, Rozas and Odum 1988, Sogard and Able 1991, Castellanos and Rozas 2001, Sheridan and Minello 2003).

The density of the vegetation influences survivorship of prey. Generally, deeper beds support denser foliage, which in turn provide more refuge for prey and further hinder predators' visual abilities. Also, it is more difficult for larger predators to maneuver inside the beds. However, at some densities, the seagrasses will become too thick to support fish and invertebrate prey. During periods of high respiration, the large densities of grasses can reduce oxygen concentrations to stressful levels (Heck and Orth 1980).

Because of the larger abundances and increased survival of juveniles present inside seagrass beds, seagrasses are often considered nursery habitats, particularly for blue crabs (Thomas et al.1990, Wilson et al.1990a, Castellanos and Rozas 2001, Epifanio et al.2003, Spitzer et al. 2003). Beck et al. (2001) claim that 'a habitat is a nursery for juveniles of a particular species if its contribution per unit area to the production of individuals that recruit to adult populations is greater, on average, than production from other habitats in which juveniles occur.' Some species select vegetated habitats because of the increased protection while some larvae are retained in the grasses due to the sieving of the water as it passes through the leaves (Summerson and Peterson 1984, Bell and Pollard 1989, Bologna and Heck 2002, Stockhausen and Lipcius 2003). Juveniles utilizing seagrasses as a nursery will occupy the beds at different life history stages for each species, while different species will also utilize different parts of the seagrass beds, such as the canopy, roots, or bottom stems and leaves (Bell and Pollard 1989).

Seagrasses can also alter the physics and chemistry of a system, which may make seagrasses more suitable habitats for some fishes and invertebrates (Connolly 1997, Deegan 2002). The stems hinder water as it moves through the seagrass bed, which acts to remove sediments from the water column, thus increasing water clarity. Water clarity is also increased by stabilization of sediments, enhanced by the seagrass roots (Hemminga and Nieuwenhuize 1990, Short and Wyllie-Escheverria 1996, Dawes 1998, Heise and Bortone 1999, Bologna and Heck 2002). Lowering of water current speed also acts to protect shorelines from erosion, which in turn can also decrease turbidity (Hemminga and Nieuwenhuize 1990, Short and Wyllie-Echeverria 1996, Heise and Bortone 1999). The seagrasses alter the chemistry of the water column by cycling nutrients and a diel pattern dominated by daylight photosynthesis and nighttime respiration (Hemminga and Nieuwenhuize 1990, Deegan 2002). The dissolved oxygen (DO) and temperature, in the grass beds may be more suitable for smaller fishes than larger predators (Deegan 2002).

One problem with evaluating seagrass beds as habitat is that they vary locally. Some beds support larger abundances and diversities of nekton, while other beds of the same seagrass species do not. For this reason, I chose to look at a grass bed in Louisiana that is small in area, generally persistent from year to year, and has not been previously studied. The primary goals were to determine (1) if the nekton communities differed between seagrass and bare substrate habitat types and (2) what nekton species or environmental differences may be driving the differences between the two habitat types.

MATERIALS AND METHODS

Study Area

A series of shallow ponds known as Goose Flat was the chosen location for this study because of the known resiliency of seagrasses in the ponds. Goose Flat is located inside the Biloxi Marsh Management Area in St. Bernard Parish, Louisiana (Figure 1.1).

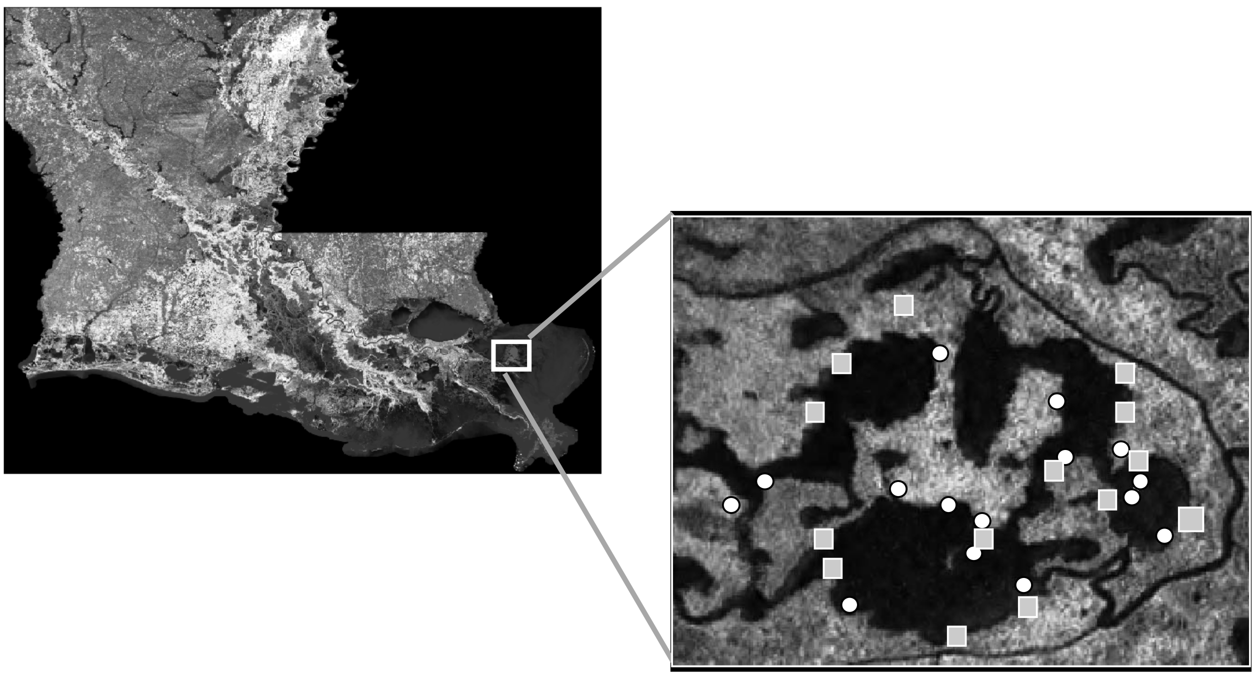


Figure 1.1. Map of seagrass sites (◯) and bare substrate sites (■) sampled in Goose Flat.

Biloxi Marsh spans an area of 51,893 hectares of brackish (4-18 ppt) and intermediate (2-8 ppt) marshes (Lopez 2005). Like most of southern Louisiana, Biloxi Marsh is located on a complex of abandoned river deltas. It is a unique wetland in that it is relatively undeveloped and degrading at a much slower rate than other wetlands in southern Louisiana. The slower degradation is attributed to many factors; most notably that it is not positioned over the deep trench formed by the Mississippi River. The

marshlands are considered vertically stable, fostered in large part by the numerous tropical systems that re-suspend sediment and deposit it on the marsh surface. Elevation increases of up to 35 mm have been recorded from individual tropical storms and hurricanes. Designation as a wildlife management area limits industrial influence on the wildlife and marshes. One of the few and prominent manmade features of Biloxi Marsh is the Mississippi River Gulf Outlet (MRGO), a 122 km deep-draft navigational channel. Dredging of the Mississippi River Gulf Outlet and leveeing of the Mississippi River are probably responsible for a large part of the degradation in the Biloxi Marsh Complex (King et al. 2006).

Biloxi Marsh is also valued for fisheries yields and providing protection against hurricanes. Common fisheries in Biloxi Marsh include oyster, brown shrimp, white shrimp, blue crab, spotted seatrout, and red drum (Wicker et al. 1982). The marshlands serve to buffer storm surge and dissipate energy before it reaches St. Bernard and Orleans parishes. However, the presence of the Mississippi River Gulf Outlet not only increases the habitat degradation, but also facilitates the progress of storm surges affecting the area (King et al. 2006). In 2005, Biloxi Marsh attenuated storm surges ranging from 1.2 - 2.0 m for Hurricanes Cindy (Stewart 2006) and Rita (Knabb et al. 2006b) and a surge of 4.5 - 5.8 m for Hurricane Katrina (Knabb et al. 2006a). However, it is speculated that surges in the area of the Mississippi River Gulf Outlet have been substantially increased due to a funneling effect (Stokstad 2005).

On July 6, 2005, Goose Flat was hit by Hurricane Cindy (Figure 1.2). At landfall, Cindy was a category one hurricane on the Saffir-Simpson scale with winds at 65 knots

and a storm surge of ~2 m near Goose Flat. As a result of the high winds and surge, most of the seagrasses were uprooted and deposited on nearby marshes.

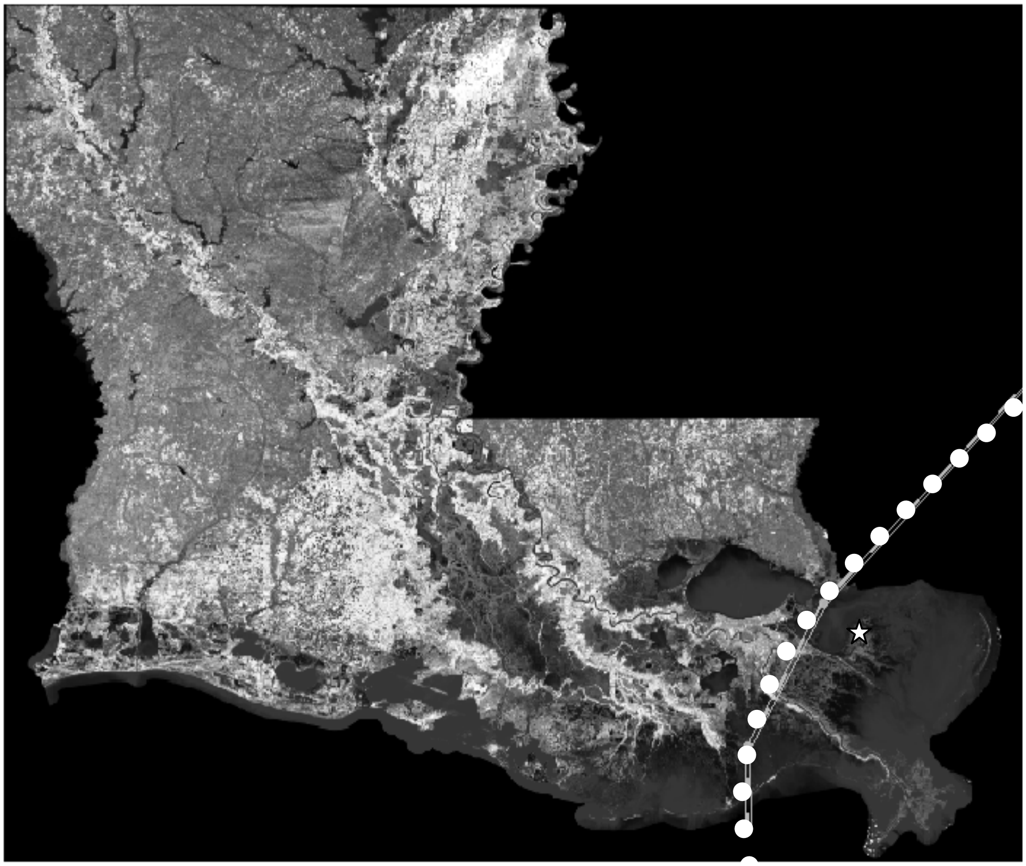


Figure 1.2. The Track of Hurricane Cindy (dotted line) in July 2005. The star (☆) marks the approximate location of Goose Flat.

Seagrasses

The dominant seagrass in Goose Flat was widgeon grass, *Ruppia maritima* L. Although not universally regarded as a true seagrass, it can withstand prolonged exposure to fresh water and has a high salinity tolerance (Thayer et al. 1975). *Ruppia,* common in shallow, brackish and saline ponds and bayous, has long, slender, alternating leaves and dark, oval-shaped seeds. Its slender, leafy form enhances its structural habitat

complexity and refuge value as well as its food value for nekton and wildlife (Chabreck and Condrey 1979, Godfrey and Wooten 1979).

A second species of seagrass, *Zannichellia palustris* L., also known as horned pondweed, was also found in Goose Flat. Like *Ruppia*, *Zannichellia* is a slender plant that occurs in fresh and brackish waters. It is similar in structure, but easily distinguishable by opposite leaves and seed-body color and location (Godfrey and Wooten 1979). Because *Z. palustris* had a similar structure and was rare (<1% seagrass dry weight), both seagrass species were combined in analysis.

Field Methods

Fifteen seagrass sites and fifteen bare substrate sites were randomly chosen in May 2005. Each site was sampled pre- (May 2005) and post-Hurricane Cindy (August 2005) using a 1.18 m^2 drop sampler (Baltz et al. 1993, 1998) modified from the design used by Zimmerman et al. (1984). The sampler was suspended in front of a 5.2 m Boston Whaler via a mast and boom.

To sample a site, the boat was quietly maneuvered into position and the trap was deployed via a pull-pin release mechanism. Once the trap was securely seated, minimum and maximum depths, distance to marsh edge (m), and current speed (cm/s) were recorded; temperature, salinity, and dissolved oxygen (DO) were measured using a YSI model 85. Also, a water sample and several 25 mm diameter soil cores were collected for turbidity and Microtox pore-water analyses. Dominant and subdominant substrates were characterized on an ordinal scale as silt, clay, organic detritus, sand, or shell.

At seagrass sites, the grasses were pulled from the trap, shaken inside the trap to remove any organisms and placed into a net to retain any remaining organisms. The

grasses were then bagged with wet paper towels and iced. Water in the trap was removed by a trash pump and filtered through a 333 μm mesh plankton net. The remaining enclosed water was then thoroughly swept with dip nets for organisms until two netters made three consecutive empty passes (Steele 2006). Invertebrates were then preserved in 10% formalin solution, while the fishes were bagged and iced.

In the lab, fishes and invertebrates were identified, measured, counted, and preserved in 70% ethanol solution. All individuals were measured to the nearest mm of standard length (SL) for fishes, carapace width (CW) for crabs, and total length (TL) for shrimp and other invertebrates. The grasses were washed, identified, placed in paper bags, and dried at 60°C for ~48 hours. The dry weight (DW) of the seagrasses was estimated to the nearest 0.1 g. Water samples were analyzed for turbidity and pore water for toxicity. Turbidity was measured with a Hach 21000N turbidimeter. The soil cores were centrifuged with a 33.2 cm diameter rotor for ten minutes at 2000 rpm to extract pore water, which was analyzed using the SDI Microtox m500 analyzer. Because no toxic pore water was detected, the Microtox data was not included in analyses.

For data analysis, two new depth variables were calculated from field measurements. Change in depth was the difference between minimum depth and maximum depth. This estimates slope of the substrate inside the trap. Mid-range depth was calculated by taking the mean of minimum and maximum depths in each sample.

Data Analysis

In statistical analyses, only the most frequently occurring taxa (i.e., those occurring in ≥ 5% of samples) were selected to minimize outlier effects (Digby and Kempton 1987). Of the 38 taxa captured, 17 qualified: Family Xanthidae, *Gobiosoma*

bosc, Farfantepenaeus aztecus, Callinectes sapidus, Anchoa mitchilli, Myrophis punctatus, Mysidopsis spp., *Lucania parva, Palaemonetes pugio, Microgobius gulosus, Ctenogobius boleosoma, Syngnathus scovelli, Sphoeroides parva, Symphurus plagiusa, Gobiesox strumosus, Citharichthys spilopterus,* and *Cynoscion nebulosus.*

Because fishes and invertebrates may respond differently to presence of seagrasses, the communities were analyzed at three levels: the overall community (fishes and invertebrates), the fish community, and the invertebrate community. Analysis of the overall community included seventeen taxa. Analysis of the fish community included the twelve fish taxa: *G. bosc, A. mitchilli, M. punctatus, L. parva, C. boleosoma, M. gulosus, S. scovelli, G, strumosus, S. parvus, S. plagiusa, C. spilopterus,* and *C. nebulosus.* Analysis of the invertebrate community included the five invertebrate taxa: Family Xanthidae, *Mysidopsis* spp., *P. pugio, F. aztecus,* and *C. sapidus.*

Each community was analyzed in terms of species composition and community structure. Species composition refers to which species were present or absent at the sampling time. Analysis for species composition was conducted on a presence/absence data set, in which each species was assigned a one if present and a zero if absent for each sample. Community structure analyses were based on the comparative abundances of species. Community structure refers to the distribution of fish and invertebrate species and individuals in the system.

To evaluate species composition, and community structure, two matrices were created with the distance procedure in SAS (SAS Institute 2004). Species composition was evaluated using a Jaccard metric in the distance procedure to create a similarity matrix by calculating the similarities between each of the samples based on the

presence/absence of each species. Community structure measures the relative abundances of each species in each sample. To evaluate community structure, a Manhattan metric was used to create a distance matrix based on abundances.

To asses the effects of Hurricane Cindy, the seagrass and bare substrate sites sampled in May 2005 were revisited as stations in August 2005. A Garmin Etrex Legend GPS was used to get as close to the geographic locations of the May 2005 sites as possible. Only three of the original seagrass sites contained seagrass after Hurricane Cindy. For the purpose of analyses, pre- and post-Cindy sites which had not changed were designated as seagrass and bare substrate stations, respectively, while seagrass sites which changed to bare substrate were designated as transition stations.

To determine if seagrass and bare substrate habitats differed in terms of community structure, multidimensional scaling (MDS) analysis (level=absolute, dimensions=3) was conducted on Manhattan distances and Jaccard similarities to generate clusters of more similar samples (SAS Institute 2004). Then, a MANOVA was run on the MDS dimensions using the general linear model procedure to determine if the clusters created in the MDS plot were significantly different (α =0.05).

A second MDS was run on the combined communities of May and August to determine if Hurricane Cindy had any impacts. To distinguish between seagrass, bare substrate, and transition station groupings in the MANOVA, a least square means (LSmeans) statement with Tukey's adjustment was used.

To evaluate species composition in the two habitat types, the similarity matrix created using the Jaccard metric was used in MDS as above (Digby and Kempton 1987,

Kirkman et al. 2004). Then, a MANOVA was run on the MDS dimensions to determine if the species composition of the two habitat types differed.

When the communities differed, a canonical correlation analysis was used to determine how species and environmental variables were related (SAS Institute 2004). Canonical correlation finds linear combinations of the species and the environmental variables such that the correlations between the two are maximized (Johnson and Wichern 2002). Those with values of 0.3873 or more explained at least fifteen percent of the variance and thus were considered to load heavily on one of the canonical variables (Lambert and Durand 1975).

RESULTS

Seagrass vs. Bare Substrate

In May 2005, a total of 1514 g DW of seagrasses were collected from the fifteen seagrass sites. The mean dry weight of seagrasses per site was 101 g DW. Nineteen taxa of fish and seven taxa of invertebrates were captured in May 2005, together totaling 885 individuals. Of these, 614 individuals were captured in seagrass sites, while only 271 were captured on bare substrates. *S. scovelli*, *S. parvus*, and *C. nebulosus* were only found in the samples with seagrasses, while *G. strumosus* and *A. mitchilli* were only found in bare substrate samples.

When comparing the means of environmental variables of May 2005 (Table 1.1), salinity and temperature were similar between the seagrass and bare substrate sites. Mid-range depth, change in depth, DO, and distance from marsh edge were greater in seagrass sites, while current speed and turbidity were greater in bare substrate sites.

Table 1.1. Means ± 2SE of environmental variables and species abundances for seagrass and bare substrate sites sampled in May and August 2005 in Goose Flat.

	May 2005		**August 2005**	
Variable	**Bare**	**Seagrass**	**Bare**	**Seagrass**
Mid-range Depth	58.2 ± 9.54	64.3 ± 7.27	59.2 ± 3.70	70.7 ± 4.87
Change in Depth	6.1 ± 1.67	3.6 ± 0.78	6.4 ± 2.70	3.7 ± 0.72
Temperature	29.4 ± 0.90	29.8 ± 0.86	29.3 ± 0.81	29.3 ± 0.64
Salinity	7.8 ± 0.09	7.9 ± 0.10	8.8 ± 0.15	8.8 ± 0.18
Dissolved Oxygen	7.9 ± 1.00	9.8 ± 1.54	8.7 ± 1.39	8.4 ± 0.74
Current Speed	4.1 ± 1.70	1.3 ± 1.03	1.9 ± 0.43	2.1 ± 0.74
Distance to Marsh Edge	4.2 ± 1.14	11.7 ± 4.53	2.7 ± 1.07	7.4 ± 4.42
Turbidity	17.0 ± 4.30	12.4 ± 3.40	22.0 ± 5.43	25.4 ± 5.06
Dry Weight	0.2 ± 0.13	100.8 ± 17.84	5.0 ± 9.57	7.1 ± 9.48
Symphurus plagiusa	0.0 ± 0.00	0.0 ± 0.00	0.1 ± 0.18	0.3 ± 0.31
Anchoa mitchilli	1.3 ± 2.50	0.0 ± 0.00	2.6 ± 2.67	1.0 ± 1.45
Lucania parva	0.3 ± 0.41	15.9 ± 9.79	0.0 ± 0.00	10.5 ± 14.98
Gobiesox strumosus	0.3 ± 0.46	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00
Gobiosoma bosc	1.5 ± 0.93	1.3 ± 1.17	6.6 ± 7.39	0.7 ± 0.46
Ctenogobius boleosoma	1.5 ± 2.13	0.5 ± 0.47	0.2 ± 0.29	0.0 ± 0.00
Microgobius gulosus	0.1 ± 0.27	0.3 ± 0.42	0.9 ± 0.73	0.4 ± 0.55
Myrophis punctatus	0.8 ± 1.19	0.7 ± 0.54	0.9 ± 0.70	0.0 ± 0.00
***Mysidopsis* spp.**	0.5 ± 0.64	6.1 ± 4.47	4.3 ± 6.34	13.3 ± 20.70
Palaemonetes pugio	0.1 ± 0.18	4.3 ± 2.19	0.0 ± 0.00	14.7 ± 20.18
Farfantepenaeus aztecus	1.1 ± 1.13	2.5 ± 1.67	2.9 ± 4.47	0.4 ± 0.43
Callinectes sapidus	0.5 ± 0.43	1.6 ± 1.01	0.3 ± 0.31	0.1 ± 0.13
Cynoscion nebulosus	0.0 ± 0.00	0.1 ± 0.13	0.1 ± 0.13	0.1 ± 0.13
Syngnathus scovelli	0 .0 ± 0.00	0.9 ± 0.75	0.2 ± 0.40	0.5 ± 0.80
Family Xanthidae	9.5 ± 6.10	4.5 ± 2.61	5.5 ± 3.05	0.1 ± 0.07
Sphoeroides parvus	0.0 ± 0.00	0.1 ± 0.13	0.4 ± 0.33	0.0 ± 0.00
Total Number of Individuals	18.1 ± 9.98	40.9 ± 13.11	25.1 ± 11.51	43.1 ± 38.74

When analyzing MDS plots, the stress value indicates how well the plot represents the data and values < 0.2 are considered acceptable (Johnson and Wichern 2002). For the pre-hurricane sampling in May 2005, MDS analysis of species composition yielded slightly high, but acceptable, stress values. The MDS plots for the overall community and for the fish community (Figure 1.3) showed a clear separation

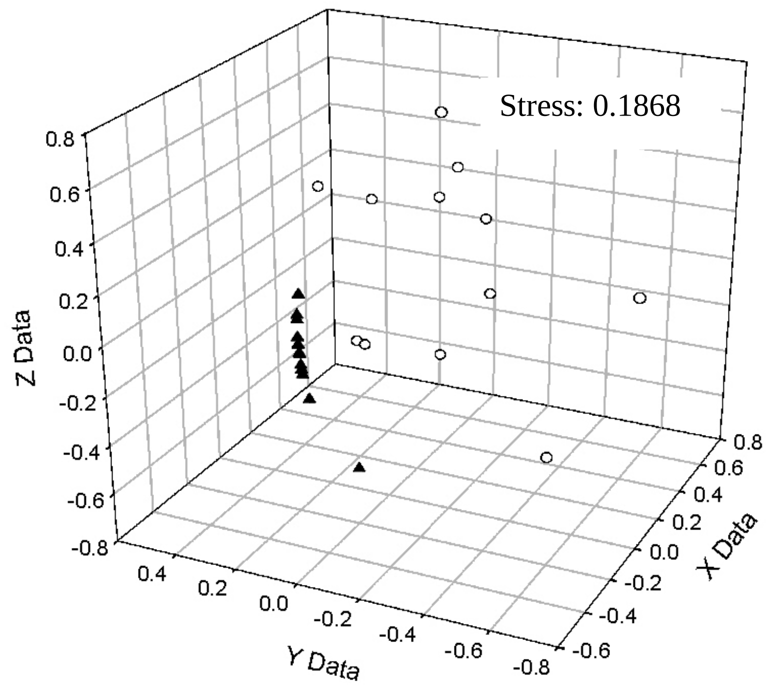
based on species composition between the two habitat types. However, the separation in the MDS plot for invertebrate species composition (Figure 1.3c) was not as marked. In the MANOVAs, all three communities, overall ($p<0.0001$), fish ($p<0.0001$), and invertebrate ($p=0.0312$), differed significantly between the two habitat types.

Similarly, the pre-hurricane MDS analysis of community structure yielded acceptable stress values for all communities considered (Figure 1.4). Although the separation between seagrass and bare substrates was most evident in the fish community (Figure 1.4b), MANOVA results show that all three communities: the overall community ($p=0.0011$), the fish community ($p<0.0001$), and the invertebrate community ($p=0.0164$), differed significantly between the two habitats.

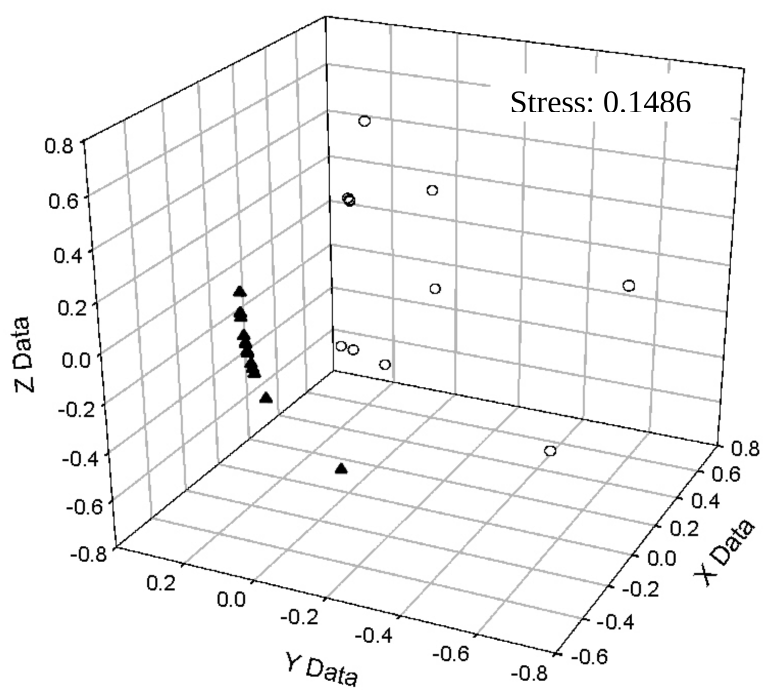
Hurricane Cindy

After the disturbance of Hurricane Cindy, the MDS analyses of community structure (Figure 1.5) also yielded acceptable stress values. MANOVA revealed significant models for the overall community ($p<0.001$), the fish community ($p<0.0001$), and the invertebrate community ($p=0.0262$). For the overall ($p\leq0.0293$) and fish ($p\leq0.0041$) communities, LSmeans results revealed that the bare substrate stations differed from seagrass stations but not from the transition stations. The seagrass and transition stations also differed in terms of community structure for both the overall community and the fish community. However, the pattern of invertebrate community structure was different: seagrass and bare substrate stations differed ($p=0.0041$), but the transition stations did not differ from seagrass or bare substrate stations.

Canonical correlation analysis revealed that only the first two canonical correlations were significant ($p<0.0001$ and $p=0.0033$, respectively), and accounted for

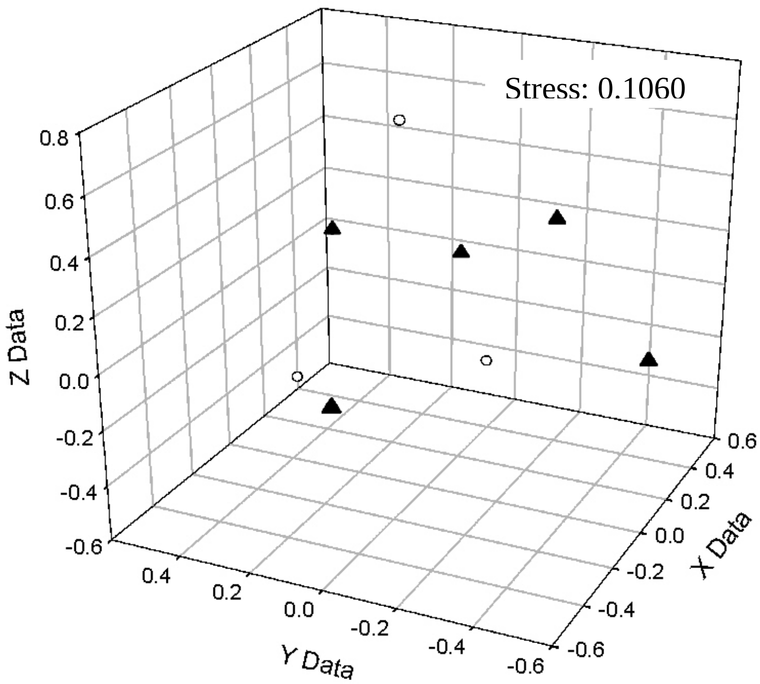


(a)



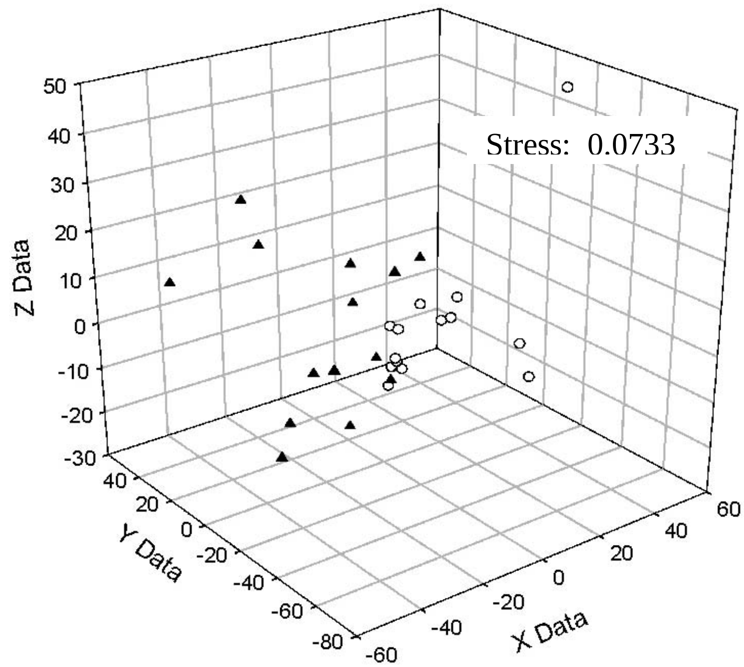
(b)

Figure 1.3. MDS plot of species composition in seagrass (▲) and bare substrate (○) sites in May 2005 for (a) the overall community (fish and invertebrates), (b) the fish community, and (c) the invertebrate community.

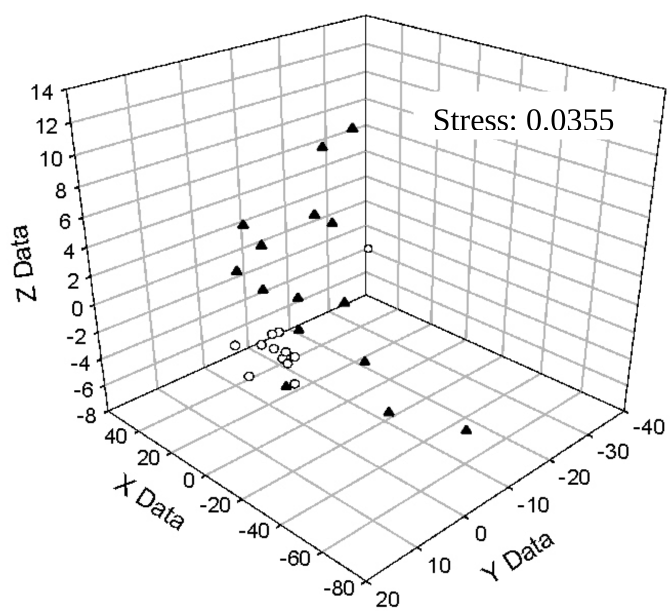


(c)

Figure 1.3. (cont.)

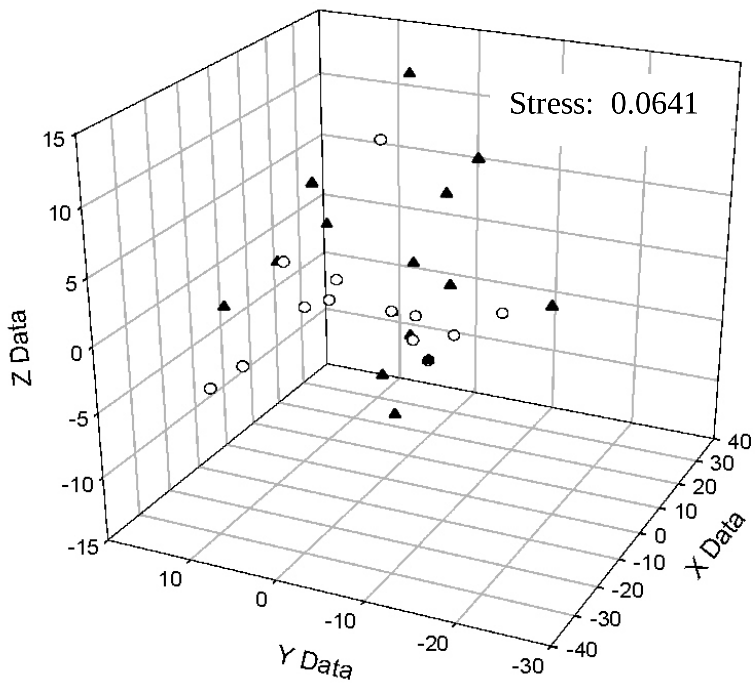


(a)



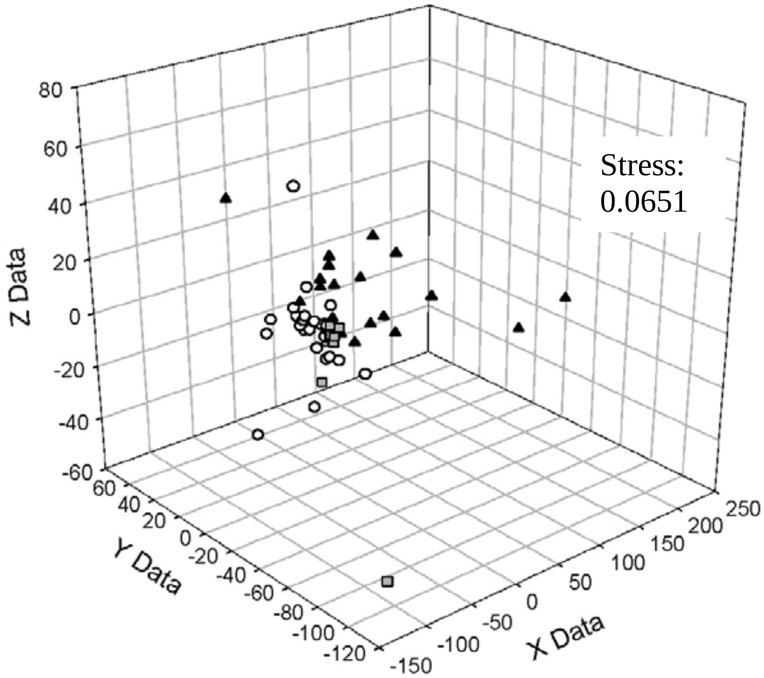
(b)

Figure 1.4. MDS plot of community structure of seagrass (▲) and bare substrate (○) sites in May 2005 for (a) the overall community (fish and invertebrates), (b) the fish community, and (c) the invertebrate community.

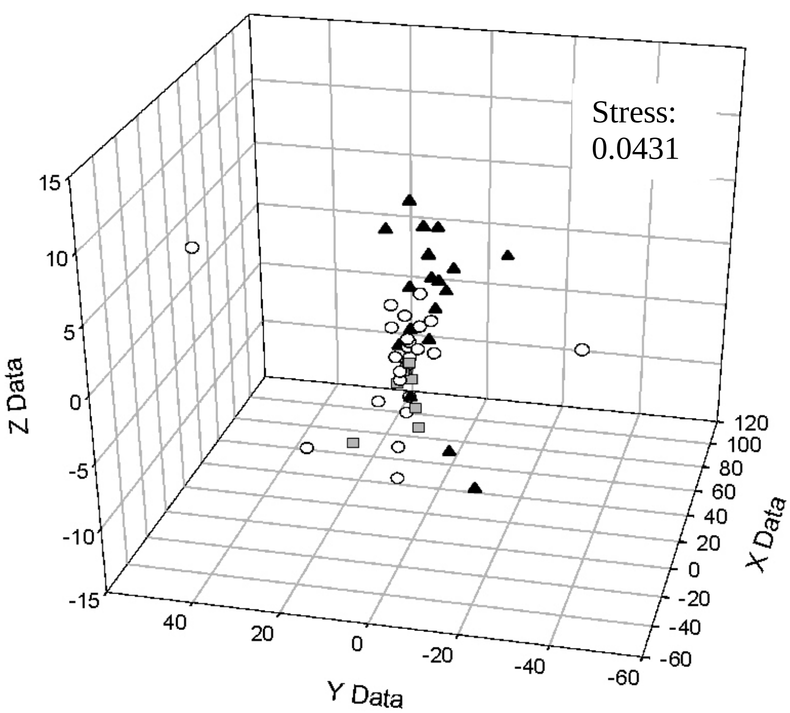


(c)

Figure 1.4 (cont.)

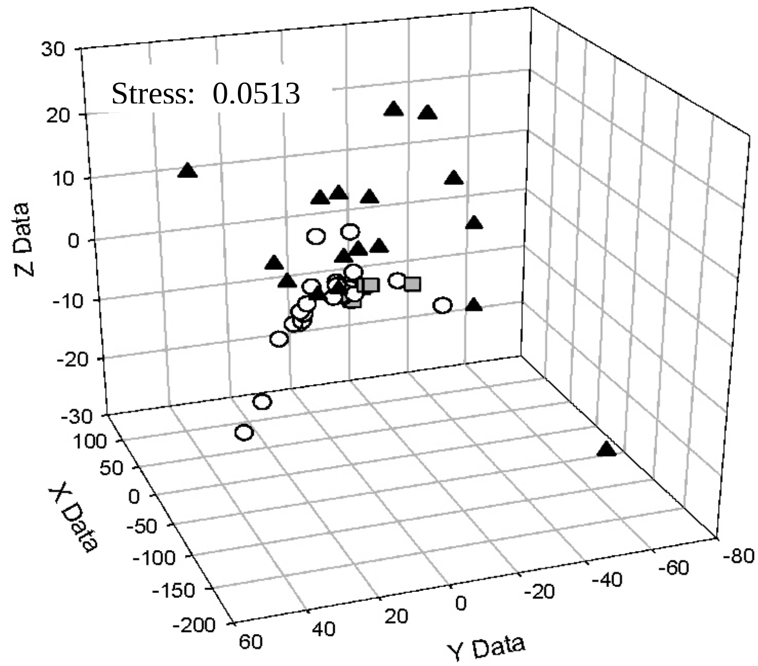


(a)



(b)

Figure 1.5. Community Structure across May and August 2005 in seagrass (▲) bare substrate (◯) and transition sites (□) for (a) the overall community (fish + invertebrates), (b) the fish community, and (c) the invertebrate community.



(c)

Figure 1.5 (cont.)

68% of the variance. The environmental variables, bottom type, habitat type, turbidity, and dry weight of the seagrasses, as well as the species abundances of *L. parva, P. pugio,* and *S. scovelli* were highly correlated with the first canonical variable (CV1), which accounted for 56% of the variation. The second canonical variable, (CV2) explained 12% of the variance and was highly correlated with month, habitat type, dominant substrate, and *S. parva* (Table 1.2).

DISCUSSION

Evidence suggests that seagrasses were the most important factor leading to differences in community structure and species composition between major habitat types in Goose Flat. After the mild disturbance of Hurricane Cindy, most seagrasses were

Table 1.2. Correlations between canonical variables and environmental and species variables pre- and post-Hurricane Cindy. Bold numbers are those that load heavily on the canonical variable.

	CV1	CV2
Bottom	**0.9690**	-0.0052
Habitat type	**0.5129**	**-0.4014**
Month	-.3840	**0.3929**
Mid-range depth	0.0301	-0.3791
Change in depth	-0.1703	0.0409
Temperature	0.1176	0.0153
Salinity	-0.3829	0.1768
DO	0.2612	-0.0715
Current Speed	-0.2339	0.2881
Distance to marsh edge	0.1732	-0.2447
Dominant substrate	-0.2699	**0.4916**
Turbidity	**-0.4007**	0.1954
Dry weight of seagrass	**0.9253**	-0.2084
Anchoa mitchilli	-0.2642	0.2208
Ctenogobius boleosoma	0.0148	0.0523
Callinectes sapidus	0.3612	-0.1214
Farfantepenaeus aztecus	**0.4148**	0.2284
Gobiosoma bosc	-0.1142	0.3802
Gobiesox strumosus	-0.1099	0.0753
Cynoscion nebulosus	-0.0198	0.016
Lucania parva	**0.8132**	-0.0178
Microgobius gulosus	0.0458	0.2293
Myrophis punctatus	0.0457	0.2266
Mysidopsis spp.	0.1163	-0.2475
Palaemonetes pugio	**0.6735**	0.1552
Sphoeroides parvus	0.0853	**0.4433**
Symphurus plagiusa	-0.2223	-0.086
Syngnathus scovelli	**0.5793**	0.2665
Family Xanthidae	0.1718	0.182

removed, and thus disrupted the communities of the study area. After the disturbance, the communities of transition sites converged with those of bare substrate communities.

Seagrasses are an important habitat for nekton, supporting higher faunal abundances (Rozas and Odum 1988, Connolly 1997, Minello et al. 2003). The slender nature of the leaves and stems may hinder invertebrate colonization of the Goose Flat seagrasses (Humphries et al. 1992), which could account for lower invertebrate abundances. However, Heck and Thoman (1984) found that vegetated habitats support larger numbers of decapods, but not larger numbers of fishes.

The higher abundances of fishes and invertebrates in the seagrasses are generally attributed to the advantages that seagrasses provide for nekton in terms of increased food availability and shelter (Humphries et al. 1992, Connolly 1997, Jenkins et al. 1997). While seagrasses are thought to provide protection from common predators, such as pinfish, Gulf killifish, spotted seatrout, and southern flounder, some studies suggest that predation is not as important as once thought (Summerson and Peterson 1984, Zimmerman et al. 1984, Edgar and Shaw 1995a). While the spotted seatrout was captured only in seagrass stations, much like a previous study by Zimmerman et al. (1984), seatrout catches were small, indicating that either predation in the area is minimal or the predators are large, pelagic species that can successfully avoid the drop trap (Steele et al. 2006).

Nekton communities of seagrass beds are often composed of small cryptic species, such as *S. scovelli, S. parvus, L. parva, and P. pugio,* whereas bare substrate habitat types are dominated by pelagic fishes, such as *A. mitchilli* (Rozas and Odum 1987, Sogard and Able 1991, Humphries et al. 1992, Edgar and Shaw 1995b, Jenkins et

al 1997). In addition to *A. mitchilli, G. strumosus,* and Family Xanthidae typically occur over muddy or sandy bottoms and/or oyster shell (Day and Lawton 1988, Simpson et al. 2006).

Differences observed in the communities may be attributed to environmental differences between the two habitat types. Similar to Zimmerman et al. (1984), the mean salinity and temperature did not vary between the two habitat types because the sampling area is a small, isolated location. While Zimmerman et al. (1984) did not observe the differences in DO, current speed, and turbidity as observed in Goose Flat, these differences could be explained by the presence of the seagrasses. The daytime DO levels should be higher due to photosynthesis. Current speed is reduced by vegetation and turbidity should be lower due to current speed reduction and sediment trapping that occurs in seagrass beds.

Some other environmental variables that differed between seagrasses and bare substrates sites were distance to edge, depth, and dominant substrate. The differences between habitats are not directly due to the presence of the grasses, but the positioning of the grasses in the system. As in an Australian estuary (Humphries et al. 1992), the seagrasses of Goose Flat grew near the center of ponds and radiated to approximately five meters from shore, thus seagrass sites were usually farther from shore and deeper. Similar studies have found that vegetated sites are deeper than unvegetated sites (Zimmerman 1984, Rozas and Minello 1998). Because the seagrass beds of Goose Flat are deeper grass beds, they are more beneficial to the faunal that rely on them. The deeper beds are denser than shallow beds, thus providing better protection from predators, and more food (Zimmerman et al.1984, Jenkins et al.1997, Rozas and Minello

1998, Deegan 2002). Thus, the depth of the seagrass beds may further attribute to the increased abundances found in the seagrasses when compared to bare substrate.

After the mild disturbance of Hurricane Cindy, the importance of seagrasses to the community was further emphasized. When seagrasses are removed, as in Cindy, nekton can become entwined in the grasses, and are thus removed from the area with the seagrasses (Tabb and Jones 1962, Short and Wyllie-Escheverria 1996). After Hurricane Andrew, Rozas and Reed (1994) reported similar findings, with reduced numbers of seagrass associated fauna, such as rainwater killifish, Gulf pipefish, blue crab and grass shrimp.

LITERATURE CITED

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

Baltz, D. M., J. W. Fleeger, C. Rakocinski, and J. N. McCall. 1998. Food, density, and microhabitat: factors affecting growth and recruitment potential of juvenile saltmarsh fishes. *Environmental Biology of Fishes* 53:89-103.

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

Bell, J. D. and D. A. Pollard. 1989. Ecology of fish assemblages and fisheries associated with seagrasses, p. 565-609. *In* A. W. D. Larkum, A. J. McComb, and S. A. Shepard (eds.). Biology of Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region. Elsevier, Amsterdam.

Bell, J. D. and M. Westoby. 1986a. Abundance of macrofauna in dense seagrass is due to habitat preference, not predation. *Oecologia* 68:205-209.

Bell, J. D. and M. Westoby. 1986b. Importance of local changes in leaf height and density to fish and decapods associated with seagrasses. *Journal of Experimental Marine Biology and Ecology* 104:249-274.

Bologna, P. A. X. and K. L. Heck, Jr. 2002. Impact of habitat edges on density and secondary production of seagrass-associated fauna. *Estuaries* 25:1033-1044.

Castellanos, D. L. and L. P. Rozas. 2001. Nekton use of submerged aquatic vegetation, marsh and shallow unvegetated bottom in the Atchafalaya River Delta, a Louisiana tidal freshwater system. *Estuaries* 24:184-197.

Chabreck, R. H., and R. E. Condrey. 1979. Common Vascular Plants of the Louisiana Marsh. Center for Wetland Research, Louisiana State University, Baton Rouge, Louisiana.

Connolly, R. M. 1997. Differences in composition of small, motile invertebrate assemblages from seagrass and unvegetated habitats in a southern Australian estuary. *Hydrobiologia* 346:137-148.

Dawes, C. J. 1998. Marine Botany, 2nd edition. John Wiley and Sons, Incorporated, New York.

Day, E. A. and P. Lawton. 1988. Mud crab (Crustacea: Brachyura: Xanthidae) substrate preference and activity. *Journal of Shellfish Research* 7: 421-426.

Deegan, L. A. 2002. Lessons learned: the effects of nutrient enrichment on the support of nekton by seagrass and salt marsh ecosystems. *Estuaries* 25:727-742.

Digby, P. G. N. and R. A. Kempton. 1987. Multivariate Analysis of Ecological Communities. Chapman and Hall, New York.

Edgar, G. J. and C. Shaw. 1995a. The production and trophic ecology of shallow-water fish assemblages in southern Australia I. Species richness, size-structure and production of fishes in Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* 194:53-81.

Edgar, G. J. and C. Shaw. 1995b. The production and trophic ecology of shallow-water fish assemblages in southern Australia II. Diets of fishes and trophic relationships between fishes and benthos at Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* 194:83-106.

Epifanio, C. E., A. I. Dittel, R. A. Rodriguez, and T. E. Targett. 2003. The role of macroalgal beds as nursery habitat for juvenile blue crabs, *Callinectes sapidus. Journal of Shellfish Research* 22:881-886.

Godfrey, R. K. and J. W. Wooten. 1979. Aquatic and Wetland Plants of Southeastern United States Monocotyledons. The University of Georgia Press, Athens, Georgia.

Heck, Jr., K. L., G. Hays, and R. J. Orth. 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series* 253:123-136.

Heck, Jr., K. L. and R. J. Orth. 1980. Seagrass habitats: the roles of habitat complexity, competition and predation in structuring associated fish and motile macroinvertebrate assemblages, p. 449-464. *In* V.S. Kennedy (eds.). Estuarine Perspectives. Academic Press, Inc., New York.

Heck, Jr., K. L. and T. A. Thoman. 1981. Experiments on predator-prey interactions in vegetated aquatic habitats. *Journal of Experimental Marine Biology and Ecology 53:125*-134.

Heck, Jr., K. L. and T. A. Thoman. 1984. The nursery role of seagrass meadows in the upper and lower reaches of the Chesapeake Bay. *Estuaries* 7:70-92.

Heise, R. J. and S. A. Bortone. 1999. Estuarine artificial reefs to enhance seagrass planting and provide fish habitat. *Gulf of Mexico Science* 2:59-74.

Hemminga, M. A. and J. Nieuwenhuize. 1990. Seagrass wrack-induced dune formation on a tropical coast (Banc d'Arguin, Mauritania). *Estuarine, Coastal and Shelf Science* 31:499-502.

Howard, R. K., G. J. Edgar, and P. A. Hutchings. 1989. Faunal assemblages of seagrass beds, p. 536-564. *In* A. W. D. Larkum, A. J. McComb, and S. A. Shepard (eds.). Biology of Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region. Elsevier, Amsterdam.

Humphries, P., I. C. Potter, and N. R. Loneragan. 1992. The fish community in the shallows of a temperate Australian estuary: relationships with the aquatic macrophyte *Ruppia megacarpa* and environmental variables. *Estuarine, Coastal and Shelf Science* 34:325-346.

Jenkins, G. P., H. M. A. May, M. J. Wheatley, and M. G. Holloway. 1997. Comparison of fish assemblages associated with seagrass and adjacent unvegetated habitats of Port Phillip Bay and Corner Inlet, Victoria, Australia, with emphasis on commercial species. *Estuarine, Coastal and Shelf Science* 44:569-588.

Johnson, R. A. and D. W. Wichern. 2002. Applied Multivariate Statistical Analysis, 5th edition. Prentice Hall, Upper Saddle River, New Jersey.

King, K.J., R.C. Landry, G. McMahon, J. Ellis, R. Moertle, S. Penland, D.J. Reed, W. Rudolf, and J. Suhayda. 2006. The Biloxi Marsh Stabilization and Restoration Plan St. Bernard Parish, Louisiana. Prepared for The Biloxi Marsh Lands Corporation.

Kirkman, L. K., K. L. Coffey, R. J. Mitchell, and E. B. Moser. 2004. Ground cover recovery patterns and life-history traits: implications for restoration obstacles and opportunities in a species-rich savanna. *Journal of Ecology* 92:409-421.

Knabb, R. D., D. P. Brown, and J. R. Rhome. 2006a. Tropical cyclone report Hurricane Katrina 23-30 August 2005. National Hurricane Center.

Knabb, R. D., D. P. Brown, and J. R. Rhome. 2006b. Tropical cyclone report Hurricane Rita 18-26 September 2005. National Hurricane Center.

Lambert, Z. V. and R. M. Durand. 1975. Some precautions in using canonical analysis. *Journal of Marketing Research* 12: 468-475.

Lopez, J. A. 2005. The multiple lines of defense strategy to sustain Louisiana's coast. Lake Pontchartrain Basin Foundation.

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

Orth, R. J., R. A. Batiuk, P. W. Bergstrom, and K. A. Moore. 2002. A perspective on two decades of policies and regulations influencing the protection and restoration of submerged aquatic vegetation in Chesapeake Bay, USA. *Bulletin of Marine Science* 71:1391-1403.

Rozas, L. P. and T. J. Minello. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: a review of sampling design with focus on gear selection. *Estuaries* 20:199-213.

Rozas, L. P. and T. J. Minello. 1998. Nekton use of salt marsh, seagrass, and nonvegetated habitats in a south Texas (USA) estuary. *Bulletin of Marine Science* 63:481-501.

Rozas, L. P. and W. E. Odum. 1987. .The role of submerged aquatic vegetation in influencing the abundance of nekton on contiguous tidal fresh-water marshes. *Journal of Experimental Marine Biology and Ecology* 114: 289-300.

Rozas, L. P. and W. E. Odum. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. *Oecologia* 77:101-106.

Rozas, L. P. and D. J. Reed. 1994. Comparing nekton assemblages of subtidal habitats in pipeline canals traversing brackish and saline marshes in coastal Louisiana. *Wetlands* 14:262-275.

SAS Institute Inc. 2004. SAS/STAT 9.1 user's guide. SAS Institute Inc, Cary, North Carolina.

Sheridan, P. and T. J. Minello. 2003. Nekton use of different habitat types in seagrass beds of lower Laguna Madre, Texas. *Bulletin of Marine Science* 72:37-61.

Short, F. T. and S. Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* 23:17-27.

Simpson, R. G., D. M. Allen, S. A. Luthy, and K. A. Foley. 2006. Fishes of the North Inlet: an identification Guide. Belle W. Baruch Institute Special Publication. University of South Carolina.

Sogard, S. M. and K. W. Able. 1991. A comparison of eelgrass, sea lettuce macroalgae, and marsh creeks as habitats for epibenthic fishes and decapods. *Estuarine, Coastal and Shelf Science* 33:501-519.

Spitzer, P. M., K. L. Heck, Jr., and J. F. Valentine. 2003. Then and now: a comparison of patterns in blue crab post-larval abundance and post-settlement mortality during the early and late 1990s in the Mobile Bay system. *Bulletin of Marine Science* 72:435-452.

Steele, M. A., S. C. Schroeter, and H. M. Page. 2006. Sampling characteristics and biases of enclosure traps for sampling fishes in estuaries. *Estuaries and Coasts* 29:630-638.

Stewart, S. R. 2006. Tropical cyclone report Hurricane Cindy 3-7 July 2005. National Hurricane Center.

Stockhausen, W. T. and R. N. Lipcius. 2003. Simulated effects of seagrass loss and restoration on settlement and recruitment of blue crab postlarvae and juveniles in the York River, Chesapeake Bay. *Bulletin of Marine Science* 72:409-422.

Stokstad, E. 2005. Louisiana's wetlands struggle for survival. *Science* 310:1264-1266.

Summerson, H. C. and C. H. Peterson. 1984. Role of predation in organizing benthic communities of a temperate-zone seagrass bed. *Marine Ecology-Progress Series* 15:63-77.

Tabb, D. C. and A. C. Jones. 1962. Effect of Hurricane Donna on the aquatic fauna of North Florida Bay. *Transactions of the American Fisheries Society* 91:375-378.

Thayer, G. W., D. A. Wolfe, and R. B. Williams. 1975. The impact of man on seagrass. Systems. *American Scientist* 63:288-296.

Thomas, J. L., R. J. Zimmerman, and T. J. Minello. 1990. Abundance patterns of juvenile blue crabs (*Callinectes sapidus)* in nursery habitats of two Texas bays. *Bulletin of Marine Science* 46:115-125.

Wicker, K. M., G. C. Castille, III, D. J. Davis, S. M. Gagliano, D. W. Roberts, D. S. Sabins and R. A. Weinstein. 1982. St. Bernard Parish: A Study in Wetland Management. Coastal Environments, Inc., Baton Rouge, LA.

Wilson, K. A., K. W. Able, and K. L. Heck, Jr. 1990a. Habitat use by juvenile blue crabs: a comparison among habitats in southern New Jersey. *Bulletin of Marine Science* 46:105-114.

Wilson, K. A., K. W. Able, and K. L. Heck, Jr. 1990b. Predation rates on juvenile blue crabs in estuarine nursery habitats: evidence for the importance of macroalgae (*Ulva lactuca)*. *Marine Ecology Progress Series* 58:243-251.

Woodley, C. M. and M. S. Peterson. 2003. Measuring responses to simulated predation threat using behavioral and physiological metrics: the role of aquatic vegetation. *Oecologia* 136: 155-160.

Zimmerman, R. J., T.J. Minello, and G. Zamora, Jr. 1984. Selection of vegetated habitat by brown shrimp, *Penaeus aztecus*, in a Galveston Bay salt marsh. *Fishery Bulletin* 82:325-336.

CHAPTER 2. EFFECTS OF HURRICANES CINDY AND KATRINA ON NEKTON COMMUNITIES OF GOOSE FLAT.

INTRODUCTION

Seagrasses are important resources for fish and invertebrate populations. The seagrasses are both primary food source for grazers and a secondary food source for detritivores (Dawes 1998, Heise and Bartone 1999, Orth et al. 2002). Structure provided by the plants' stems and their roots serves to protect smaller nekton from larger predators (Heck and Orth 1980, Orth et al. 1984, Thomas et al. 1990, Castellanos and Rozas 2001, Heck et al. 2003). Seagrasses can also alter the physics and chemistry of the water column. The stems and leaves act to slow currents and trap sediments, which can, in turn, decrease turbidity in seagrass beds. Photosynthesis and nutrient cycling are also carried out by the seagrasses (Minello and Zimmerman 1985, Hemminga and Nieuwenhuize 1990, Orth and van Montfrans 1990, Short and Wyllie-Escheverria 1996, Heise and Bartone 1999). The food, protection, and increased nutrient availability in seagrasses make the beds a good nursery ground and habitat for a variety of individuals (Heck and Orth 1980, Heck and Thoman 1981, Thomas et al. 1990, Epifanio et al. 2003, Heck et al. 2003). In fact, seagrasses have been labeled as essential fish habitat (EFH) for many species (Orth et al. 2002). Seagrass beds typically support larger densities, diversities, and numbers of individuals than nearby bare substrate habitats (Ferrell and Bell 1991, Sogard and Able 1991, Connolly 1997, Deegan 2002, Sheridan and Minello 2003).

Seagrasses are indicators of the overall health of a system because they are sensitive to slight environmental changes, including anthropogenic, geological, biological and meteorological disturbances (Orth and Moore 1983) related to propeller scarring,

industrial pollution, erosion, subsidence, grazing, bioturbation, ice formation and retreat, frontal passages, and hurricanes (Short and Wyllie-Escheverria 1996).

Hurricanes can be detrimental to seagrass beds. Wave and wind action associated with storms and surges can uproot seagrasses and deposit the wrack on nearby shores (Hemminga and Nieuwenhuize 1990, Pulich and White 1991, Short and Wyllie-Escheverria 1996, Greenwood et al. 2006). Wave action and/or increased rainfall can increase the turbidity in the system, which limits light penetration, which can kill the seagrasses (Short and Wyllie-Escheverria 1996, Steward et al. 2006). Erosion of nearby marshes and sediment carried by the storm surge can bury the seagrasses, which also limits light penetration in the water column (Wanless et al. 1988, Pulich and White 1991, Short and Wyllie-Escheverria 1996, Paperno et al. 2006, Steward et al. 2006). Storm surges can also bring saltier, oceanic water into the estuarine and freshwater systems (Tabb and Jones 1962, Greenwood et al. 2006). Because most seagrasses cannot tolerate higher salinities, they die if the salt water is not flushed out of the system quickly. However, in some cases, the opposite is also true. Salinities inside estuaries may decrease after the passage of a major storm event. The increased freshwater drainage from rainfall and flooding associated with the storm may temporarily convert estuaries into freshwater environments (Greenwood et al. 2006, Paperno et al. 2006, Steward et al. 2006, Switzer et al. 2006).

MATERIALS AND METHODS

Study Area

The area chosen for this study was Goose Flat. A series of shallow ponds containing the seagrass, *Ruppia maritima*, Goose Flat is located inside Biloxi Marsh

Wildlife Management area, a 518,902 ha complex of brackish (4-18ppt) and intermediate (2-8ppt) marshes (Lopez 2005). Biloxi Marsh is vital to the greater New Orleans area because of its role in buffering storm surges. The seagrass beds inside Goose Flat and the surrounding areas are known for their resiliency after the passage of natural disasters, such as hurricanes. On July 6, 2005 the eye of Hurricane Cindy (Figure 2.1) passed over Biloxi Marsh followed closely by Hurricane Katrina's eye on August 29, 2005 (Figure 2.1). In the same year, the marsh also played a role in attenuating storm surges of 1-2 m for Hurricanes Cindy (Stewart 2006) and Rita (Knabb et al. 2006b) and a surge of 4-6 m for Hurricane Katrina (Knabb et al 2006a).

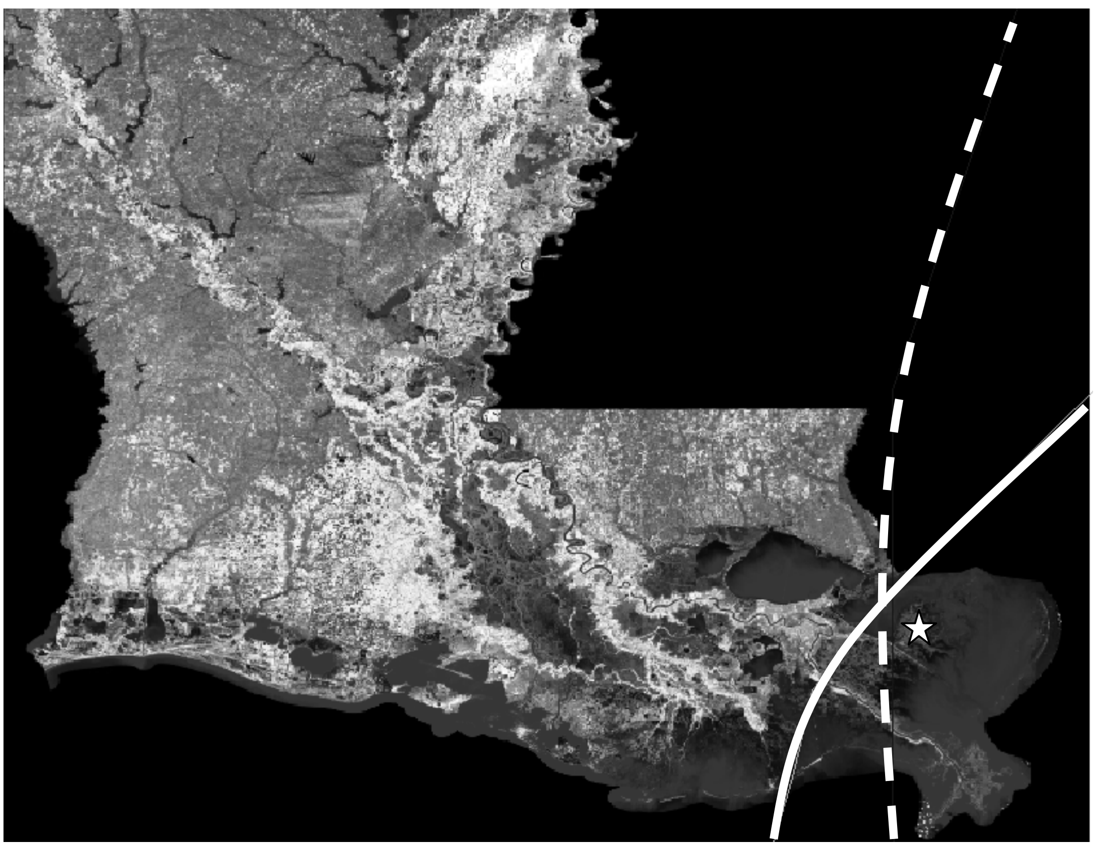


Figure 2.1. The paths of Hurricanes Cindy (solid line) in July 2005 and Katrina (dashed line) in August 2005 . The star (☆) is positioned at the location of Biloxi Marsh.

Field Methods

Fifteen seagrass stations and fifteen bare substrate stations were randomly chosen in May 2005. Each station was sampled pre-hurricanes (May 2005), post-Hurricane Cindy (August 2005) and post-Hurricane Katrina (May 2006). A drop trap with a basal area of 1.18 m^2 (Baltz et al. 1993, 1998), modified after Zimmerman and Minello (1984), was used to sample fifteen seagrass stations and fifteen bare substrate stations in Goose Flat (Figure 2.2). The sampler was suspended in front of a 5.2 m Boston Whaler via a mast and boom.

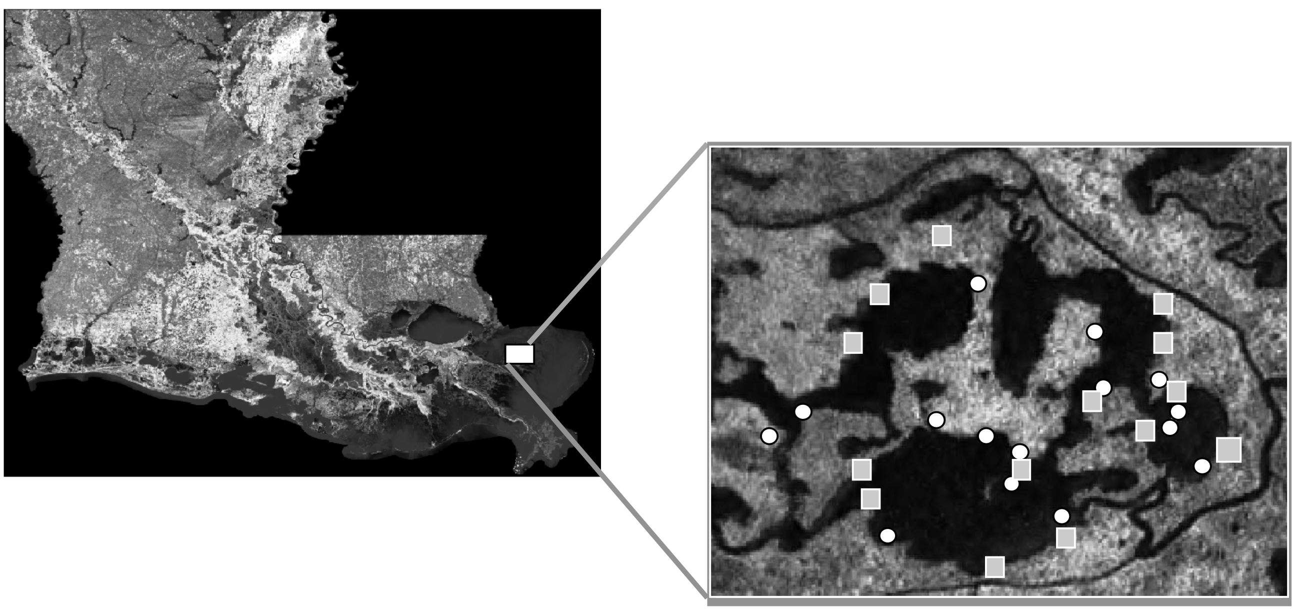


Figure 2.2. Seagrass (◯) and Bare substrate (■) sites in Goose Flat.

After a site was quietly approached, the trap was released via a pull-pin mechanism. Once the trap was securely seated in the substrate, minimum and maximum

depths, distance to marsh edge (m) and current speed (cm/s) were recorded; temperature, salinity and dissolved oxygen (DO) were measured using a YSI model 85. Also a water sample and several 25 mm diameter soil cores were collected for turbidity and Microtox pore-water analyses. Dominant and subdominant substrates were characterized on an ordinal scale as silt, clay, organic detritus, sand, or shell.

At seagrass sites, the seagrasses were pulled from the trap, shaken to remove any organisms and placed into a net to retain any remaining organisms. The seagrasses were then bagged with wet paper towels and iced. Water in the trap was removed by a trash pump and filtered through a 333 μm plankton net. The remaining water was then thoroughly swept with dip nets for remaining organisms until two netters made three consecutive empty passes each (Steele 2006). Invertebrates were then preserved in 10% formalin solution, while fishes were bagged and iced.

In the lab, fishes and invertebrates were identified, measured, counted, and preserved in 70% ethanol solution. All individuals were measured to nearest mm of carapace width (CW) for crabs, standard length (SL) for fishes, and total length (TL) for shrimp and other invertebrates. The grasses were washed, identified, placed in paper bags, and dried at 60°C for ~48 hours. The dry weight (DW) of the seagrasses was estimated to the nearest 0.1 g. Water samples were analyzed for turbidity and pore water for toxicity. Turbidity was measured with a Hach 210000 N turbidimeter. The soil cores were centrifuged on a 33.2 cm diameter rotor for ten minutes at 2000 rpm to extract pore water, which was then analyzed using the SDI Microtox m500 analyzer. Because no toxic pore water was detected, the Microtox data was not included in the analysis.

Data Analysis

In May 2005, the dominant seagrass species was *R. maritima*. However, another seagrass species, *Zannichellia palustris*, was also present. Because the species were similar in structure and the dry weight of *Z. palustris* constituted less than one percent of the total dry weight found in the samples, the two species were not considered separately in analyses.

Two new variables were created from the recorded variables. Mid-range depth was calculated by summing the minimum and maximum depths and dividing by two. Change in depth was calculated by subtracting minimum depth from maximum depth.

The May 2005 sites were revisited as stations in August 2005 and May 2006 to evaluate the effects of Hurricanes Cindy and Katrina, respectively. A Garmin Etrex Legend GPS was used to get as close as possible to the geographic coordinates of the sites sampled in May 2005 so that they may be re-sampled. Due to cumulative effects of Hurricanes Cindy and Katrina, all seagrasses in Goose Flat were uprooted or buried. Thus, the habitat types assigned to each site in May 2005 were assigned to the respective sites in August 2005 and May 2006. This enabled analyses on just the seagrass sites and bare substrate sites to see if changes in community were evident in one habitat but not another.

To evaluate species composition and community structure, two matrices were created with the distance procedure in SAS (SAS Institute 2004). The Jaccard metric was used to create a similarity matrix by calculating the distance between each of the samples based on the presence/absence of species, whereas the Manhattan metric was used to create a distance matrix based on abundances. The Jaccard metric was chosen because it

is common in ecology, it emphasizes differences, and it performs best when compared to other similarity measures. The Manhattan metric was chosen to de-emphasize outliers (Digby and Kempton 1987, Boyce and Ellison 2001).

To compare species composition of the two habitat types and to compare the species composition pre- and post- hurricanes, the similarity matrix was input into MDS analysis to see if habitat types or sampling events differed. A MANOVA was then run on the MDS dimensions to determine if the differences observed in MDS plots were significantly (α<0.05) different.

For the community structure analysis, the distance matrix input into a three dimensional multidimensional scaling (MDS) analysis to see if the two habitats or sampling periods differed in terms of community structure. In MDS plots, clustering of the separate groupings with a stress level between zero and 0.2 is acceptable (Johnson and Wichern 2002). The stress value measures how well the data is represented by the plot, thus lower numbers are better. Dimensions output from the MDS results were then input to a MANOVA to determine if the habitat groupings were significantly (α<0.05) different from each other. To compare hurricane effects, MANOVAs were run to evaluate habitat and time effects as well as their interactions.

To evaluate the relationship of species and environmental variables canonical correlation was run. In canonical correlation, linear combinations of the environment data and species data are formed such that the correlations between the species and environment are maximized (Johnson and Wichern 2002). Those with values of 0.3873 or more explained at least fifteen percent of the variance and thus were considered to load heavily on one of the canonical variables (Lambert and Durand 1975).

Analysis of the data from May 2005 was conducted to establish that there was a difference between seagrass and bare substrate sites. To evaluate the effects of Hurricane Cindy, the data from the sampling trips in May 2005 and August 2005 were compared, whereas the data from the sampling trips of May 2005 and May 2006 were compared to evaluate the effects of Hurricane Katrina.

RESULTS

In May 2005, a total of 886 individuals were captured, of which, 423 were fishes representing nineteen taxa and 462 were invertebrates, representing seven taxa. Of these, 614 were captured in seagrass sites, while only 271 were captured over bare substrate. In contrast, 1024 individuals were caught in post-Hurricane Cindy samples collected in August 2005, with 389 individuals representing 11 fish taxa and 635 individuals representing 7 invertebrate taxa. Post-Katrina samples in May 2006 contained only 402 individuals, with 155 fishes representing ten taxa and 247 invertebrates representing five taxa.

A MANOVA of the environmental variables showed that the seagrass and bare substrate sites differed from each other in May 2005 ($p<0.0001$), but not in August 2005 ($p=0.2907$) or May 2006 ($p=0.6616$). In May 2005, distance to shore ($p=0.0034$), current speed ($p=0.0076$), DO ($p=0.0439$), seagrasses DW ($p<0.0001$), and change in depth ($p=0.0102$) differed significantly between the seagrass and bare substrate sites, while turbidity ($p=0.1016$), temperature ($p=0.4243$), salinity ($p=0.7709$), and mean depth ($p=0.3203$) did not.

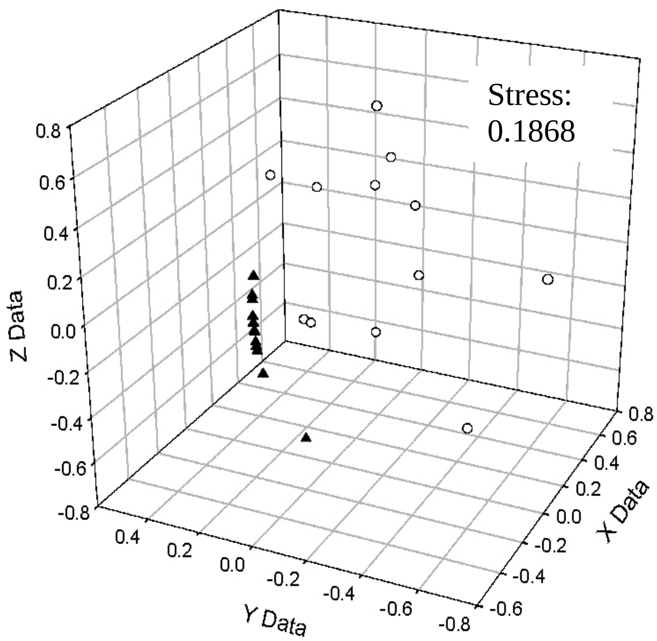
From the MANOVA of MDS dimensions, the community structure of seagrass and bare substrate habitat types was different ($p=0.0011$) in May 2005, prior to the

passage of the Hurricanes Cindy and Katrina (Figure 2.3b). Evaluation of the presence-absence data revealed that the communities were composed of different species ($p<0.0001$) (Figure 2.3a). Two species, *Anchoa mitchilli,* and *Gobiesox strumosus,* occurred exclusively in bare substrate sites, while *Sphoeroides parvus*, *Syngnathus scovelli,* and *Cynoscion nebulosus* occurred exclusively in seagrass sites. Several species, such as the rainwater killifish, mysid shrimp, and grass shrimp had much higher mean abundances in seagrass sites as opposed to bare substrate sites, which had higher mean abundances of darter gobies and mud crabs.

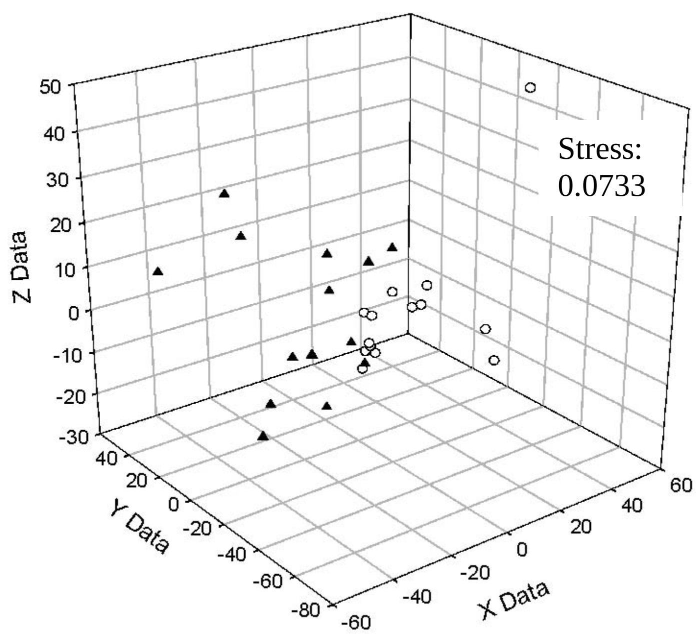
Hurricane Cindy

As a result of Hurricane Cindy, both the species composition ($p<0.0141$) and the community structure ($p=0.0449$) showed an interaction between habitat and month due to the alteration of the habitat by Cindy (Figure 2.4). Upon closer analysis, the species composition remained different between the pre-assigned habitat types in August 2005 ($p=0.0284$), while the community structure did not differ ($p=0.0921$) (Figure 2.5). Comparison of the August 2005 means between the habitats showed that *Lucania parva* and *Palaemonetes pugio* occurred only in seagrass sites, while *Myrophis punctatus*, *Ctenogobius boleosoma*, and *Sphoeroides parvus* occurred only on bare substrate sites (Table 2.1).

When looking at each habitat type separately, it was clear that the nekton community structure ($p=0.0006$) was altered after the passage of Cindy only in the seagrass sites (Figure 2.6). In addition to community structure differences, the environmental conditions of seagrass and bare substrate habitat types were also altered by Cindy. Salinity ($p<0.0001$) was significantly higher in August in both habitat types.

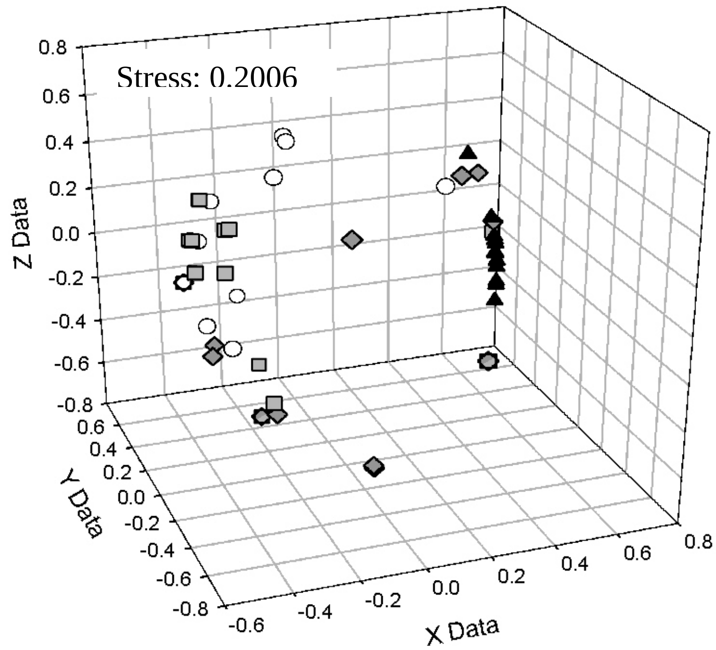


(a)

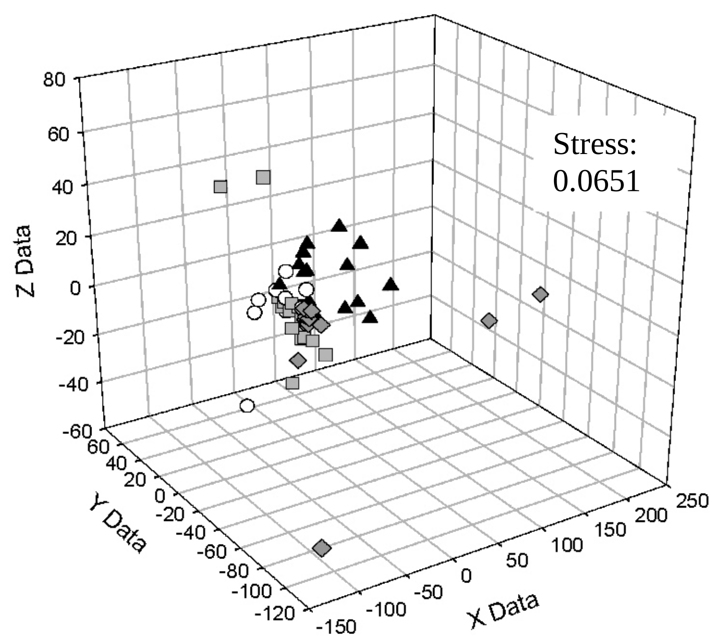


(b)

Figure 2.3. MDS plot of (a) species composition and (b) community structure for the pre-disturbance seagrass (▲) and bare substrate (○) communities of May 2005.

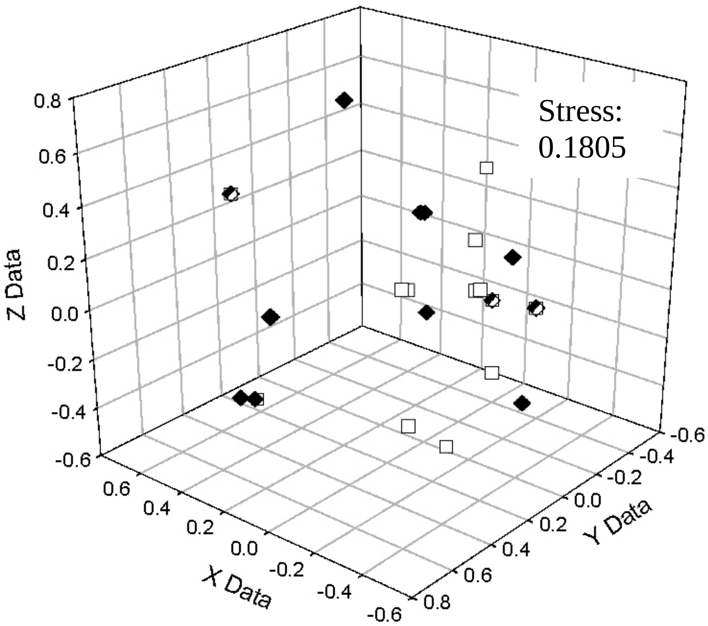


(a)

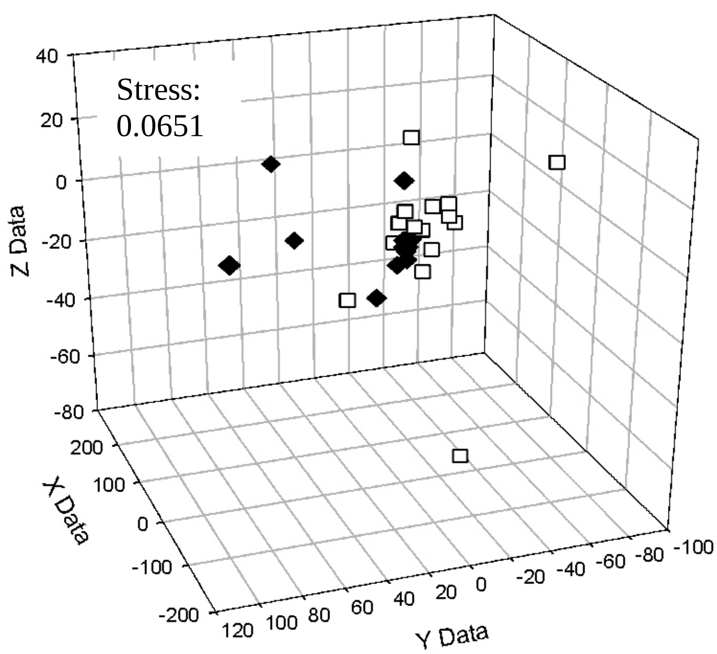


(b)

Figure 2.4. MDS plots of the (a) species composition and (b) community structure of pre-Cindy seagrass sites (▲), pre-Cindy bare substrate sites (○), post-Cindy seagrass sites (◇), and post-Cindy bare substrate sites (□).



(a)



(b)

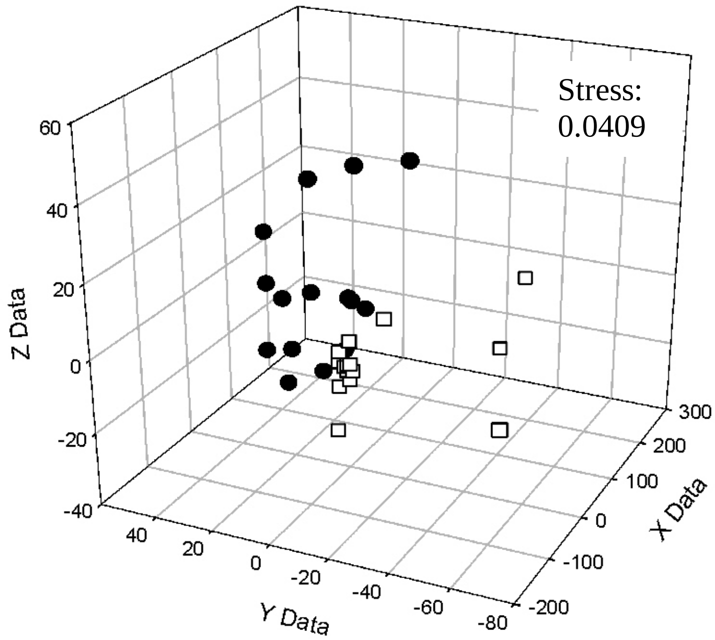
Figure 2.5. MDS plot of (a) species composition and (b) community structure for seagrass (◆) and bare substrate (□) sites in August 2005.

Table 2.1. The mean ± 2SE species abundances in bare substrate and seagrass sites in August 2005.

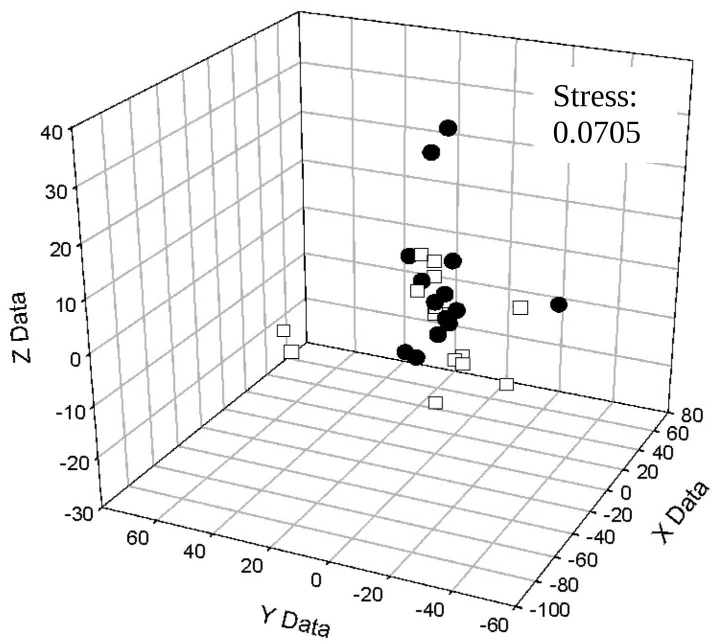
Taxa	**Common Name**	**Bare**	**Seagrass**
Symphurus plagiusa	blackcheek tonguefish	0.1 ± 0.18	0.3 ± 0.31
Anchoa mitchilli	bay anchovy	2.6 ± 2.67	1.0 ± 1.45
Lucania parva	rainwater killifish	0.0 ± 0.00	10.5 ± 14.98
Gobiesox strumosus	skilletfish	0.0 ± 0.00	0.0 ± 0.00
Gobiosoma bosc	naked goby	6.6 ± 7.39	0.7 ± 0.46
Ctenogobius boleosoma	darter goby	0.2 ± 0.29	0.0 ± 0.00
Microgobius gulosus	clown goby	0.9 ± 0.73	0.4 ± 0.55
Myrophis punctatus	speckled worm eel	0.9 ± 0.70	0.0 ± 0.00
***Mysidopsis* spp.**	mysid shrimp	4.3 ± 6.34	13.3 ± 20.70
Palaemonetes pugio	grass shrimp	0.0 ± 0.00	14.7± 20.18
Farfantepenaeus aztecus	brown shrimp	2.9 ± 4.47	0.4 ± 0.43
Callinectes sapidus	blue crab	0.3 ± 0.31	0.1 ± 0.13
Cynoscion nebulosus	spotted seatrout	0.1 ± 0.13	0.1 ± 0.13
Syngnathus scovelli	Gulf pipefish	0.2 ± 0.4	0.5 ± 0.80
Family Xanthidae	mud crab	5.5 ± 3.05	0.1 ± 0.07
Sphoeroides parvus	least puffer	0.4 ± 0.33	0.0 ± 0.00
Individuals		25.1 ± 11.51	43.1 ± 38.74

Turbidity (p=0.0002) and dry weight of seagrass (p<0.0001) differed between months only in seagrass stations due to the removal of most seagrasses, whereas only current speed differed in bare substrate stations.

Canonical Correlation analysis of Hurricane Cindy data revealed that two canonical correlations were significant (p<0.0001 and p=0.0033, respectively), accounting for 68% of the variance explained. The first canonical variable accounted for 52% of the variance with the environmental variables of bottom type, habitat type, turbidity and dry weight of the seagrasses loading heavily on it. Habitat type, month and dominant substrate loaded heavily on the second canonical variable, which accounted for 16% of the variance (Table 2.2). The taxa that loaded heavily on the first canonical



(a)



(b)

Figure 2.6. MDS plot of communities of (a) seagrass sites and (b) bare substrate sites pre-Hurricane Cindy (●) and post-Hurricane Cindy (□).

Table 2.2. Loadings of environmental variables on canonical variables to evaluate effects of Hurricane Cindy. Bold numbers indicate heavy loadings on the respective canonical variable.

	CV1	**CV2**
Bottom	**0.9690**	-0.0092
Habitat Type	**0.5129**	**-0.4014**
Month	-0.3840	**0.3929**
Mid Range Depth	0.0301	-0.3791
Change in Depth	-0.1703	0.0409
Temperature	0.1176	0.0153
Salinity	-0.3829	0.1768
DO	0.2612	-0.0715
Current Speed	-0.2339	0.2881
Distance to Edge	0.1732	-0.2447
Dominant Substrate	-0.2699	**0.4916**
Turbidity	**-0.4007**	0.1954
Dry Weight	**0.9253**	-0.2084

Table 2.3. Loadings of taxa on the first two canonical variables in analysis of effects of Hurricane Cindy. Bold numbers indicate heavy loadings on the respective canonical variable.

	CV1	**CV2**
Anchoa mitchilli	-0.2642	0.2208
Ctenogobius. boleosoma	0.0148	0.0523
Callinectes sapidus	0.3612	-0.1214
Farfantepenaeus aztecus	**0.4148**	0.2284
Gobiosoma. bosc	-0.1142	0.3802
Gobiesox strumosus	-0.1099	0.0753
Cynoscion nebulosus	-0.0198	0.0160
Lucania parva	**0.8132**	-0.0178
Microgobius gulosus	0.0458	0.2293
Myrophis punctatus	0.0457	0.2266
Mysid shrimp	0.1163	-0.2475
Palaemonetes. pugio	**0.6735**	0.1552
Sphoeroides. parva	0.0853	**0.4433**
Symphurus plagiusa	-0.2223	-0.0860
Syngnathus scovelli	**0.5793**	0.2665
Family **Xanthidae**	0.1718	0.1820

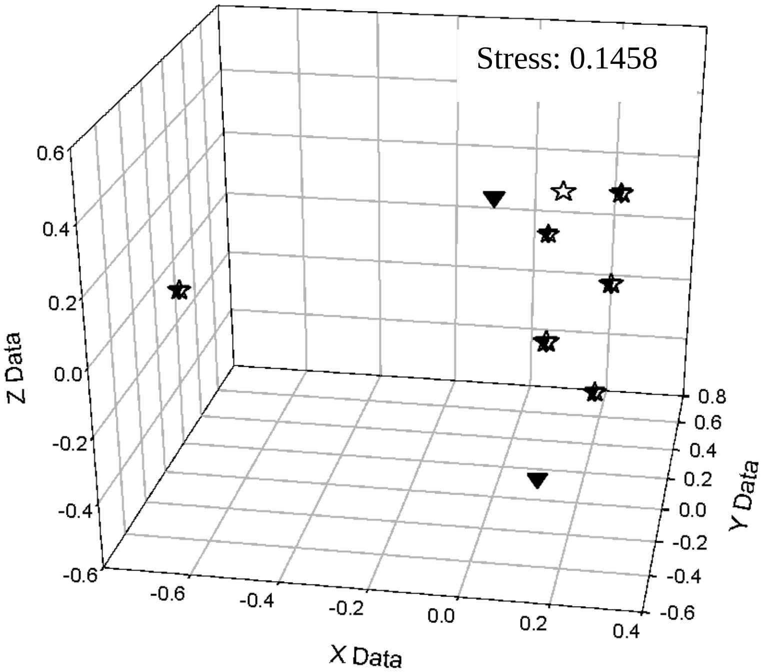
variable were *C. sapidus*, *F. aztecus*, *L. parva,* and *S. scovelli*. The only taxa that loaded heavily on the second canonical variable was *S. parva* (Table 2.3).

Hurricane Katrina

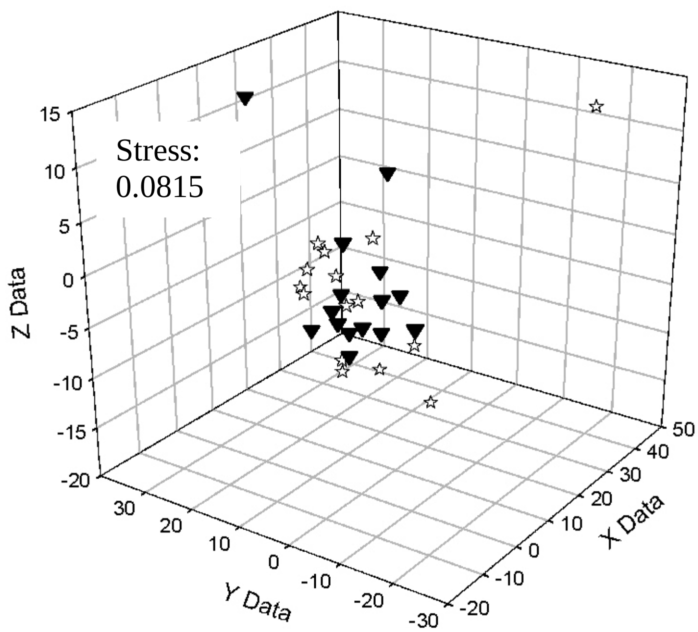
After the passage of Katrina in August 2005, there was no sign of seagrasses in Goose Flat. In May 2006, there were no detectable differences between habitat types in terms of environment (p=0.6616), species composition (p=0.4047) or community structure (p=0.5812) (Figure 2.7). All species present in May 2006 occurred in both habitat types except for skilletfish and clown goby, both of which were only present in pre-Katrina bare substrate sites. Although located in both habitat types, the mean abundances of mud crabs were three times greater in pre-Katrina bare substrate sites than in seagrass sites.

When comparing the May samples between the years, there was a significant interaction between habitat and year for both species composition (p<0.0001) and community structure (p=0.0030) (Figure 2.8). Upon looking at each habitat type individually, MDS/MANOVAs revealed that the community structure was significantly altered (p=0.0005) only in seagrass sites (Figure 2.9). The MANOVA of environmental variables revealed that there was an interaction (p<0.0001) between habitat and year. Turbidity, dry weight, and salinity differed between sampling efforts in both habitat types, while change in depth and DO were different only in former seagrass stations. Current speed differed only in bare substrate stations.

Canonical correlation analysis of the pre- (May 2005) and post-Katrina (May 2006) samples indicated that there was only one significant canonical variable

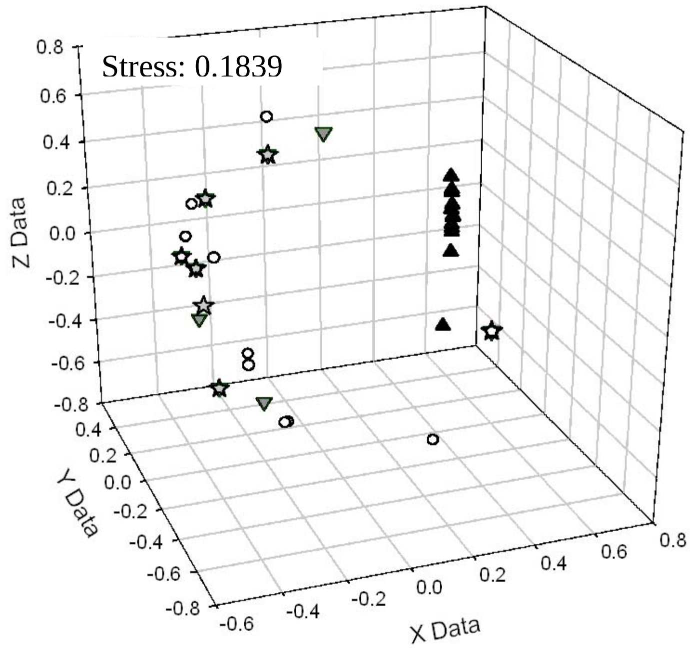


(a)

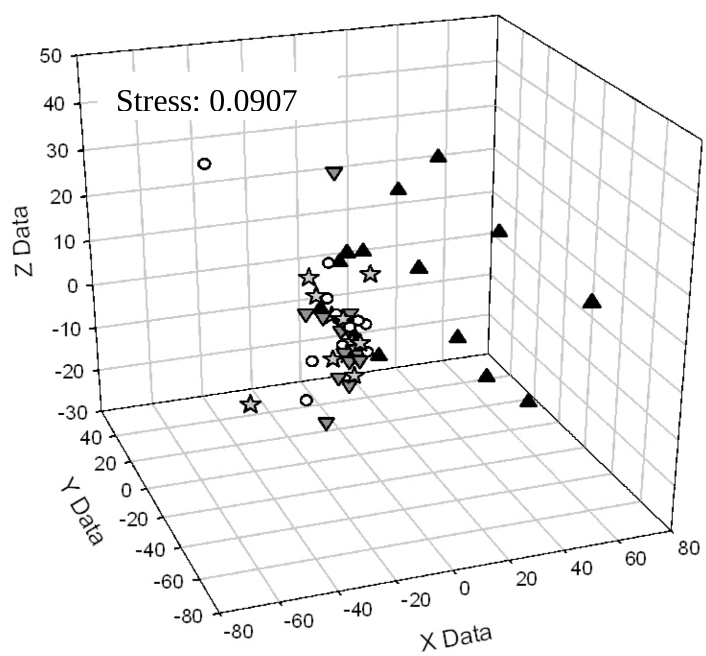


(b)

Figure 2.7. MDS plots of (a) species composition and (b) community structure for sites labeled as seagrass (▼) and bare substrate (☆) in May 2006.

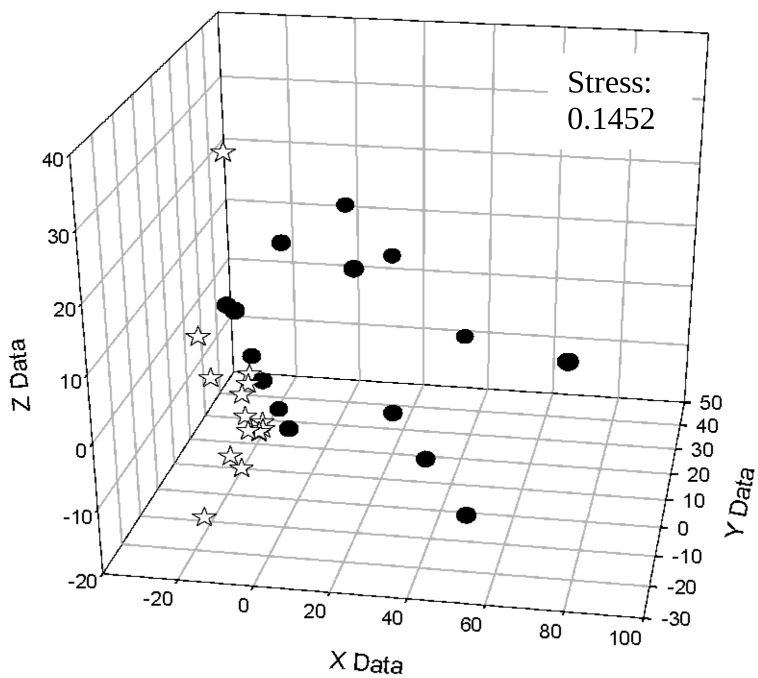


(a)

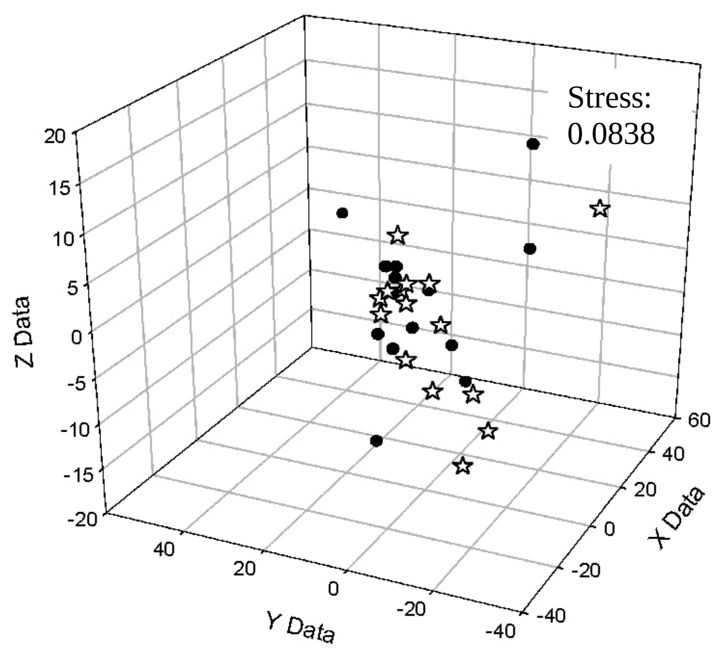


(b)

Figure 2.8. MDS plot of (a) species composition and (b) community structure for pre-Katrina seagrass sites (▲), pre-Katrina bare substrate sites (○), post-Katrina seagrass sites (☆), and post-Katrina bare substrate sites (▽).



(a)



(b)

Figure 2.9. MDS plot of community structure in (a) seagrass sites and (b) bare substrate sites pre-Katrina (●) and post-Katrina (☆).

(p=0.0057), which explained 57% of the variance in the system. Of the environmental variables, bottom type and dry weight of seagrasses loaded most heavily and positively (Table 2.4.), while year, salinity, DO, and turbidity loaded moderately. *L. parva*, *S. scovelli*, *P. pugio,* and mysid shrimp loaded heavily and positively, while *A. mitchilli* loaded moderately and negatively on the first canonical variable (Table 2.5).

Table 2.4. Correlations of environmental variables with the first canonical variable for analysis of effects of Hurricane Katrina. Bold numbers indicate those variables that load heavily on the canonical variable.

	CV1
Bottom	**0.9465**
Habitat Type	**0.4836**
Mid-Range depth	0.0583
Change in Depth	-0.2846
Temperature	0.0490
Year	**-0.5512**
Salinity	**-0.5504**
DO	**0.5445**
Current Speed	-0.2520
Distance to Edge	0.0917
Dominant Substrate	-0.3070
Turbidity	**-0.4692**
Dry Weight	**0.9365**

DISCUSSION

Alteration of seagrass habitats by the cumulative effects of Hurricanes Cindy and Katrina yielded changes in community structure. The species that were affected most by the removal of the seagrasses were those that selected the seagrass habitats over nearby bare substrate habitats. Of the communities analyzed, fishes were affected more than

Table 2.5. Correlations between the species and the first canonical variable to compare the effects of Hurricane Katrina. Bold numbers indicate those variables that load heavily on the canonical variable.

	CV1
Anchoa mitchilli	**-0.3917**
Ctenogobius boleosoma	0.1088
Callinectes sapidus	0.2584
Farfantepenaeus aztecus	0.1666
Gobiosoma bosc	-0.1340
Gobiesox strumosus	-0.1360
Cynoscion nebulosus	0.0649
Citharichthys spilopterus	-0.2000
Lucania parva	**0.9145**
Microgobius gulosus	0.1456
Myrophis punctatus	0.1280
***Mysidopsis* spp.**	**0.5968**
Palaemonetes pugio	**0.6780**
Sphoeroides parva	-0.0656
Syngnathus scovelli	**0.5739**
Family **Xanthidae**	0.0822

invertebrates by the removal of the seagrasses. In addition to the removal of the seagrasses, the hurricanes resulted in a sustained perturbation in the form of increased salinity. This increase in salinity could also be partly responsible for the changes in community structure that were observed. This system is also unique because the effects to the environment brought about by the storms appear to be long lasting, persisting nine months after the passage of the last storm, with little evidence of recovery for many faunal elements.

Hurricane Cindy removed most of the seagrasses in Goose Flat and deposited them on nearby marshes. Then, Hurricane Katrina removed any remaining seagrasses or buried any remains. Although Cindy removed most of the grasses, the root systems

appeared to be relatively intact in the sediment in August 2005. The differences in community observed after the passage of Hurricane Cindy were due to removal of the seagrasses. Damage to seagrasses by hurricanes has been observed on numerous occasions, including Hurricanes Donna (Wanless et al. 1988), Carla, Camille (Pulich and White 1991), Andrew (Rozas and Reed 1994), Gilbert (Gallegos et al. 1992) and Hugo (Short and Wyllie-Escheverria 1996). Post-disturbance changes in the communities associated with seagrass beds have been attributed to many factors. Nekton can become entrapped in the seagrasses and deposited with seagrass wrack onshore (Tabb and Jones 1962, Short and Wyllie-Escheverria 1996). Without seagrasses, areas may no longer serve as a suitable habitat due to reduced food and refuge, prompting mobile species to leave an area to find more suitable habitat (Bell and Westoby 1986, Deegan 2002, Greenwood et al. 2006, Switzer et al. 2006).

Pelagic and epibenthic species, especially those associated with seagrasses, were more affected than benthic species. After the passage of Hurricane Cindy, rainwater killifish, grass shrimp, and Gulf pipefish were only found in the three sites with measurable quantities of living seagrass. However, after Katrina, with no grasses present to sustain their populations, these three species were absent from the area. Changes in communities, particularly decreases in abundance and diversity of the communities, as a result of hurricanes have been reported on numerous occasions (Tabb and Jones 1962, Gallegos et al. 1992, Deegan 2002, Paperno et al. 2006, Switzer et al. 2006). Greenwood et al. (2006) found increased abundances of species associated with bare substrates and decreased abundances of seagrass associated fauna (i.e., pipefish and killifish) after the passage of hurricanes. Rozas and Reed (1994) found that species such as the naked goby,

rainwater killifish, Gulf pipefish, blue crab and grass shrimp were present in much greater numbers when seagrasses were present. After the passage of Hurricane Andrew, however, these species were either found in extremely low numbers, or as in the case of rainwater killifish and Gulf pipefish, not at all. In contrast to the pelagic communities, benthic communities suffer from stresses induced by low dissolved oxygen and salinity changes rather than removal of seagrasses (Frazer et al. 2006, Paperno et al. 2006).

Hurricane Cindy may be the reason that observed community changes occurred. However, differences between May and August 2005 may be confounded by season. As some species do not typically occur during both months, only two species showed absences in one of the sampling periods: skilletfish was present pre-Cindy, but absent post-Cindy, whereas blackcheek tonguefish was absent pre-Cindy and present post-Cindy.

In addition to removal of seagrasses, salinity may have caused the alterations in community that were observed. Post-Katrina, the salinity in Goose Flat doubled. Bay whiffs appeared in Goose Flat only post-Katrina. It is difficult to attribute the presence of bay whiff to the increased salinity as these are euryhaline species (Allen and Baltz 1997). Changes in salinity can stress nekton communities, which can alter community structure (Frazer et al. 2006).

Salinities can be increased by hurricane storm surge or decreased by hurricane induced rainfall and land runoff (Tabb and Jones 1962, Frazer et al. 2006, Greenwood et al. 2006). In the case of Goose Flat, the increased salinities were due to the saltier water brought in by the sequential storm surges. Alteration of the salinity can result in changes in the types and quantity of seagrasses found (Short and Wyllie-Escheverria 1996), which

can in turn alter the communities that rely on the seagrasses (Tabb and Jones 1962, Greenwood et al. 2006, Switzer et al. 2006). While changes in salinity alone have been shown to alter community structure (Greenwood et al. 2006, Switzer et al. 2006) , in most of these cases, the salinity has decreased due to increased freshwater inflow (Greenwood et al. 2006, Paperno et al. 2006, Steward et al. 2006, Switzer et al. 2006). With the decrease in salinity, there are other complicating factors, such as increase in freshwater flow and nutrients that can create hypoxia, which could lead to fish kills and changes in community structure (Greenwood et al. 2006).

As of May 2006, Goose Flat showed no signs of recovery in terms of seagrass sprouting and salinity decreasing. In most studies where changes in environment and/or faunal community structure were documented, the return to pre-storm status occurred within a few months to a year of storm passage (Pulich and White 1991, Paperno et al. 2006, Stevens et al. 2006, Steward et al. 2006, Switzer et al. 2006). In fact, most systems show recovery of the community, salinity, and seagrasses by the following spring after the storm (Paperno et al. 2006, Switzer et al. 2006). In one long term study, Greenwood et al. (2006) found that the changes in fish community structure due to storms were within the range of variability experienced over an eight year period, suggesting that the fish community structures are resilient to natural disturbances. Paperno et al. (2006) suggested that seasonal effects, such as temperature changes, impact the communities more than many disturbances.

While nekton may be resilient to disturbances, they may not be able to repopulate an area if an important habitat type, such as seagrasses, has been lost (Switzer et al. 2006). Many factors influence recovery times, including environmental condition prior

to disturbance, the disturbance itself (i.e., type, duration and frequency), and the extent of physical damage (Short and Wyllie-Escheverria 1996, Switzer et al. 2006). Once a seagrass bed is destroyed by a natural disaster, it is unlikely that it will recover (Pulich and White 1991, Byron and Heck 2006,). However, in some cases, the buried seagrasses can re-grow through the sediment layer that buried them if the root systems are still intact and the proper environmental conditions persist (Wanless et al. 1988, Steward et al. 2006).

Seagrasses that are ripped from their roots and seagrasses that are buried by the storm surge can recover from the disturbances individually. However, the seagrasses of Goose Flat experienced two major disturbances within a short time period. Had the system only experienced disturbance by Hurricane Cindy, it is likely that the system would have recovered by spring 2006. However, due to the amount of sediment burying the seagrasses, re-colonization may require more time. Nevertheless, hopeful signs of recovery were evident in April 2007 when growth of *Zannichellia palustris*, the subdominant species in May 2005, was noted in the study area.

LITERATURE CITED

Allen, R. and D. M. Baltz. 1997. Distribution and microhabitat use by flatfishes in a Louisiana estuary. *Environmental Biology of Fishes* 50:85-103.

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

Baltz, D. M., J. W. Fleeger, C. Rakocinski, and J. N. McCall. 1998. Food, density, and microhabitat: factors affecting growth and recruitment potential of juvenile saltmarsh fishes. *Environmental Biology of Fishes* 53:89-103.

Bell, J. D. and M. Westoby. 1986. Abundance of macrofauna in dense seagrass is due to habitat preference, not predation. *Oecologia* 68:205-209.

Byron, D. and K. L. Heck, Jr. 2006. Hurricane effects on seagrasses along Alabama's gulf coast. *Estuaries and Coasts* 29: 939-942.

Boyce, R. L. and P. C. Ellison. 2001. Choosing the best similarity index when performing fuzzy set ordination on binary data. *Journal of Vegetation Science* 12:711-720.

Castellanos, D. L. and L. P. Rozas. 2001. Nekton use of submerged aquatic vegetation, marsh, and shallow unvegetated bottom in the Atchafalaya River Delta, a Louisiana tidal freshwater system. *Estuaries* 24:184-197.

Connolly, R. M. 1997. Differences in composition of small, motile invertebrate assemblages from seagrass and unvegetated habitats in a southern Australian estuary. *Hydrobiologia*. 346: 137-148.

Dawes, C. J. 1998. Marine Botany. John Wiley and Sons, Inc., New York.

Deegan, L. A. 2002. Lessons learned: the effects of nutrient enrichment on the support of nekton by seagrass and salt marsh ecosystems. *Estuaries* 25:727-742.

Digby, P. G. N. and R. A. Kempton. 1987. Multivariate Analysis of Ecological Communities. Chapman and Hall, New York, New York.

Epifanio, C. E., A. I. Dittel, R. A. Rodriguez, and T. E. Targett. 2003. The role of macroalgal beds as nursery habitat for juvenile blue crabs, *Callinectes sapidus. Journal of Shellfish Research* 22:881-886.

Ferrell, D. J. and J. D. Bell. 1991. Differences among assemblages of fish associated with *Zostera capricorni* and bare sand over a large spatial scale. *Marine Ecology Progress Series* 72:15-24.

Frazer, T. K, S. K. Notestein, C. A. Jacoby, C. J. Littles, S. P. Keller, and R. A. Swett. 2006. Effects of storm-induced salinity changes on submerged aquatic vegetation in Kings Bay, Florida. *Estuaries and Coasts* 29:943-953.

Gallegos, M. E., M. Merino, N. Marba, and C. M. Duarte. 1992. Flowering of *Thalassia testudinum* banks ex Konig in the Mexican Caribbean: age-dependence and interannual variability. *Aquatic Botany* 43:249-255.

Greenwood, M. F. D., P. W. Stevens, and R. E. Matheson, Jr. 2006. Effects of the 2004 hurricanes on the fish assemblages in two proximate southwest Florida estuaries: change in the context of interannual variability. *Estuaries and Coasts* 29:985-996.

Heck, Jr., K. L., G. Hays, and R. J. Orth. 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series* 253:123-136.

Heck, Jr., K. L. and T. A. Thoman. 1981. Experiments on predator-prey interactions in vegetated aquatic habitats. *Journal of Experimental Marine Biology and Ecology* 53:125-134.

Heck Jr., K. L. and R. J. Orth. 1980. Seagrass habitats: the roles of habitat complexity, competition and predation in structuring associated fish and motile macroinvertebrate assemblages, p. 449-464. *In* V.S. Kennedy (eds.), Estuarine Perspectives. Academic Press, Inc., New York, New York.

Heise, R. J. and S. A. Bortone. 1999. Estuarine artificial reefs to enhance seagrass planting and provide fish habitat. *Gulf of Mexico Science* 2:59-74.

Hemminga, M. A. and J. Nieuwenhuize. 1990. Seagrass wrack-induced dune formation on a tropical coast (Banc-Darguin, Mauritania). *Estuarine, Coastal and Shelf Science* 31:499-502.

Johnson, R. A. and D. W. Wichern. 2002. Applied Multivariate Statistical Analysis, 5th edition. Prentice Hall, Upper Saddle River, New Jersey.

Knabb, R. D., D. P. Brown, and J. R. Rhome. 2006a. Tropical cyclone report Hurricane Rita 18-26 September 2005. National Hurricane Center.

Knabb, R. D., D. P. Brown, and J. R. Rhome. 2006b. Tropical cyclone report Hurricane Katrina 23-30 August 2005. National Hurricane Center.

Lambert, Z. V. and R. M. Durand. 1975. Some precautions in using canonical analysis. *Journal of Marketing Research* 12: 468-475.

Lopez, J. A. 2005. The multiple lines of defense strategy to sustain Louisiana's coast. Lake Pontchartrain Basin Foundation.

Minello, T. J., and R. J. Zimmerman. 1985. Differential selection for vegetative structure between juvenile brown shrimp (*Penaeus aztecus)* and white shrimp (*P. setiferus),* and implications in predator-prey relationships. *Estuarine, Coastal and Shelf Science* 20:707-716.

Orth, R. J., R. A. Batiuk, P. W. Bergstrom, and K. A. Moore. 2002. A perspective on two decades of policies and regulations influencing the protection and restoration of submerged aquatic vegetation in Chesapeake Bay, USA. *Bulletin of Marine Science* 71:1391-1403.

Orth, R. J., K. L. Heck, Jr., and J. van Montfrans. 1984. Faunal communities in seagrass beds: a review of the influence of plant structure and prey characteristics on predator-prey relationships. *Estuaries* 7:339-350.

Orth, R. J. and K. A. Moore. 1983. Chesapeake Bay: an unprecedented decline in submerged aquatic vegetation. *Science* 222:51-53.

Orth, R. J. and J. van Montfrans. 1990. Utilization of marsh and seagrass habitats by early stages of *Callinectes sapidus*: a latitudinal perspective. *Bulletin of Marine Science* 46:126-144.

Paperno, R., D. M. Tremain, D. H. Adams, A. P. Sebastian, J. T. Sauer, and J. Dutka-Gianelli. 2006. The disruption and recovery of fish communities in the Indian River Lagoon, Florida, following two hurricanes in 2004. *Estuaries and Coasts* 29:1004-1010.

Pulich, W. M., and W. A. White. 1991. Decline of submerged vegetation in the Galveston Bay system: chronology and relationships to physical processes. *Journal of Coastal Research* 7:1125-1138.

Rozas, L. P. and D. J. Reed. 1994. Comparing nekton assemblages of subtidal habitats in pipeline canals traversing brackish and saline marshes in coastal Louisiana. *Wetlands* 14:262-275.

SAS Institute Inc. 2004. SAS/STAT 9.1 user’s guide. SAS Institute Inc, Cary, North Carolina.

Sheridan, P. and T. J. Minello. 2003. Nekton use of different habitat types in seagrass beds of lower Laguna Madre, Texas. *Bulletin of Marine Science* 72:37-61.

Short, F. T. and S. Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* 23:17-27.

Sogard, S. M. and K. W. Able. 1991. A comparison of eelgrass, sea lettuce macroalgae, and marsh creeks as habitats for epibenthic fishes and decapods. *Estuarine, Coastal and Shelf Science* 33:501-519.

Steele, M. A., S. C. Schroeter, and H. M. Page. 2006. Sampling characteristics and biases of enclosure traps for sampling fishes in estuaries. *Estuaries and Coasts* 29:630-638.

Stevens, P. W., D. A. Blewett, and J. P. Casey. 2006. Short-term effects of a low dissolved oxygen event on estuarine fish assemblages following the passage of Hurricane Charley. *Estuaries and Coasts* 29:997-1003.

Steward, J. S., R. W. Virnstein, M. A. Lasi, L. J. Morris, J. D. Miller, L. M. Hall, and W. A. Tweedale. 2006. The impacts of the 2004 hurricanes on hydrology, water quality, and seagrass in the central Indian River Lagoon, Florida. *Estuaries and Coasts* 29:954-965.

Stewart, S. R. 2006. Tropical cyclone report Hurricane Cindy 3-7 July 2005. National Hurricane Center.

Switzer, T. S., B. L. Winner, N. M. Dunham, J. A. Whittington, and M. Thomas. 2006. Influence of sequential hurricanes on nekton communities in a southeast Florida Estuary: short-term effects in the context of historical variations in freshwater inflow. *Estuaries and Coasts* 29:1011-1018.

Tabb, D. C. and A. C. Jones. 1962. Effect of Hurricane Donna on the aquatic fauna of North Florida Bay. *Transactions of the American Fisheries Society* 91:375-378.

Thomas, J. L., R. J. Zimmerman, and T. J. Minello. 1990. Abundance patterns of juvenile blue crabs (*Callinectes sapidus)* in nursery habitats of two Texas bays. *Bulletin of Marine Science* 46:115-125.

Wanlass, H. R., L. P. Tedesco, and K. M. Tyrrell. 1988. Production of subtidal tubular and surficial tempestites by Hurricane Kate, Caicos platform, British West Indies. *Journal of Sedimentary Petrology* 58:739-750.

Zimmerman, R. J., T. J. Minello, and G. Zamora, Jr. 1984. Selection of vegetated habitat by brown shrimp, *Penaeus aztecus*, in a Galveston Bay salt marsh. *Fishery Bulletin* 82:325-336.

GENERAL SUMMARY AND CONCLUSIONS

There were two major goals to this study. The first was to determine if seagrass sites differed from bare substrate sites in terms of community structure and species composition. The second goal was to determine if the passage of category one and category three hurricanes on the Saffir-Simpson scale altered these communities. Once the communities of bare substrate and seagrass habitat types were established as different, correlations with environmental variables were assessed to determine if the presence of seagrass was the only reason for these differences.

In May 2005, I found that the community structure and species composition of the seagrass sites differed from nearby bare substrate sites when considered for the overall, fish, and invertebrate communities. Having established that all three communities differed, only the overall community was considered for the remainder of the analyses. In July 2005, Hurricane Cindy, a category one storm, passed directly over Biloxi Marsh. After the passage of Cindy, most of the seagrasses in the area were uprooted. However, three sites that had seagrasses remaining were more similar to the seagrass sites in May 2005 than to the bare substrate sites of either May or August 2005. Additionally, the environmental variables most highly correlated with the nekton species were the seagrass biomass, salinity, and variables that were responsive to seagrass biomass (i.e. turbidity and dominant substrate). Location was also an important environmental variable. However, after Cindy only one of the ponds had seagrasses remaining. Prior to Cindy, ANOVAs revealed that there were no differences between the locations (ponds). Thus, the location variable also varied with seagrass presence.

On August 29, 2005, Hurricane Katrina, a category three hurricane, passed over the same area. After Katrina, seagrasses remained absent for eighteen months. Six nekton species were captured that had not been captured in previous sampling trips. The salinities were nearly double that of May 2005. Analysis of communities revealed that all sites resembled that of bare substrate habitats in May 2005, with changes in community only evident in sites labeled as seagrass sites. Canonical correlation revealed that dry weight and bottom type loaded heaviest on the first canonical variable, with habitat type, year, salinity, dissolved oxygen, and turbidity also loading heavily on the first canonical variable. Of the species, bay anchovy, rainwater killifish, mysid shrimp, grass shrimp, and Gulf pipefish loaded heavily on the first canonical variable, which accounted for the most variation. Thus, these species accounted for the most variation in the system.

Of the variables that loaded heavily on the canonical variables, DO, turbidity, and the habitat type variables (dry weight, habitat type, and bottom) should be altered when seagrasses were removed from the system. Thus, the heavy loadings of these variables were expected. However, year and salinity also loaded heavily on the canonical variable. Thus, the community differences can be attributable to the presence of seagrass, time, and salinity changes or some interaction of the three. The communities consisted of rainwater killifish, grass shrimp, and Gulf pipefish pre-Katrina, but after the storm, the communities shifted from species associated with seagrasses to more pelagic, salt-tolerant species such as the bay anchovy.

APPENDIX: SUPPLEMENTAL MATERIAL

Table A.1. Abundances of species caught in seagrass and bare substrate sites in May 2005.

Scientific Name	**Common Name**	**Seagrass**	**Bare Substrate**	**Total**
Anchoa mitchilli	**bay anchovy**	0	20	20
Callinectes sapidus	**blue crab**	24	7	31
Ctenogobius boleosoma	**darter goby**	7	22	29
Cynoscion nebulosus	**spotted sea trout**	1	0	1
Cyprinodon variegatus	**sheepshead minnow**	2	0	2
Dormitator maculatus	**fat sleeper**	1	3	4
Elops lacerta	**ladyfish**	3	0	3
Farfantepenaeus aztecus	**brown shrimp**	37	16	53
Fundulus grandis	**Gulf killifish**	1	0	1
Gobiesox strumosus	**skilletfish**	0	5	5
Genus *Gobiidae*	**goby species**	0	2	2
Gobiosoma bosc	**naked goby**	20	22	42
Heterandria formosa	**least killifish**	22	0	22
Leiostomus xanthurus	**spot**	0	1	1
Lucania parva	**rainwater killifish**	239	4	243
Lutjanus griseus	**mangrove snapper**	1	0	1
Microgobius gulosus	**clown goby**	5	2	7
Myrophis punctatus	**speckled worm eel**	10	12	22
Genus *Mysidopsis*	**mysid shrimp**	91	7	98
Palaemonetes pugio	**daggerblade grass shrimp**	65	2	67
Scartella cristata	**molly miller**	0	1	1
Sphoeroides parvus	**least puffer**	1	0	1
Squilla empusa	**mantis shrimp**	0	1	1
Strongylura marina	**Atlantic needlefish**	1	1	2
Syngnathus scovelli	**Gulf pipefish**	13	0	13
Synodus foetens	**inshore lizardfish**	0	1	1
Unidentified Invertebrate	**unidentifiable invertebrate**	2	0	2
Family Xanthidae	**mud crab**	68	142	210
Fish		327	96	423
invertebrates		287	175	462
totals		614	271	885

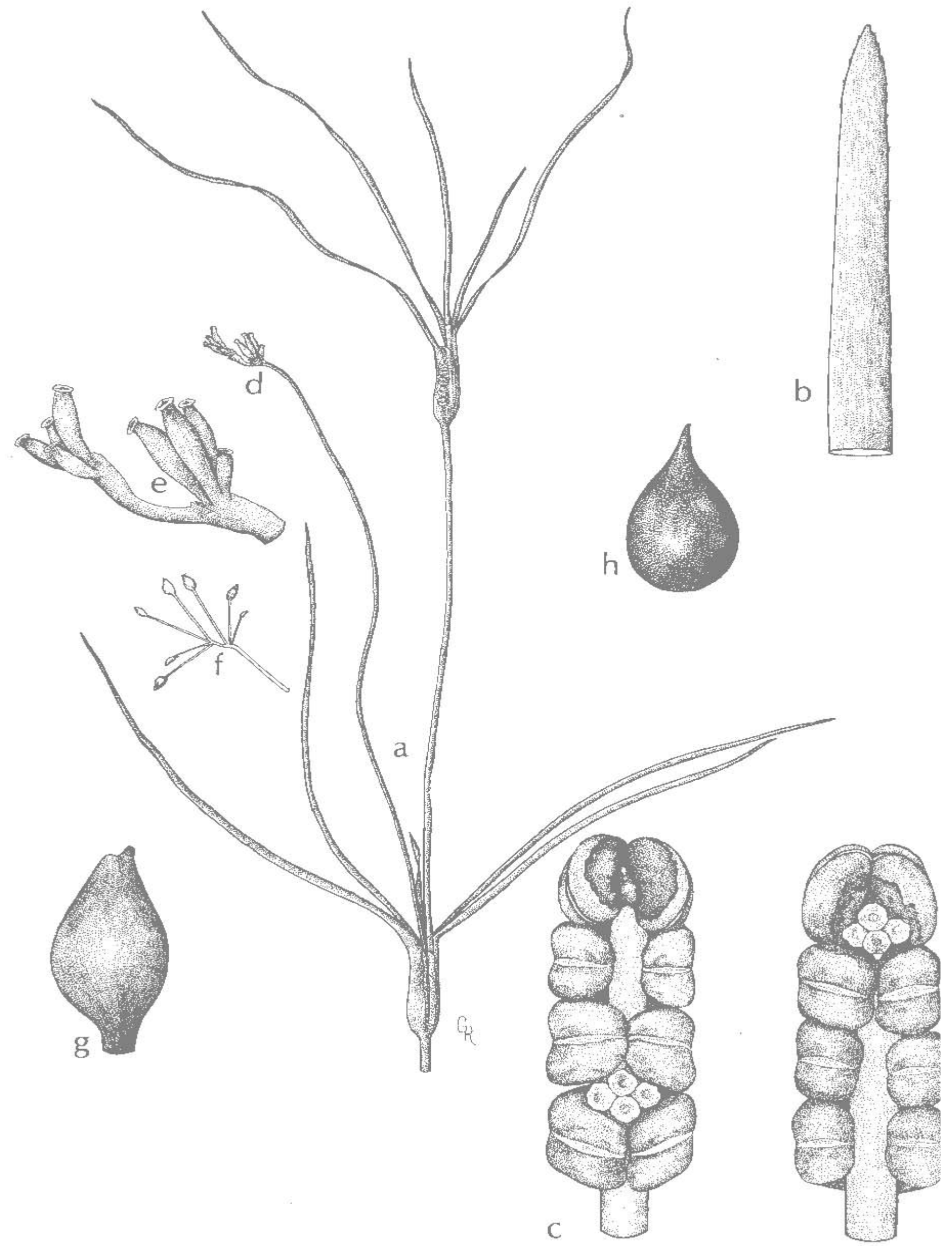


Fig. 15. **Ruppia maritima:** a, small portion of plant; b, tip of leaf; c, inflorescence with two flowers, views of opposite sides; d, inflorescence after early development of fruits and e, enlarged portrayal of same; f, tip of fruiting inflorescence at maturation showing stipes on fruits; g, fruit; h, seed.

36

Figure A.1. *Ruppia maritima* (Godfrey and Wooten, 1976).

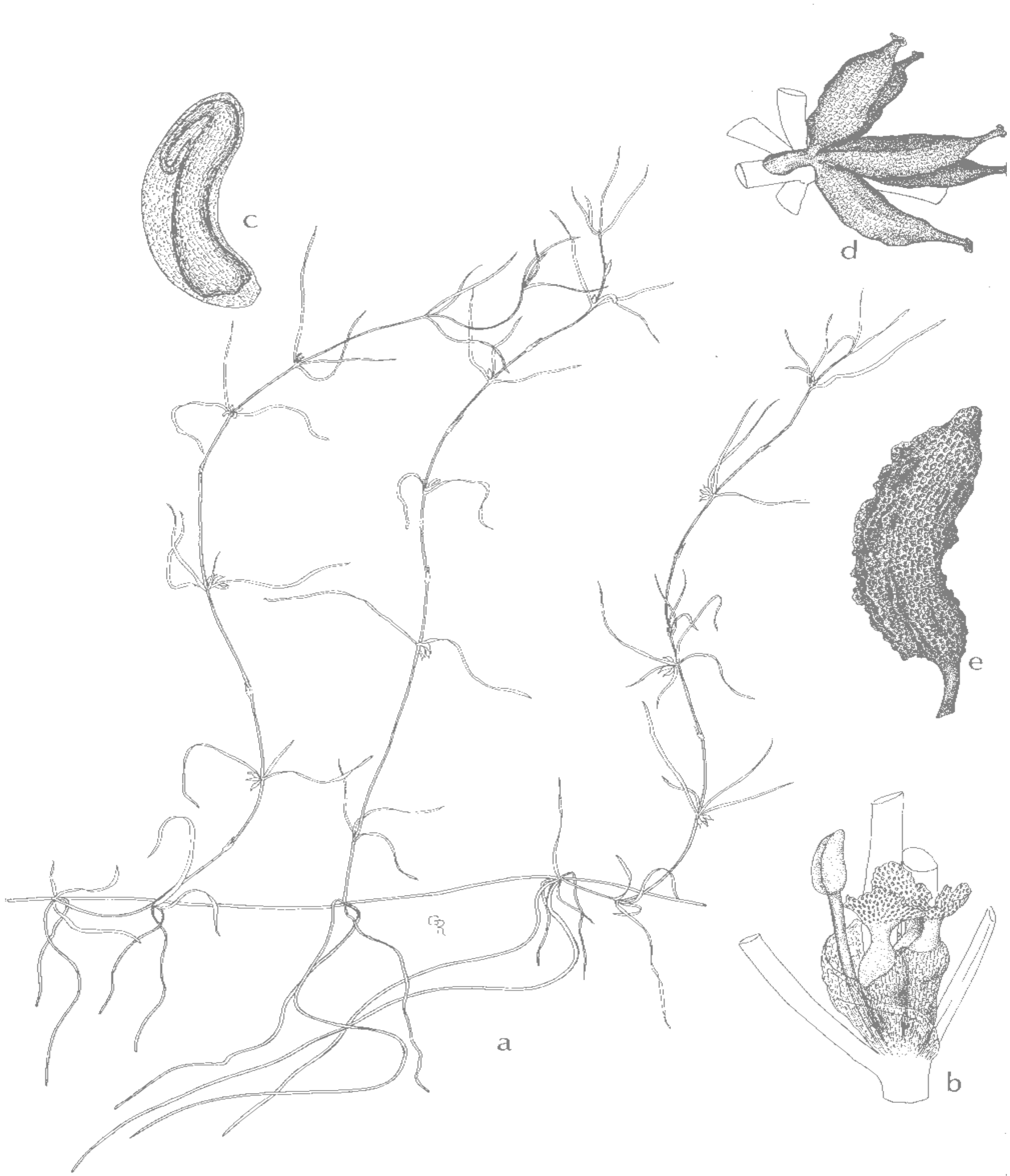


Fig. 12. **Zannichellia palustris:** a, habit; b, involucre or spathe with 3 pistillate flowers and 1 staminate; c, embryo in endocarp; d, fruiting cluster; e, fruit.

30

Figure A.2. *Zannichellia palustris* (Godfrey and Wooten 1976).

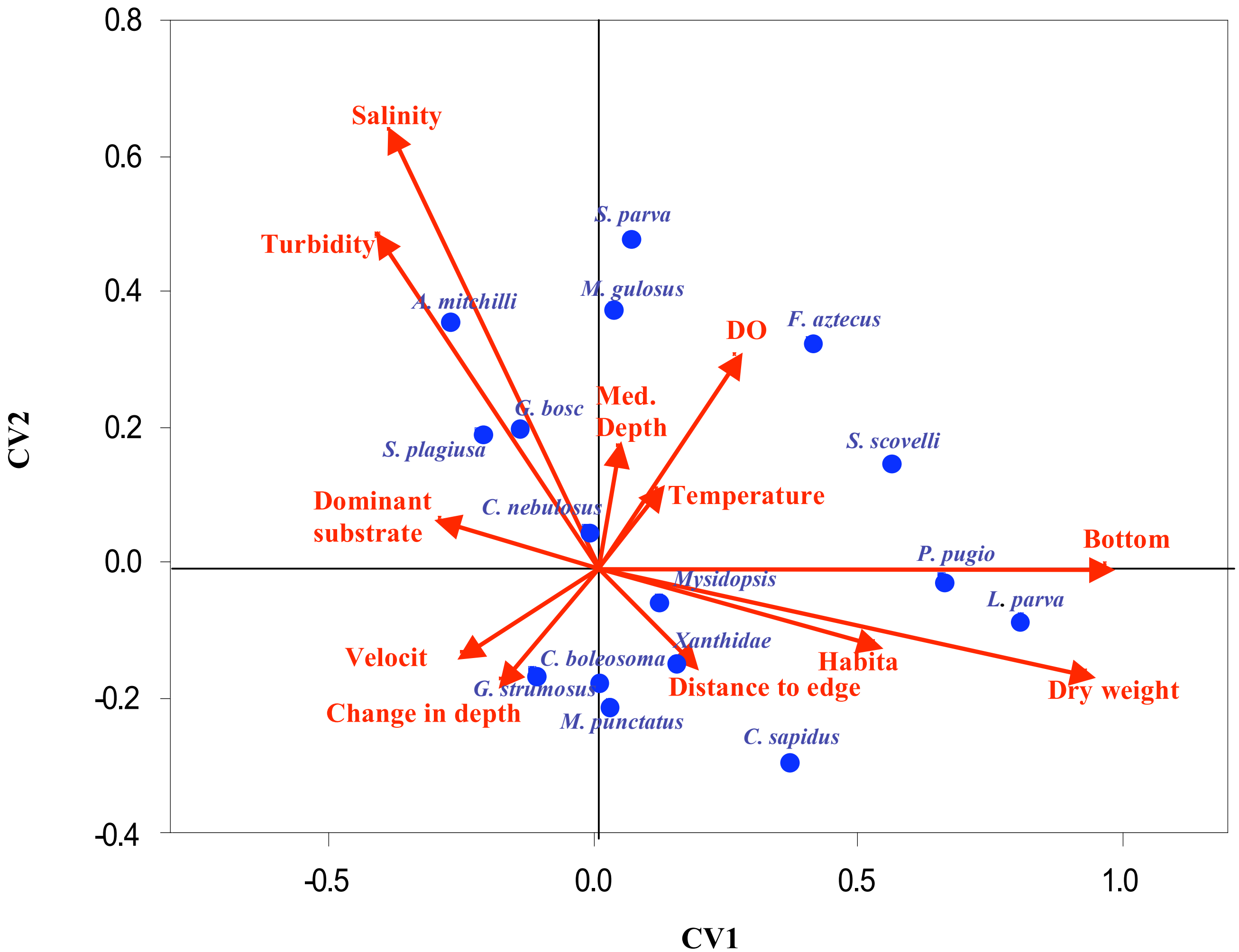


Figure A.3. Biplot of Canonical Correlations between the environmental variables (red) and the species (blue). This biplot includes data from May and August 200

VITA

Jamie Maiaro was born on December 1, 1982 in New Orleans, Louisiana, to Albert and Debbie Maiaro. She graduated from Archbishop Phillip M. Hannan High School with honors in 2000. She obtained her Bachelor of Science in biological sciences, concentrated in marine biology, from Louisiana State University in May 2004. She then spent five weeks in Australia working on rainforest restoration as an international student volunteer. Upon return from Australia, she began her master's degree in the Department of Oceanography and Coastal Sciences. She will graduate in August 2007.