EFFECTS OF HURRICANE KATRINA ON THE MAMMALIAN AND VEGETATIVE COMMUNITIES OF THE BARRIER ISLANDS OF MISSISSIPPI

A Thesis

by

ANNALIESE KEMPER SCOGGIN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2008

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee, Roel R. Lopez
Committee Members, Robert A. McCleery
Fred E. Smeins
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ABSTRACT

Effects of Hurricane Katrina on the Mammalian and Vegetative Communities of the Barrier Islands of Mississippi. (December 2008)

Annaliese Kemper Scoggin

Chair of Advisory Committee: Dr. Roel R. Lopez

The barrier islands of the gulf coast of the U.S. have been shaped and changed by hurricanes for centuries. These storms can alter the vegetation of the barrier islands by redistributing sediments, scouring off vegetation, physical damage to the plants, and by salt stress following the storm. Hurricanes also alter the mammal communities of the barrier islands through direct mortality and by altering vegetative communities.

It is important to understand how the vegetation of barrier islands recovers after major hurricanes because the vegetation provides the structure that maintains and builds these islands. Following the landfall of Hurricane Katrina in August of 2005, I studied the changes in the herbaceous ground cover and the density of woody plants in Gulf Islands National Seashore in Mississippi from the winter of 2005 to the summer of 2007. Growth from existing plants and seed banks quickly revegetated the islands after the storm. The amount of live ground cover increased and bare ground decreased on each island and in every vegetation type. Most woody plant species also showed a net increase in density, with the exception of pine (*Pinus elliottii*) and Florida rosemary (*Ceratiola ericoides*). The regeneration of woody species and the uniform increase in

the live ground cover seemed to indicate that the vegetation of the islands was not irreversibly impacted.

I also studied the changes in the composition of mammal populations in Gulf Islands National Seashore from the winter of 2005 to the summer of 2007. Prior to the storm 11 terrestrial mammal species were recorded in studies of the barrier islands. In the 2 years following Hurricane Katrina, I recorded only 1 of the 7 species on Cat Island, 5 of the 9 species on Horn Island and 2 species each on East Ship, West Ship, and Petit Bois Islands (which previously had 4, 4, and 2 each). Populations of mammals that used multiple vegetation types (raccoons [*Procyon lotor*], nutria [*Myocastor coypus*], and eastern cottontail [*Sylvilagus floridanus*]) seemed to show more tolerance to hurricane disturbance than more specialized species (black rat [*Rattus rattus*], marsh rice rat [*Oryzomys palustris*]). I also recorded at least one colonization event by river otter (*Lutra canadensis*), a species not recently recorded on the islands. This research serves as a baseline for future comparison following similar storms.

DEDICATION

I would like to dedicate this to my grandmother, for always believing me capable of the impossible and encouraging me every step of the way. And to my father, my first and best teacher in all things outdoors.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Roel Lopez, for his guidance and encouragement as I began my research. I would also like to give a special thanks to Dr. Bob McCleery for his careful criticism and for giving me the motivation that helped me through the hardest times in my research. This document has improved dramatically thanks to Dr. McCleery's input. Thanks also to Dr. Fred Smeins for his insightful input.

This research could not have happened without the support of several people during my field work. I would like to thank Gary Hopkins of the National Park Service, my mentor and first 'boss', for his support. I must also thank Logan Gallant, James Page, Stephen Ross, Liza Soliz, Iain Crichton, and Dominic Watts, you all worked as hard as anyone could have asked. You not only gave me the help I needed, but also made the hard work enjoyable. Thanks also to the biting insects of Gulf Islands National Seashore, who taught me just how much irritation and pain I could endure.

Thanks to the faculty and staff of the Department of Wildlife and Fisheries Sciences and Texas A&M University for making my time at Texas A&M University such a rewarding experience. I also want to extend my gratitude to the National Park Service, which provided funding for this project.

Finally, thanks to my mother and father for their encouragement and support in my academic career and in life, I love you both. My thanks also go to my husband, Will, for lending me his strength and giving me his love. Thank you for everything, you make it all worthwhile.

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CHAPTER I

INTRODUCTION

BACKGROUND

Hurricanes are major natural disturbances that affect barrier islands and coastal areas in the United States (Boose et al. 1994). In the last 2 centuries, several major hurricanes impacted the islands of Gulf Islands National Seashore (GUIS; see Stoneburner 1978). These barrier islands are important economically and ecologically. They serve as recreational areas for visitors, habitat for migrating birds, and offer protection for back bay waters and marshes (Cofer-Shabica 1984, Moore et al. 1990). At the landscape level, hurricanes have the potential to reshape shorelines, cause extensive damage to vegetation in forested areas, and change hydrological properties (Boose et al. 1994, Loope et al 1994, Provencher et al. 2001). It is critical to understand how the vegetation of these barrier islands recovers after major hurricanes because the vegetation provides the structure that maintains and builds these islands (Leatherman 1982, Cousens 1988). Without this vegetation, the islands will retain less sand, and diminish in size (Shabica et al. 1984, Rucker and Snowden 1989). The barrier islands of GUIS also provide an important buffer that limits salt water mixing and lowers the wave intensity in the Mississippi Sound (Cofer-Shabica 1989, Knowles 1989). This protects marshes on the mainland that provide habitat for many economically important species that are part of Mississippi's sport and commercial fisheries (Leatherman 1982).

This thesis follows the style of Journal of Wildlife Management.

Not only does barrier island vegetation stabilize the islands under current conditions, good vegetation cover is required if the islands are to cope with the predicted climate and sea level changes in the coming decades. According to a recent study by Webster et al. (2005), the number and intensity of hurricanes are increasing world wide. Global climate change has also caused an increase in sea level that will lead to even greater barrier island deterioration and the possible loss of pine forests on the island (Titus 1990, Ross et al. 1994). Without stable barrier islands, the Mississippi Sound will be exposed to greater wave action which can have detrimental impacts on the marsh habitats along the mainland (Stone and McBride 1998).

Additionally, hurricanes can have serious potential impacts on the fauna of the islands including direct mortality and/or a reduction in species productivity of the mammalian communities (Loope et al. 1994, Swilling et al. 1998, Labisky et al. 1999, Lopez et al. 2003). At GUIS I studied the post-hurricane recovery of 9 species of mammals with varied diets and habitat requirements. Most of these mammals had widespread distributions and this research is relevant to hurricane impacts across their coastal range.

The amount of recent and historical data from GUIS was another reason for studying the post-hurricane recovery of mammals and vegetation on these islands. Multiple vegetation and mammal studies exist for these islands (Lloyd and Tracey 1901, Penfound and O'Neill 1934, Pessin and Burleigh 1941, Richmond 1962, Miller and Jones 1967, Richmond 1968, Eleuterius1979, Wolfe 1985a, Esher et al. 1988). In 2005, the National Park Service (NPS) at GUIS and Texas A&M University biologists initiated a research project to (1) survey the impacts of non-native deer introduced on Cat Island and (2) conduct a general survey of all mammals both non-native and native on parklands. The biologists completed the surveys of the mammal populations and vegetation impacts in June 2005. In August 2005, Hurricane Katrina made landfall near New Orleans, Louisiana, impacting the coastal barrier islands of the Gulf Islands National Seashore. The prior sampling of mammalian and vegetative communities on Cat Island and historic data for the remaining islands offered a unique opportunity to evaluate the impact of Hurricane Katrina on these barrier islands. I measured changes in 5 separate vegetation types on the islands and on 5 islands that vary by size and community composition. This should provide insight into the relationship between island size and vegetation cover on a broader scale. An understanding of hurricane impacts on natural resources will aid managers in developing long-term strategies to recover or maintain resources within barrier island systems.

STUDY AREA

Gulf Islands National Seashore (GUIS) in southern Mississippi is composed of 5 barrier islands and a mainland site, where the visitor's center and other facilities are located (Fig. 1.1). These 5 islands that enclose the Mississippi Sound lie 16–23 km south of the Mississippi coast are part of a chain of islands that extends 113 km from Dauphin Island, Alabama in the east to Cat Island in the west (Rucker and Snowden 1989). Island geology was similar between islands, comprised of fine to medium grain white sand on a dark clay base (Penfound and O'Neill 1934, Otvos 1970). Topography and vegetative communities, however, varied between islands (Miller and Jones 1967, Eleuterius 1979). Flora and fauna on barrier island habitats are extremely dynamic, due to the violent and disruptive disturbances that accompany large storm systems as well as the constant wind and wave action.

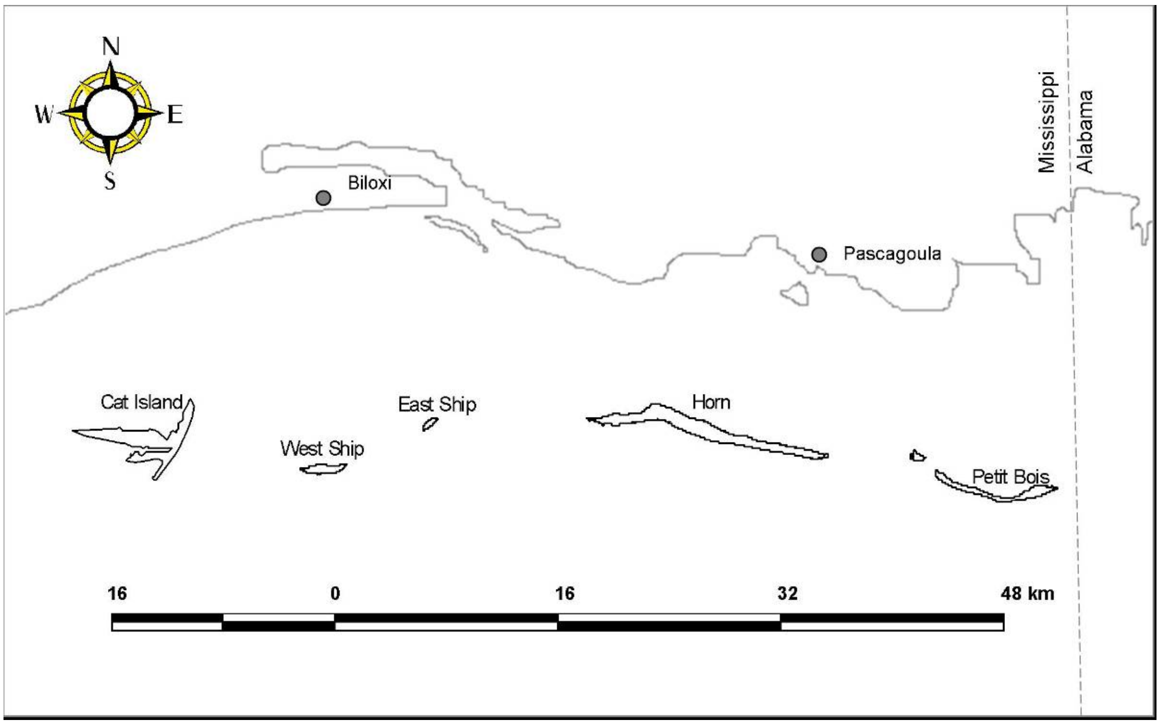


Figure 1.1. The islands of Gulf Islands National Seashore, mapped following Hurricane Katrina in September 2005.

OBJECTIVES

I studied vegetation on the islands to document and describe the changes in vegetation that are most likely to affect island stability and growth. I accomplished this by (1) measuring change in woody vegetation to describe vegetation loss and new growth, and by (2) measuring percent ground cover as an indicator of herbaceous plant biomass (Eleuterius 1979, Cousens 1988). This will provide a baseline of vegetation data that can be referred to after future storms.

I studied mammals to (1) inventory all the species present on the islands and (2) evaluate habitat use of each species. This also allowed me to record changes in community composition on each island and rates of colonization or extinction following the storm.

The thesis outlined above follows in 2 independent, stand-alone chapters. Though the specific objectives of each chapter differ, the overall objective of this thesis is the same, to increase understanding of the recovery of barrier island flora and fauna following strong hurricanes. Therefore, some information is necessarily repeated in each chapter (i.e., problem description, study area description).

CHAPTER II

EFFECTS OF HURRICANE KATRINA ON BARRIER ISLAND VEGETATION

SYNOPSIS

The barrier islands of the gulf coast of the U.S. have been shaped and changed by hurricanes for centuries. Hurricanes can alter the vegetation of the barrier islands by redistributing sediments, scouring off vegetation, damaging plants, and by stressing them with salt. It is important to understand how the vegetation of barrier islands recovers after major hurricanes because the vegetation provides structure that maintains and builds these islands. Following the landfall of Hurricane Katrina in August of 2005, I studied the changes in the herbaceous ground cover and the density of woody plants on Gulf Islands National Seashore in Mississippi from the winter of 2005 to the summer of 2007. Growth from existing plants and from seed banks quickly revegetated the islands after the storm. The amount of live ground cover increased and bare ground decreased on each island and in every vegetation type. Most woody plant species also showed a net increase in density, with the exception of pine and Florida rosemary. The regeneration of woody species and the uniform increase in the live ground cover seems to indicate vegetation on the islands was not irreversibly impacted. This research serves as a baseline for future comparison following similar storms.

INTRODUCTION

High winds and storm surges that accompany large tropical disturbances can have devastating effects on barrier islands. Hurricane force winds can cause extensive blow down of trees and damage standing trees (Stoneburner 1978, Loope et al. 1994). Additionally, they can level dunes, redistribute sediment, scour off above ground vegetation (Snyder and Boss 2002) and kill vegetation by submersion and the associated salt deposits (Eleuterius 1979). In August 2005, Hurricane Katrina passed within 30 km of the westernmost barrier island of Gulf Islands National Seashore (GUIS) with hurricane force winds (over 119 km/hr) extending over 166 km from the eye (Knabb et al. 2005). In the vicinity of the islands the National Weather Service recorded winds over 160 km/h and a 8.5 m storm surge that completely inundated the islands (Knabb et al. 2005).

GUIS in southern Mississippi consists of 5 barrier islands and a mainland site, where the visitor's center and other facilities are located (Fig. 1.1). These 5 islands that enclose the Mississippi Sound lie 16–23 km south of the Mississippi coast and are part of a chain of islands that extends 113 km from Dauphin Island, Alabama in the east to Cat Island in the west (Rucker and Snowden 1989). The barrier islands of GUIS provide an important buffer that limits salt water mixing and lowers the wave intensity in the Mississippi Sound (Cofer-Shabica 1989, Knowles 1989). Without stable barrier islands the Mississippi Sound would be exposed to greater wave action which can have detrimental effects on the marsh habitats along the mainland (Stone and McBride 1998).

It is important to understand how the vegetation of barrier islands recovers after major hurricanes because vegetation provides structure that maintains and builds these islands (Leatherman 1982, Cousens 1988). Without vegetation, barrier islands will retain less sand and shrink (Shabica et al. 1984, Rucker and Snowden 1989). Healthy vegetation will stabilize the barrier islands and may help mitigate the effects of sea level rises and increases in hurricane frequency and intensity (Titus 1990, Ross et al. 1994, Webster et al. 2005, Hoyos et al. 2006).

In 2005, the National Park Service (NPS) at GUIS and Texas A&M University biologists initiated a research project to survey the impacts of non-native deer introduced on Cat Island on vegetation (NPS Task Agreement J5040 04 0007). The biologists completed the surveys of vegetation impacts in June 2005 and in August 2005, Hurricane Katrina made landfall. The prior sampling of vegetative communities on Cat Island offered a unique opportunity to evaluate the impact of the hurricane on the coastal barrier islands.

This research was intended to document the recovery of all the different islands and vegetation types as a baseline for future comparison. It was also initiated to identify specific areas and vegetation types that are not recovering. Areas not revegetating may be target for management, so island structure is not compromised by future storms. My main objective for studying the vegetation on the islands was to document and describe the changes in vegetation that are most likely to affect island stability and growth and provides a baseline of vegetation response to hurricanes.

STUDY AREA

GUIS in southern Mississippi consists of 5 barrier islands and a mainland site, where the visitor's center and other facilities are located (Fig. 1.1). I conducted this study on Cat, West Ship, East Ship, Horn, and Petit Bois islands. These 5 islands that enclose the Mississippi Sound lie 16–23 km south of the Mississippi coast are part of a chain of islands that extends 113 km from Dauphin Island, Alabama in the east to Cat Island in the west (Rucker and Snowden 1989). The geology of the islands was similar, comprised of fine to medium grain white sand on a dark clay base (Penfound and O'Neill 1934, Otvos 1970). Topography and vegetative communities, however, varied between islands (Miller and Jones 1967, Eleuterius 1979). Flora and fauna communities on these barrier islands have been dynamic, due to disturbances caused by large storm systems as well as the constant wind and wave action.

The 5 islands had the following vegetative communities: dune, relic dune, scrub, marsh (including wet meadows), and upland forest (Penfound and O'Neill 1934, Eleuterius 1979; all plant names follow Small 1933). Dune communities were found near the shore on open sand and were comprised of sparse vegetation such as sea oats (*Uniola paniculata*), gulf bluestem (*Schizachyrium maritimum*), panic grasses (*Panicum* spp.), morning glory (*Ipomoea* spp.), and sea rocket (*Cakile edentula*). Relic dune communities located on the interior side of dunes were comprised of woody goldenrod (*Solidago pauciflosculosa*), coastal-sand frostweed (*Helianthemum arenicola*), panic grasses (*Panicum* spp.), greenbrier (*Smilax* spp.), cacti (*Opuntia* spp.), and Florida rosemary, which grows only in the relic dune areas (Richmond 1962). Upland forest communities, restricted to higher elevations, were dominated by slash pine with an understory of yaupon (*Ilex vomitoria*) and palmettos (*Sabal minor* and *Serenoa repens*) interspersed with occasional sand live oaks (*Quercus geminata*; Richmond 1962). Scrub communities on the edge of dune and marsh vegetation were dominated by wax myrtle (*Myrica cerifera*) and groundsel (*Baccharis halimifolia*). Wetlands on the islands ranged from salt and brackish tidal marshes to freshwater ponds and meadows (Penfound and O'Neill 1934, Eleuterius 1979). According to Eleuterius (1979), the marshes were the most diverse vegetation type and were primarily composed of salt meadow cordgrass (*Spartina patens*), black needlerush (*Juncus roemerianus*), rush fuirena (*Fuirena scirpoidea*), and other mixed grasses. The distribution of these vegetation types on each island was directly related to the elevation and topography of the island. Most of the woody species of the islands required moderately elevated and protected areas to grow (Penfound and O'Neill 1934, Eleuterius 1979, Ross et al. 1994).

METHODS

Following Hurricane Katrina I surveyed the vegetation on all 5 islands during winter 2005, summer 2006, and summer 2007. To measure the ground cover and woody species densities, I established vegetation plots (10 × 1 m) every 100 m along a main transect running the length of each island (Fig. 2.1; Fig 2.2; Brower and Zar 1982). The plots were placed at random distances and directions from the main transect (distances [up to 100m] and direction [north or south] were determined using a random number chart). I placed 40 vegetation plots on each island, with East and West Ship sharing 40 vegetation plots due to their small size (35.1 and 139.6 ha) and because they

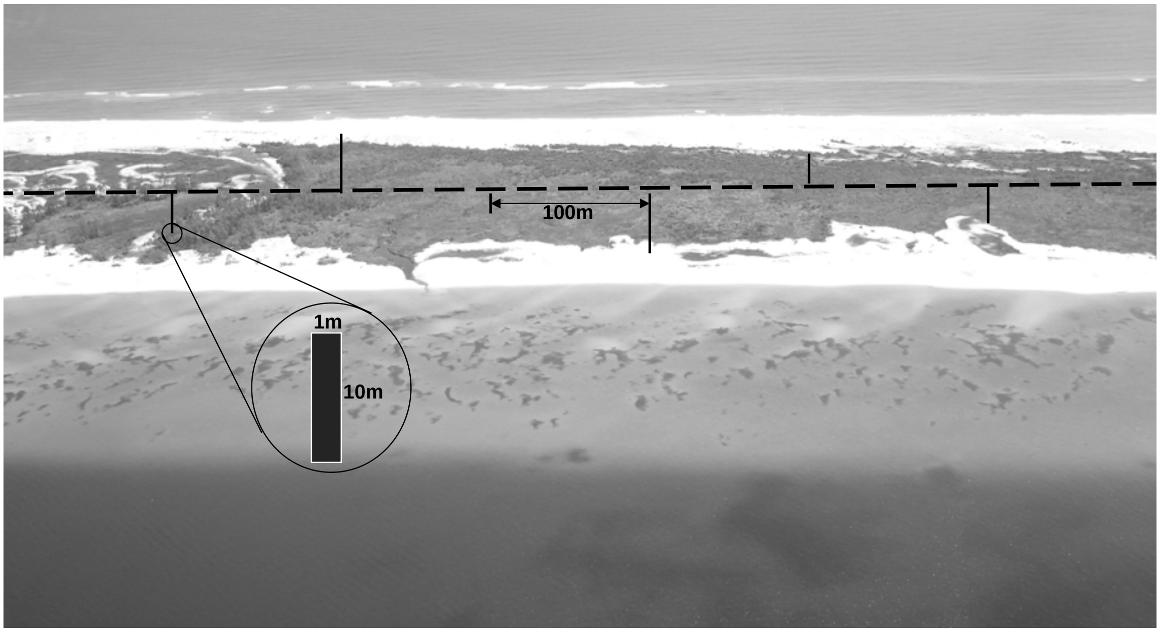


Figure 2.1. Example of vegetation plots distributed every 100 m along a main transect (dashed line). At each vegetation plot I recorded vegetation type, number of woody plants, and percent ground cover. Horn Island, Mississippi, USA, July 2005.

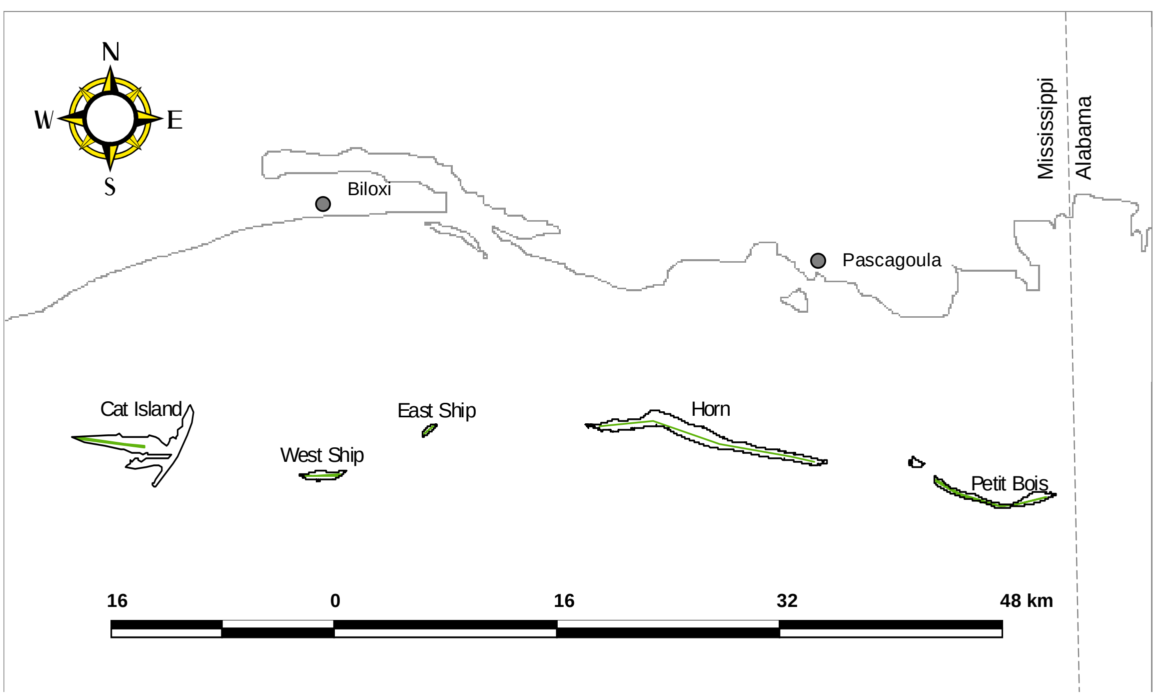


Figure 2.2. The 5 islands of the study area and the transect that I marked vegetation plots from marked in green. Gulf Islands National Seashore, Mississippi, USA, September 2005.

were recently 1 island (Knowles 1989). I recorded the location of each vegetation plot in UTM using a handheld GPS unit (GPS 12 Personal Navigator®, Garmin, Salem, OR; UTM coordinates are listed in Appendix A) I marked each plot with a 2.5cm × 5.0cm × 45.0cm wooden stake marked with the plot number in order to locate the plots again in summer 2006 and 2007 for later measurements. This survey design facilitated comparison with vegetation data collected on Cat Island in June 2005 when the Texas A&M University biologists collected browse data on 4 species (live oak, slash pine, yaupon, and smilax sp.) on 15 × 1 m transects at random points.

I measured ground cover as an index for biomass in order to evaluate the amount of cover on each island and in the different vegetation types. Eleuterius (1979) found that the percent ground cover of the vegetation on these islands was an excellent indicator of biomass. I measured percent ground cover using a 0.25 m^2 quadrat at 0m, 5m, and 10m along the length of the vegetation plots. I used ocular estimation (to the nearest 5%) to quantify the percentage of bare ground, live vegetation, and organic litter in the quadrat and recorded the vegetation type for each vegetation plot (Booth et al. 2006). I averaged the 3 measurements from each plot for statistical analysis.

To determine changes in plant communities and community structure, I counted the most common woody species in the overstory (slash pine, sand live oak, yaupon) and understory (slash pine, sand live oak, yaupon, smilax sp., palmetto, wax myrtle, and Florida rosemary) in the 10 × 1 m plots and calculated average densities/hectare for each species by vegetation type and island. I defined overstory as any plant >1.5m in height and anything ≤ 1.5m as understory. Examining the understory and overstory allowed me to determine if the hurricane affected mature or young trees differently and to measure increases in density of new growth. Some species on the island reproduce vegetatively through suckers and runners, so all new growth in the understory will be counted as an increase stem density, which includes seedlings and individual stems of clonal plants.

I compared mean density of overstory and understory woody plants and ground cover from winter 2005 and summer 2006 to summer 2007 graphically with 95% CI (Cherry 1998). I also used a non-parametric Freidman's test to examine changes in ground cover by island and by vegetation type over the same time period.

RESULTS

Ground Cover

On all the islands, the overall percentage of bare ground decreased (13%), the amount of litter decreased (8%), and the percentage of live cover increased (21%) from winter 2005 to summer 2007. This pattern was consistent across each island (Fig. 2.3, Table 2.1) and vegetation type (Fig. 2.4, Table 2.2), except Cat Island where litter increased slightly (Cat Island, net change in bare ground = -16, litter cover = 4, and live cover = 12; Fig. 2.3). Using the Friedman's test, I found significant differences (P<0.05) comparing the percentages of bare ground, litter, and live cover between seasons on each island and in each vegetation type with 7 exceptions out of 33 comparisons: bare ground on East Ship (P=0.622), litter on Petit Bois (P=0.057), bare ground in relic dune (P=0.720) or scrub (P=0.122) vegetation, and litter in relic dune (P=0.056), scrub (P=0.233), or upland (P=0.663) vegetation (Tables 2.1, 2.2; Gibbons 1985:326–327).

Table 2.1. Chi-square (χ^2) and *P*-values from Friedman's tests of ground cover from winter 2005 to summer 2007 for all islands combined and by island, Gulf Islands National Seashore, Mississippi, USA.

		n	df	χ^2	*P*
Combined					
	Bare	160	2	60.75	0.000
	Litter	160	2	21.75	0.000
	Live	160	2	144.51	0.000
Island					
Cat					
	Bare	40	2	30.23	0.000
	Litter	40	2	7.07	0.029
	Live	40	2	43.52	0.000
West Ship					
	Bare	28	2	18.58	0.000
	Litter	28	2	14.08	0.001
	Live	28	2	20.22	0.000
East Ship					
	Bare	12	2	0.95	0.622
	Litter	12	2	15.20	0.001
	Live	12	2	13.56	0.001
Horn					
	Bare	40	2	10.41	0.005
	Litter	40	2	15.99	0.000
	Live	40	2	41.29	0.000
Petit Bois					
	Bare	40	2	20.60	0.000
	Litter	40	2	5.72	0.057
	Live	40	2	33.95	0.000

Table 2.2. Chi-square (χ^2) and *P*-values from Friedman's tests of ground cover from winter 2005 to summer 2007 for all islands combined and by vegetation type, Gulf Islands National Seashore, Mississippi, USA.

	n	**df**	χ^2	***P***
Combined				
Bare	160	2	60.75	0.000
Litter	160	2	21.75	0.000
Live	160	2	144.51	0.000
Vegetation				
Dune				
Bare	40	2	7.92	0.019
Litter	40	2	9.59	0.008
Live	40	2	27.87	0.000
Florida Scrub				
Bare	18	2	0.66	0.720
Litter	18	2	5.77	0.056
Live	18	2	18.12	0.000
Marsh				
Bare	42	2	17.71	0.000
Litter	42	2	27.56	0.000
Live	42	2	38.40	0.000
Scrub				
Bare	9	2	4.21	0.122
Litter	9	2	3.00	0.223
Live	9	2	14.86	0.001
Uplands				
Bare	51	2	44.10	0.000
Litter	51	2	0.82	0.663
Live	51	2	50.44	0.000

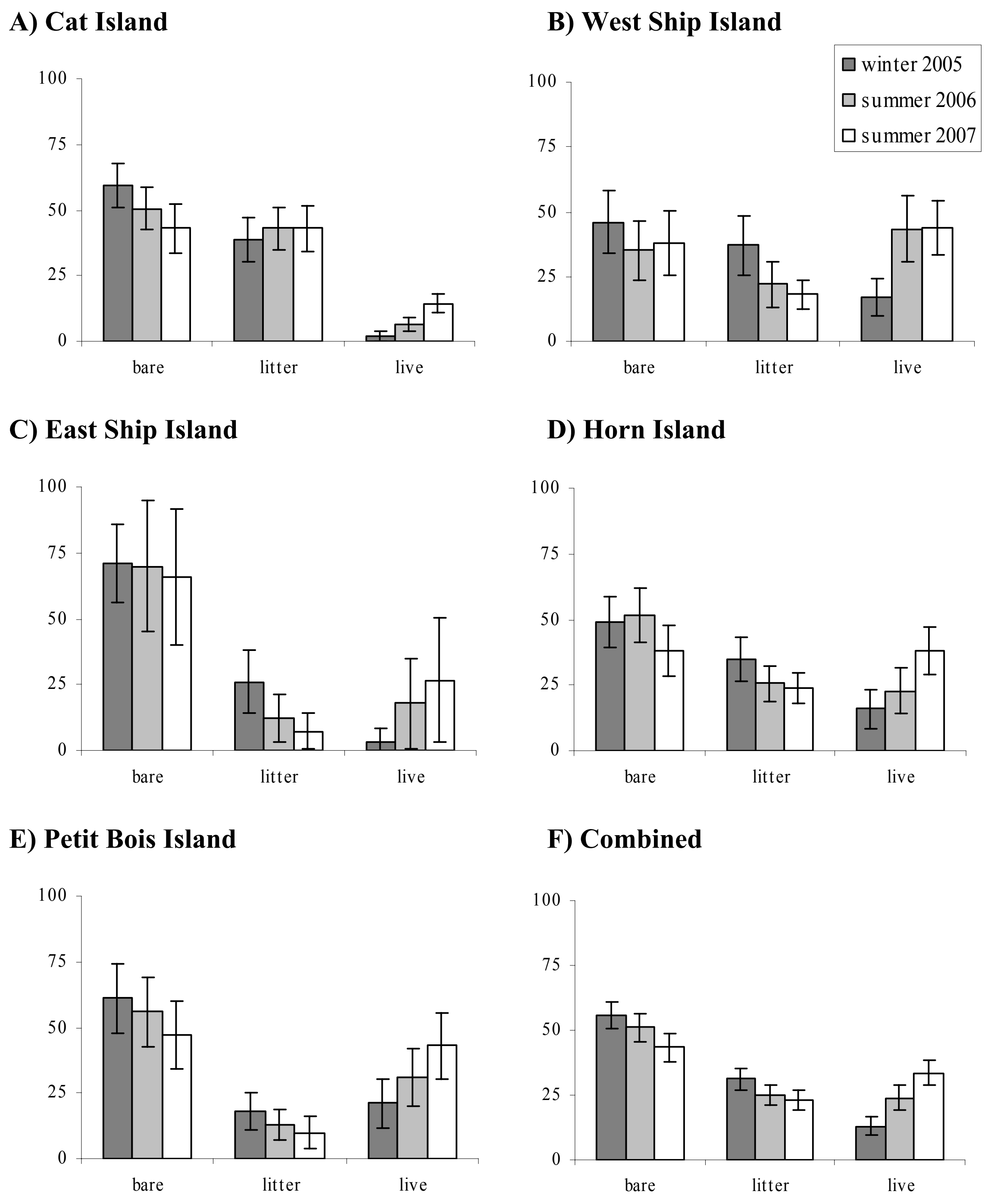


Figure 2.3. Bare ground, litter, and live ground cover (%) with 95% CIs recorded on Cat Island, West Ship, East Ship, Horn Island, Petit Bois, and all islands combined from winter 2005 to summer 2007. Gulf Islands National Seashore, Mississippi, USA.

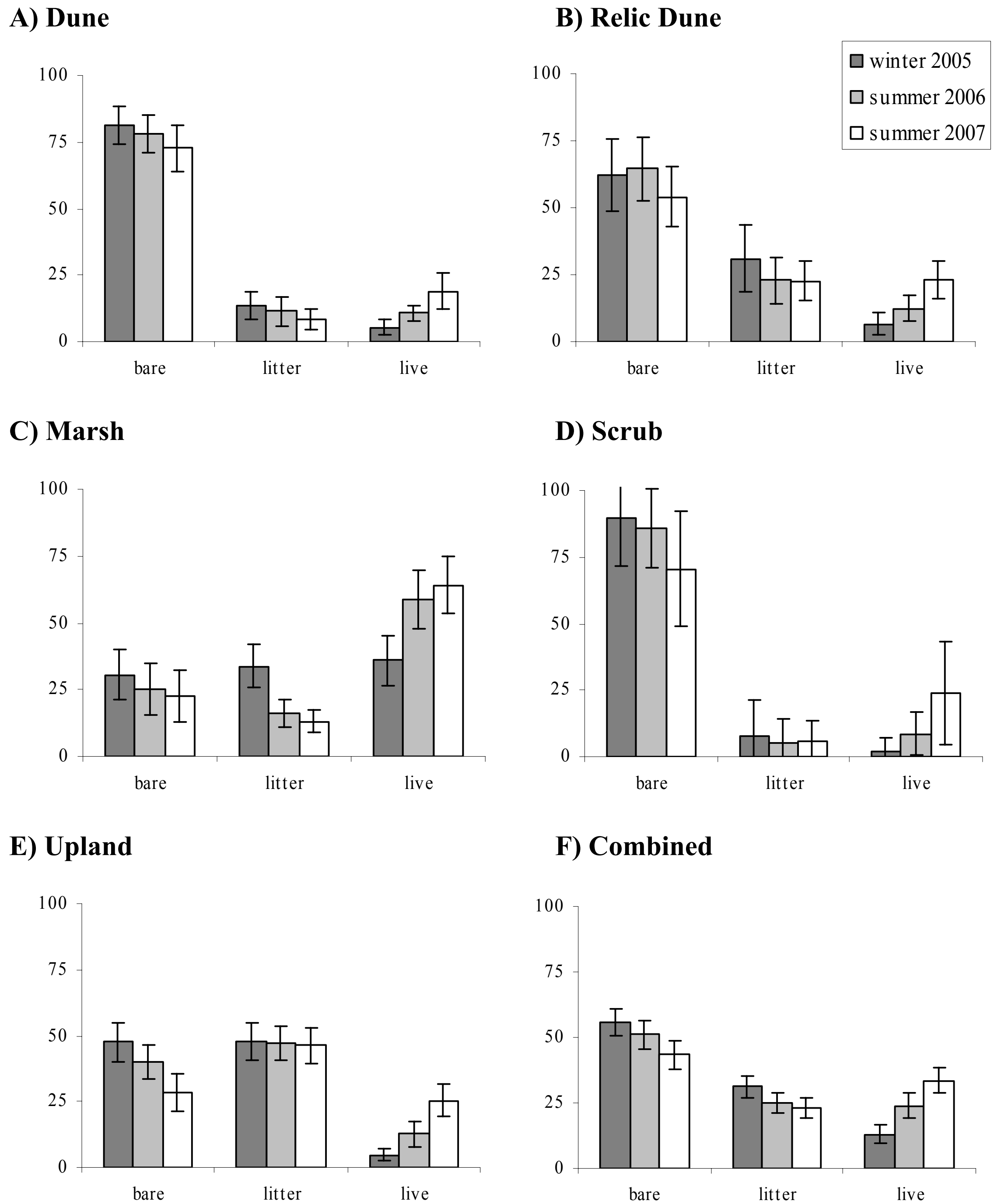


Figure 2.4. Bare ground, litter, and live ground cover (%) with 95% CIs recorded in dune, relict dune, marsh, scrub, and upland vegetation, and all vegetation types combined from winter 2005 to summer 2007. Gulf Islands National Seashore, Mississippi, USA.

Woody Species Density

Plant densities in the understory and overstory of each species showed a net increase in density (plants/ha) from winter 2005 to summer 2007 except for overstory pine (decreased 1313/ha) and Florida rosemary (decreased 375/ha; Tables 2.3, 2.4, Fig 2.5b). The greatest increases occurred in oaks (53750/ha), smilax (8063/ha), and palmetto (3250/ha; Fig. 2.5b). Florida rosemary was only present on Horn Island (densities of 1300, 1300, and 300/ha) and Petit Bois Island (500, 500, and 0/ha).

Table 2.3. Overstory and understory pine and oak densities in the vegetation plots (mean/ha × 1000) from winter 2005 to summer 2007 on Cat, West Ship, East Ship, Horn, and Petit Bois Islands. Gulf Islands National Seashore, Mississippi, USA.

		overstory				understory			
	Season	**$\bar{x}$ pine**	**± se**	**$\bar{x}$ oak**	**± se**	**$\bar{x}$ pine**	**± se**	**$\bar{x}$ oak**	**± se**
Cat	Before	1.49	0.19	1.12	0.16	0.20	0.05	0.77	0.18
	6 months	1.25	0.20	0.53	0.19	0.00	0.00	0.18	0.07
	12 months	0.83	0.20	0.53	0.16	0.38	0.28	17.08	8.96
	24 months	0.85	0.20	0.58	0.18	0.45	0.29	21.65	10.43
West Ship	6 months	--	--	--	--	--	--	--	--
	12 months	--	--	--	--	--	--	--	--
	24 months	--	--	--	--	--	--	--	--
East Ship	6 months	--	--	--	--	--	--	0.00	0.00
	12 months	--	--	--	--	--	--	0.00	0.00
	24 months	--	--	--	--	--	--	0.08	0.08
Horn	6 months	0.35	0.10	--	--	--	--	0.00	0.00
	12 months	0.30	0.10	--	--	--	--	0.03	0.03
	24 months	0.33	0.10	--	--	--	--	0.00	0.00
Petit Bois	6 months	0.13	0.08	--	--	0.00	0.00	--	--
	12 months	0.13	0.08	--	--	0.00	0.00	--	--
	24 months	0.03	0.03	--	--	0.03	0.03	--	--

Table 2.4. Yaupon overstory (y[o]), yaupon understory (y[u]), palmetto (p), smilax (s), and wax myrtle (w) densities in the vegetation plots (mean/ha × 1000) from winter 2005 to summer 2007 on Cat, West Ship, East Ship, Horn, and Petit Bois Islands. Gulf Islands National Seashore, Mississippi, USA.

	season	**$\bar{x}$ y[o]**	**± se**	**$\bar{x}$ y[u]**	**± se**	**$\bar{x}$ p**	**± se**	**$\bar{x}$ s**	**± se**	**$\bar{x}$ w**	**± se**
Cat	before	0.87	0.12	2.00	0.28	--	--	0.62	0.14	--	--
	6 mo.	0.15	0.08	0.38	0.12	2.43	0.64	0.33	0.19	0.03	0.03
	12 mo.	0.50	0.27	0.25	0.11	3.55	0.94	1.40	0.66	0.03	0.03
	24 mo.	0.58	0.27	0.33	0.11	3.55	0.93	1.40	0.67	0.10	0.08
West	6 mo.	--	--	--	--	0.04	0.04	--	--	0.12	0.06
Ship	12 mo.	--	--	--	--	0.04	0.04	--	--	0.07	0.05
	24 mo.	--	--	--	--	0.07	0.04	--	--	0.46	0.34
East	6 mo.	--	--	0.00	0.00	0.67	0.33	0.67	0.51	--	--
Ship	12 mo.	--	--	0.00	0.00	0.67	0.33	0.83	0.46	--	--
	24 mo.	--	--	0.25	0.25	0.58	0.34	2.00	1.30	--	--
Horn	6 mo.	0.20	0.12	0.78	0.25	0.10	0.08	0.95	0.40	0.33	0.21
	12 mo.	0.18	0.09	0.80	0.24	0.18	0.13	1.85	0.76	0.25	0.20
	24 mo.	0.16	0.04	0.90	0.27	0.30	0.19	1.95	0.76	0.48	0.23
Petit	6 mo.	0.05	0.03	0.53	0.33	--	--	0.48	0.16	0.05	0.03
Bois	12 mo.	0.03	0.03	0.43	0.19	--	--	0.78	0.25	0.13	0.10
	24 mo.	0.03	0.03	0.55	0.31	--	--	1.23	0.45	0.15	0.10

The change in woody species densities followed a pattern of increase in the understory and decrease or no change in the overstory (Fig. 2.5) in each vegetation type, with a few exceptions. Overstory pine decreased in each vegetation type (dune 30/ha, marsh 70/ha, upland 340/ha) except relic dune, where it remained stable (Table 2.5). Most new pine growth occurred in upland vegetation (pine increased from 0 to 350/ha), though some also occurred in relic dune vegetation (from 0 to 60/ha). All overstory and most understory oaks were recorded in the upland vegetation type. Oak regeneration was recorded in relic dune vegetation on Horn Island in summer 2006 (60/ha), but no oaks were present in summer 2007 (Table 2.5). Yaupon occurred in each vegetation type and showed a net increase in dune (50/ha), scrub (110/ha), and upland (410/ha) vegetation, but decreased in the marshes (30/ha) and relic dunes (330/ha). I recorded palmetto in each vegetation type except scrub vegetation and the palmetto density increased in the dunes (20/ha), relic dunes (330/ha), and uplands (880/ha), and remained stable in the marsh. Smilax occurred and increased in each vegetation type (Table 2.6). Wax myrtle occurred in each vegetation type and increased in every vegetation type except scrub (decreased 110/ha), with the highest increase in the marshes (3600/ha). Florida rosemary only occurred in the relic dunes and remained stable at 3900/ha from winter 2005 to summer 2006, but decreased to 600/ha by summer 2007.

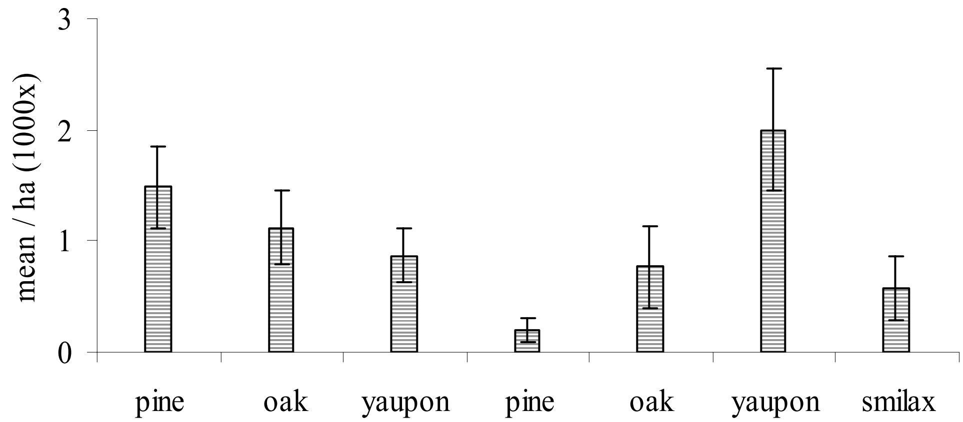
Table 2.5. Overstory densities of pine and oak in the vegetation plots (mean/ha × 1000) from winter 2005 to summer 2007 in dune, relic dune, marsh, and upland vegetation types. Gulf Islands National Seashore, Mississippi, USA.

		overstory				**understory**			
	season	**$\bar{x}$ pine**	**± se**	**$\bar{x}$ oak**	**± se**	**$\bar{x}$ pine**	**± se**	**$\bar{x}$ oak**	**± se**
Dune	6 mo.	0.03	0.03	--	--	--	--	--	--
	12 mo.	0.00	0.00	--	--	--	--	--	--
	24 mo.	0.00	0.00	--	--	--	--	--	--
Relic	6 mo.	0.17	0.09	--	--	0.00	0.00	0.00	0.00
Dune	12 mo.	0.17	0.09	--	--	0.00	0.00	0.06	0.06
	24 mo.	0.17	0.09	--	--	0.06	0.06	0.00	0.00
Marsh	6 mo.	0.12	0.06	--	--	--	--	--	--
	12 mo.	0.02	0.02	--	--	--	--	--	--
	24 mo.	0.05	0.03	--	--	--	--	--	--
Upland	6 mo.	1.18	0.17	0.41	0.15	0.00	0.00	0.14	0.06
	12 mo.	0.90	0.17	0.41	0.13	0.29	0.22	13.39	7.08
	24 mo.	0.84	0.17	0.45	0.14	0.35	0.23	17.00	8.25

Table 2.6. Yaupon overstory (y[o]), yaupon understory (y[u]), palmetto (p), smilax (s), and wax myrtle (w) densities in the vegetation plots (mean/ha × 1000) from winter 2005 to summer 2007 in each vegetation type. Gulf Islands National Seashore, Mississippi, USA.

	season	**$\bar{x}$ y [o]**	**± se**	**$\bar{x}$ y [u]**	**± se**	**$\bar{x}$ p**	**± se**	**$\bar{x}$ s**	**± se**	**$\bar{x}$ w**	**± se**
Dune	6 mo.	--	--	0.03	0.03	0.18	0.11	0.03	0.03	0.28	0.20
	12 mo.	--	--	0.08	0.08	0.20	0.14	0.08	0.04	0.25	0.20
	24 mo.	--	--	0.08	0.08	0.20	0.14	0.18	0.15	0.43	0.30
Relic	6 mo.	0.11	0.11	1.44	0.72	0.00	0.00	1.17	0.61	0.00	0.00
Dune	12 mo.	0.00	0.00	1.17	0.41	0.00	0.00	2.39	1.33	0.00	0.00
	24 mo.	0.00	0.00	1.22	0.54	0.33	0.33	3.00	1.58	0.11	0.08
Marsh	6 mo.	0.00	0.00	0.05	0.03	0.02	0.02	0.17	0.10	0.07	0.05
	12 mo.	0.02	0.02	0.00	0.00	0.02	0.02	0.24	0.12	0.12	0.10
	24 mo.	0.02	0.02	0.00	0.00	0.02	0.02	0.36	0.17	0.43	0.18
Scrub	6 mo.	--	--	0.00	0.00	--	--	0.33	0.33	0.11	0.11
	12 mo.	--	--	0.11	0.11	--	--	0.44	0.44	0.00	0.00
	24 mo.	--	--	0.11	0.11	--	--	0.44	0.44	0.00	0.00
Upland	6 mo.	0.27	0.11	0.75	0.20	2.00	0.51	0.90	0.30	0.08	0.04
	12 mo.	0.53	0.22	0.67	0.19	2.92	0.76	2.18	0.63	0.06	0.03
	24 mo.	0.49	0.21	0.94	0.26	2.88	0.75	2.49	0.67	0.10	0.04

A) Cat Island, Pre-Katrina



B) All Islands, Post-Katrina

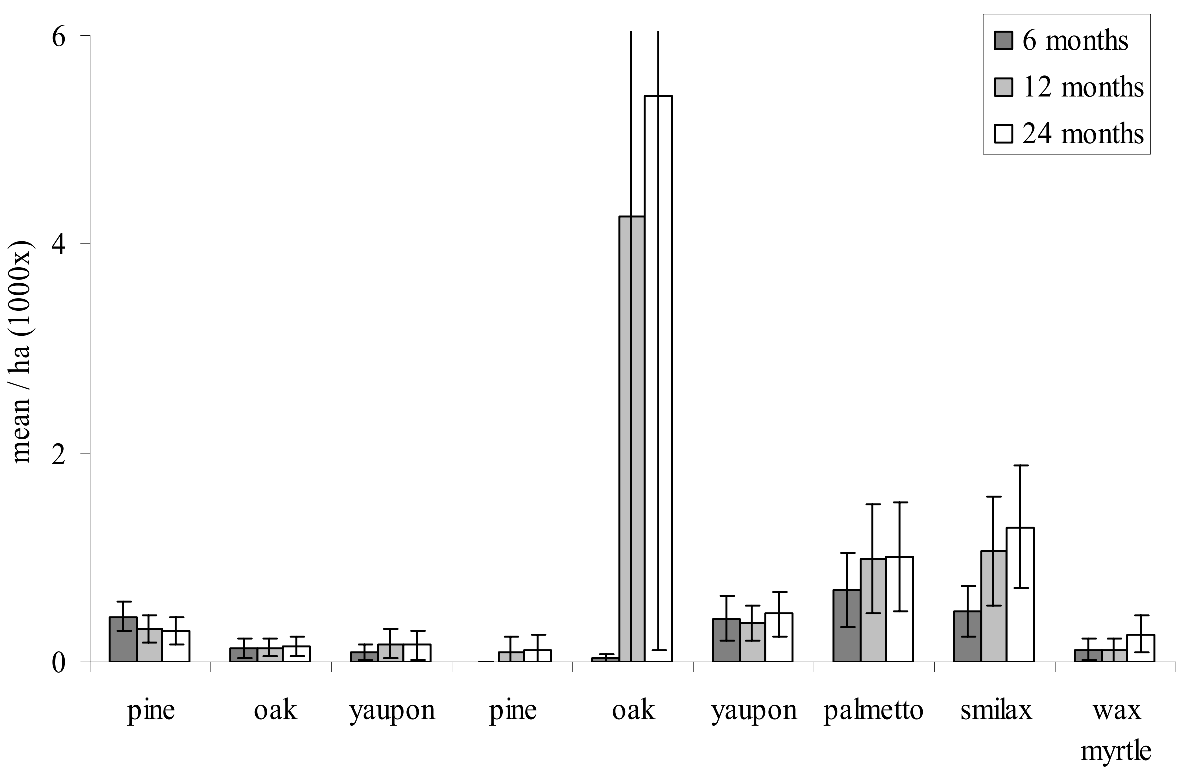


Figure 2.5. Mean woody plant densities (pine, oak, and yaupon overstory values listed first, followed by understory values) from June 2005 on Cat Island (A) and for all islands from winter 2005 to summer 2007 (B). Gulf Islands National Seashore, Mississippi, USA.

DISCUSSION

Ground Cover

Live ground cover increased from 2005-2007. All vegetation types showed this increase, but I recorded smaller changes in live ground cover and litter in relic dune and scrub vegetation types. Increase in live ground cover could be considered a response of the low growing vegetation to the reduction in overstory plants, but the pattern also held on West Ship and Petit Bois Islands, which had little or no overstory before the storm. This appears to indicate an increase in the overall plant biomass that I attribute to re-growth in areas that were stripped of vegetation or buried in sand during the storm.

The amount of litter in the forested uplands and on Petit Bois Island did not change significantly, but this is not a sign of slow recovery. If litter remains, it will still aid in capture of sand and dune building (Leatherman 1979), but bare ground and live biomass are better indicators of recovery (Snyder and Boss 2002). These 2 measures increased on every island and in every vegetation type.

However, the fact that the decrease in bare ground on East Ship Island was not significant ($p=0.622$) is troubling, even though live cover did increase. East Ship was particularly hard hit by Hurricane Katrina and reduced from 6.8 km to 1.2 km in length so that only the wooded portion of the island remained (G. Hopkins, National Park Service, unpublished data). The west end of East Ship, which consisted of low lying dune fields and sand bars, was reduced by almost 4 km in length. Though the inlet between East and West Ship (created by Hurricane Camille in 1969) had closed to 1 km wide by the summer of 2005, Hurricane Katrina increased this distance to 6 km (G.

Hopkins, National Park Service, unpublished data). The sand bars had returned and showed some pioneer vegetation by the summer of 2007, but I did not quantify this vegetation.

This study only measured recovery of established vegetation of the islands. The inability of the design to incorporate island areas that appeared after plot establishment was a major drawback of this study. If the National Park Service wishes to continue studying the recovery of vegetation of these islands, I recommend adding plots on the western ends of the islands as they form to measure vegetation establishment on these quickly changing land forms.

The herbaceous cover on the islands seemed to have reached a density that was comparable to the summer of 2005 on all islands except East Ship (personal observation). Some species, like the Florida rosemary, decreased noticeably and some species seemed to increase from their pre-storm densities. One species in particular that showed large increases was the Chinese lantern (*Physalis* sp.). This is an introduced species which spread to new areas of the islands after Hurricane Katrina colonizing the wet meadows and forested areas of the islands.

Woody Species Density

Density of woody vegetation showed some losses in the overstory and increases in the understory as new stems and young plants appeared. A few understory plants also grew into the overstory, but the overstory initially decreased as some of the remaining mature plants succumbed to the stress caused by the hurricane.

Establishment of pine seedlings in the understory only occurred on Cat and Petit Bois Islands. I recorded overstory oaks on Cat Island and oak regeneration on Cat Island was extremely dense (Fig. 2.5). I also recorded oak establishment on East Ship Island in the summer of 2007 and on Horn Island in summer 2006.

I recorded yaupon on every island except West Ship. Yaupon on Cat Island showed high rates of growth with a large number of plants reaching the overstory by the first year post-Katrina. However, densities remained less than 1/3 of pre-storm densities. I recorded yaupon on East Ship Island in summer 2007 and yaupon increased on Horn Island from 2005 to 2007. Smilax occurred on every island except West Ship and increased (often doubling) in density by the summer 2007, even surpassing the pre-storm density on Cat Island. Palmetto showed a slight increase on Cat Island and West Ship Island and a greater increase on Horn Island (Table 2.4). Cat Island had the highest density of palmetto. I recorded wax myrtle on every island except East Ship and found a net increase on each island, particularly on West Ship Island.

Overstory pines on Cat and Horn Islands showed an initial decrease in density followed by a shallow rebound. On Petit Bois the number of pines remained stable from winter 2005 to summer 2006 but decreased by summer 2007. The mean density of pines for all islands combined (overstory and understory) changed very little after the storm (decreased 100/ha), but remained well below densities from before Hurricane Katrina.

This study did not address the percentage of woody species lost on the islands following the hurricane. However, I observed roughly 10-20% mature pine loss on Cat Island, 100% pine loss on West Ship Island, 100% pine loss on East Ship, 40% pine loss on Horn Island, and 70% pine loss on Petit Bois. It is interesting to note that the percentage of pine death was inversely related to the size and density of the pine stands on each island. Also, relatively few pine trees were blown down and the majority of trees that died remained erect with needles still attached to the trees. Touliatos and Roth (1971) described some aspects of tree structure that affect sensitivity to hurricane damage and found that the long leaf pines and sand live oaks of coastal Mississippi were particularly resistant to wind damage from Hurricane Camille. The high rates of loss among the pine trees were probably due to the salt stress caused by the storm surge. Slash pine is only moderately salt and drought-tolerant and since the islands received very little rain following the storm (Edwards and Fuchs 2008), there was probably not enough precipitation to leach the salt from the soil, which killed the trees. I recommend studying pine re-establishment on the islands to see if pines approach pre-storm densities after several years or a declining trend exists due to changes in the island climate and elevation (see Ross et al. 1994 for a similar study).

On Cat Island, the only island with vegetation data from before the storm, all recorded species of trees increased in density from winter 2005 to summer 2007. However, only oak and yaupon reached or surpassed the pre-storm density, primarily due to a huge increase in new stem growth. Cat Island seemed to be least impacted of the islands (based on percentage of pines lost and island area lost), even though it was closest to the eye of Hurricane Katrina. One explanation for this is the buffering action of the dense woody vegetation on the island.

Several factors aside from hurricane intensity and island characteristics affect the recovery of vegetation post-disturbance. One aspect that should be considered is the amount of rainfall available to the islands following the storm. The islands were subjected to drought conditions for the several months following the storm with rainfall averages far below normal into 2007 (Edwards and Fuchs 2008). Rainfall not only facilitates vegetative growth, but also decreases salt-stress in the islands plants as it leaches salts from the soils and creates a freshwater lens on the islands (Eleuterius, 1979). I believe that the vegetation on the islands would have shown greater improvement under average rainfall conditions.

In conclusion, the long term stability of these islands depends on the ability of vegetation to trap and hold sand blown by the wind. Vegetation not only stabilizes the islands but also provides food and cover for wildlife on the islands (Snyder and Boss 2002). Severe storm surges can scour areas of islands free from vegetation and bury vegetation under of sand (Cousens 1988). Growth from existing plants and seed banks appears to have quickly revegetated the islands after the storm.

The regeneration of most woody species and the universal increase in live ground cover seems to indicate that the vegetation of the islands was not irreversibly impacted. Overall, this study should serve as a baseline of vegetation recovery for future comparison after similar storms.

CHAPTER III

EFFECTS OF HURRICANE KATRINA ON BARRIER ISLAND MAMMALS

SYNOPSIS

The barrier islands of the gulf coast of the United States have been shaped and changed by hurricanes for centuries. These storms can alter the faunal communities of the barrier islands through direct mortality and alteration of vegetative communities. I studied the changes in the composition of mammal populations on Gulf Islands National Seashore in Mississippi following Hurricane Katrina from the winter of 2005 to the summer of 2007. Prior to the storm 11 terrestrial mammal species were recorded in studies of the barrier islands: 7 species on Cat Island, 4 on West Ship, 4 on East Ship, 9 on Horn Island, and 2 on Petit Bois. In the 2 years following Hurricane Katrina, I recorded only 1 of the 7 species on Cat Island, 5 of the 9 species on Horn Island and 2 species each on East Ship, West Ship, and Petit Bois Islands. Populations of mammals that used multiple vegetation types (raccoons, nutria, and rabbits) seemed to show more tolerance to hurricane disturbance than more specialized species (marsh rice rats and black rats). We also recorded at least one colonization event by river otter, a species not recently recorded on the islands. This research should serve as a reference for future comparison following similar storms.

INTRODUCTION

The high winds and storm surges that accompany large tropical disturbances can alter the topography of barrier islands. Storm surges can inundate whole islands, level dunes, redistribute sediment, and remove vegetation that mammals depend on (Snyder and Boss 2002). In addition, storms can affect the faunal communities of the islands through direct mortality, reducing species productivity, expatriation of vulnerable species, and by facilitating colonization (Gunter and Eleuterius 1973, Conner et al. 1989, Swilling et al. 1998, Labisky et al. 1999, Lopez et al. 2003).

Gulf Islands National Seashore (GUIS) in southern Mississippi consists of 5 barrier islands and a mainland site, where the visitor's center and other facilities are located (Fig. 1.1). These 5 islands that enclose the Mississippi Sound lie 16–23 km south of the Mississippi coast and are part of a chain of islands that extends 113 km from Dauphin Island, Alabama in the east to Cat Island in the west (Rucker and Snowden 1989). In August 2005, Hurricane Katrina passed within 30 km of the westernmost barrier island of GUIS with winds over 160 km/h and a 8.5 m storm surge that completely inundated the islands (Knabb et al. 2005). Hurricane force winds (over 119 km/hr) occurred over 166 km from the eye (Knabb et al. 2005).

Eleven terrestrial mammal species were recorded in studies of the barrier islands prior to Hurricane Katrina (Horn, Ship, and Petit Bois islands, 1986-87; Esher et al. 1988, Cat Island 2005; Kemper et al., Texas A&M University, unpublished report). In 2005, the National Park Service (NPS) at GUIS and Texas A&M University biologists initiated a research project to (1) survey the impacts of non-native deer introduced on Cat Island and (2) conduct a general survey of all mammals both non-native and native on Cat Island (NPS Task Agreement J5040 04 0007). The biologists completed the surveys of the mammal populations and vegetation impacts in June 2005. In August

2005, Hurricane Katrina made landfall 30 km west of the coastal barrier islands of GUIS. The prior sampling of mammalian and vegetative communities on Cat Island offered a unique opportunity to evaluate the impact of the hurricane on the coastal barrier islands.

I surveyed GUIS after Hurricane Katrina for 9 species of mammals (nutria, river otter, black rats, marsh rice rats, eastern cottontail, raccoons, fox squirrels [*Sciurus niger*], axis deer [*Axis axis*], and white-tailed deer [*Odocoileus virginianus*]). Information on recovery of these populations will facilitate a better understanding of the effects of hurricanes on natural resources and aid managers in developing long-term strategies to recover or maintain resources within coastal barrier island systems. My objectives were to 1) inventory non-native and native mammals on each island, 2) determine the distribution of mammals by major vegetation type on each island, and 3) record any colonization or extinction events on the islands.

STUDY AREA

I conducted this study on 5 islands in GUIS: Cat, West Ship, East Ship, Horn, and Petit Bois islands (Fig. 1.1). Island geology was similar between islands, comprised of fine to medium grain white sand on a dark clay base (Penfound and O'Neill 1934, Otvos 1970). Topography and vegetative communities, however, varied between islands (Miller and Jones 1967, Eleuterius 1979). Flora and fauna communities on the barrier island also varied. The 5 islands in this study had the following vegetative communities: dune, relic dune, scrub, marsh (including wet meadows), and upland forest (Penfound and O'Neill 1934, Eleuterius 1979). Dune communities were found near the shore on open sand and were comprised of sparse vegetation such as sea oats (*Uniola paniculata*), gulf bluestem (*Schizachyrium maritimum*), panic grasses (*Panicum* spp.), morning glory (*Ipomoea* spp.), and sea rocket (*Cakile edentula*). Relic dune communities located on the interior side of dunes were comprised of woody goldenrod (*Solidago pauciflosculosa*), coastal-sand frostweed (*Helianthemum arenicola*), panic grasses (*Panicum* spp.), greenbrier (*Smilax* spp.), cacti (*Opuntia* spp.), and Florida rosemary (*Ceratiola ericoides*), which grows only in the relic dune areas (Richmond 1962). Upland forest communities, restricted to higher elevations, were dominated by slash pine (*Pinus elliottii*) with an understory of yaupon (*Ilex vomitoria*) and palmettos (*Sabal minor* and *Serenoa repens*) interspersed with occasional sand live oaks (*Quercus geminate*; Richmond 1962). Scrub communities on the edge of dune and marsh vegetation were dominated by wax myrtle (*Myrica cerifera*) and groundsel (*Baccharis halimifolia*). Wetlands on the islands ranged from salt and brackish tidal marshes to freshwater ponds and meadows (Penfound and O'Neill 1934, Eleuterius 1979). According to Eleuterius (1979), the marshes were the most diverse vegetation type and were primarily composed of salt meadow cordgrass (*Spartina patens*), black needlerush (*Juncus roemerianus*), rush fuirena (*Fuirena scirpoidea*), and other mixed grasses. The distribution of these vegetation types on each island was directly related to the elevation and topography of the island.

METHODS

As previously stated, biologists from Texas A&M University conducted a study of the mammals of Cat Island in the summer of 2005. The species and number of individuals recorded on the island are listed in Table 1. They also surveyed vegetation using browse surveys (1 × 15 m plots) distributed randomly across the island (Chapter II). I initiated a survey of the mammals and vegetation of all the islands in January 2006. At that time I recorded mammal sign while establishing vegetation survey plots. In the summer of 2006 I conducted more intensive searches for mammal sign and began preliminary trapping. In the summer of 2007 I conducted a thorough study of the mammals of the islands using multiple techniques to determine presence of mammal species.

In the summer of 2006, I used live traps (7.6 × 9 × 23 cm, H.B. Sherman Traps, Tallahassee, FL) to survey small mammals on Horn, Petit Bois, and Cat Islands. Every 200 m along a main transect, I placed trapping points (Fig. 2.2) at random distances from the main transect. At each trapping point I placed 5 traps within a 10m radius of the point (≥10 m apart) for a total of 100 traps on each island. I baited traps with rolled oats and corn and trapped for 3 nights. I recorded species and capture site for each mammal trapped and released individuals at the capture site. East and West Ship Islands were not surveyed.

I surveyed for axis deer, white-tailed deer, raccoons, and eastern cottontails on Cat Island using infra-red triggered digital cameras (Cuddeback, Park Falls, WI). Three camera stations were baited with corn and placed in areas likely to serve as trails.

Cameras were checked daily for activity, malfunctions, battery life, and available memory. Like the live traps, the cameras operated continuously for 3 nights. I also recorded incidental sighting of mammals and mammal sign.

I conducted a more extensive survey during the summer of 2007. Using ArcView 3.3 (ESRI, Redlands, CA), I divided each island into 10 approximately equal sections and placed a random point in each section using a random point generator in the animal movement extension in ArcView 3.3 (Fig. 3.1; Hooge and Eichenlaub 1999). East and West Ship Islands (known as Ship Island until Hurricane Camille split them in 1969; Wolfe 1985a, Esher 1988) shared 10 sections, 3 on East Ship and 7 on West Ship due to their small size and proximity.

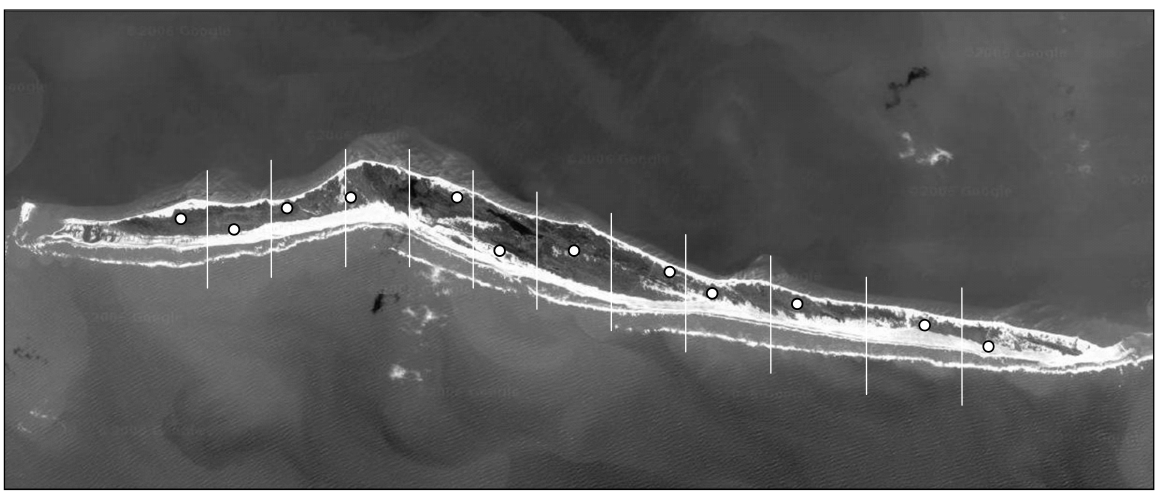


Figure 3.1. An example of Horn Island divided into ten sections with a random point placed in each section.

In each section I established sample points for the mammal surveys in each vegetation type using the following method (Fig. 3.2). I first sampled in the vegetation types where the random point occurred. Then I sampled in each remaining vegetation type (forest, meadow/relic dune, dune, and marsh) at the point closest to the random point. Not all sections contained all vegetation types. I only established sampling points in the vegetation types available within each section. Using this methodology I placed 20 points on Cat Island, 14 points on West Ship, 9 points on East Ship, 32 points on Horn Island, and 26 points on Petit Bois. I surveyed each island separately for 4 nights.

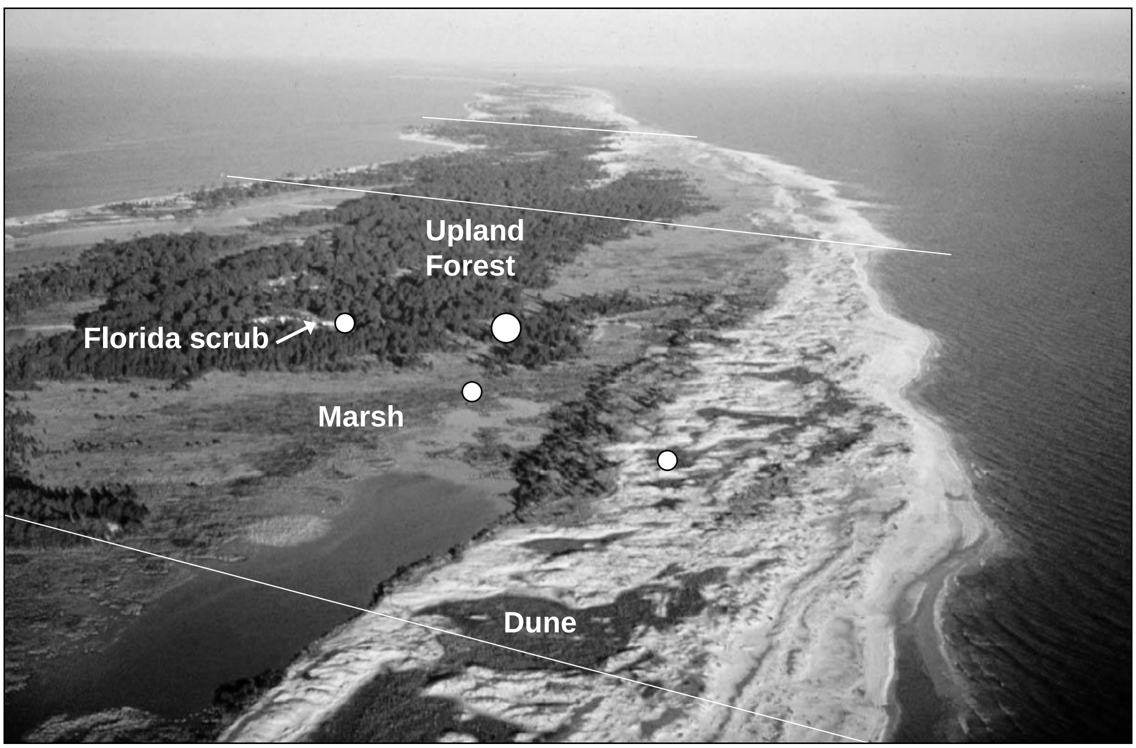


Figure 3.2. A conceptual picture of the survey points distributed in a section. The large white dot represents the random point established using ArcView 3.3 (Fig. 3.1) and the smaller white dots represent the points placed in additional vegetation types.

Small Mammals

I used live traps (7.6 × 9 × 23 cm, H.B. Sherman Traps, Tallahassee, FL) to sample black rats and marsh rice rats on the islands. I placed a trap line (10 traps, 10 m apart, Dice 1938), at each sampling point in each vegetation type in each section of the islands. I baited live traps with crimped oats and peanut butter and trapped continuously for 4 nights on each island. I recorded species, sex, vegetation type, and weight for each animal and released animals at the site of capture.

Fox squirrels were recorded on Cat Island in 2005 and proved very difficult to trap. Therefore, I surveyed for squirrels on Cat Island using time-area counts at the 20 sampling points described above (Goodrum 1937, Williamson 1983). I conducted time-area counts for 4 days, 5 minutes each day, between 0830 and 1130 (Williamson 1983).

Large and Mid-size Mammal Surveys

White-tailed deer and axis deer (*Axis axis*) were present on Cat Island before Hurricane Katrina. This was the only island to have a population of deer in the recent past and this population was introduced by humans (G. Hopkins, National Park Service, personal communication). To detect their presence I set infra-red triggered digital cameras (Cuddeback, Park Falls, WI) at the sampling points. I baited the camera stations with corn and ran the cameras for 4 nights. I checked the cameras once a day for activity, malfunctions, available memory, and battery life (Koerth and Kroll 2000).

I placed cameras at each sampling point on each island and baited them with wet cat food and apple slices to record raccoons, nutria, river otters, muskrat, and cottontails (Esher 1988, Gompper et al. 2006, Moruzzi et al. 2002).

I also established transects (100 × 1 m) at the sampling points to observe for sign of nutria and cottontails. I proposed this method because it was relatively easy to quantify rabbit and nutria sign due to the high visibility of droppings and tracks on the sandy substrate. I counted groupings of pellets as a unit and each set of tracks were only counted once if I could tell than an individual crossed the transect at more than one point or traveled along the transect for any distance.

RESULTS

The distribution, expatriation and colonization of mammals to Hurricane Katrina varied from island to island. Eleven terrestrial mammal species were recorded in studies of the barrier islands prior to Hurricane Katrina (Horn, Ship, and Petit Bois islands, 1986-87; Esher et al. 1988, Cat Island 2005; Kemper et al., Texas A&M University, unpublished report; Table 3.1). There were 7 species on Cat Island, 4 on West Ship, 4 on East Ship, 9 on Horn Island, and 2 on Petit Bois. The NPS removed one of the previously recorded species, the feral hog (*Sus scrofa*), from Horn Island in the years following the study by Esher et al. (1988). In the 2 years following Hurricane Katrina, I recorded 1 of the 7 species on Cat Island, 5 of the 9 species on Horn Island and 2 species each on East Ship, West Ship, and Petit Bois Islands (Table 3.1).

In January of 2006 I observed raccoon sign on Cat, East Ship, Horn, and Petit Bois Islands. I found nutria sign on Horn and Petit Bois Islands and eastern cottontail sign on Horn Island. I found no other mammal sign. In summer 2006 I trapped 3 black rats on Horn Island in upland forest vegetation, otherwise all mammal sign was similar to January 2006.

During the summer of 2007 I incidentally observed raccoon sign on Cat, East Ship, Horn, and Petit Bois Islands. I recorded raccoon sign along the shorelines and dunes of the islands except for Petit Bois, where both nutria and raccoon sign were concentrated around the marshes on the eastern end of the island. I also incidentally observed nutria sign on Horn and Petit Bois Islands and eastern cottontail sign on Horn Island (Fig 3.6). I recorded river otter sign on West Ship Island, however, our sign transects and the digital infrared-triggered cameras failed to record the river otter.

In 2007 a small proportion of the digital cameras recorded raccoons on Cat (10%), Horn (9%), and Petit Bois (4%) islands (2, 3, and 1 photographs, respectively; Fig. 3.3). Raccoons sign was observed on East Ship Island, though the cameras failed to detect them. Raccoons were photographed twice each in upland forest, dune, and marsh vegetation types (Fig. 3.4). Nine percent of the cameras on Horn Island also recorded nutria; both in dune vegetation.

Table 3.1. Mammals detected on Cat, West Ship, East Ship, Horn, and Petit Bois Islands, Mississippi, pre- and post-Hurricane Katrina (August 29, 2005).

Island	Scientific name	Pre-Katrina[a]	January 2006	May 2006	Summer 2007
Cat Island					
axis deer	*Axis axis*	45	--[c]	--	--
white-tailed deer	*Odocoileus virginianus*	--	--[c]	--	--
marsh rice rats	*Oryzomys palustris*	28	--[c]	--	--
black rats	*Rattus rattus*	2	--[c]	--	--
fox squirrels	*Sciurus niger*	3	--[c]	--	--
Raccoons	*Procyon lotor*	sign	sign[c]	sign	sign
eastern cottontail	*Sylvilagus floridanus*	sign	--[c]	--	--
West Ship					
Nutria	*Myocastor coypus*	present[b]			
black rats	*Rattus rattus*	present[b]	--[c]	--[c]	1
Raccoons	*Procyon lotor*	present[b]	--[c]	--[c]	--
river otter	*Lontra canadensis*		--[c]	--[c]	sign
East Ship					
black rats	*Rattus rattus*	present[b]	--	--	--
river otter	*Lutra canadensis*	present[b]	--	--	--
Raccoons	*Procyon lotor*	present[b]	sign[c]	sign[c]	sign
Nutria	*Myocastor coypus*	present[b]	--[c]	--[c]	--
Horn Island					
Muskrat	*Ondatra zibethicus*	present[b]	--	--	--
river otter	*Lutra canadensis*	present[b]	--	--	--
feral hog	*Sus scrofa*	present[b]	--	--	--
black rats	*Rattus rattus*	present[b]	--[c]	3	10
marsh rice rats	*Oryzomys palustris*	present[b]	--[c]	--	15
eastern cottontail	*Sylvilagus floridanus*	present[b]	sign[c]	sign	sign
raccoons	*Procyon lotor*	present[b]	sign[c]	sign	sign
Nutria	*Myocastor coypus*	present[b]	sign[c]	sign	sign
Petit Bois					
Raccoons	*Procyon lotor*	present[b]	sign[c]	sign	sign
nutria	*Myocastor coypus*	present[b]	sign[c]	sign	sign

[a]Unless otherwise noted, numbers represent number of captured individuals.

[b]From Esher et al. 1988

[c]Island visited and sign observed, but not systematically surveyed during time period

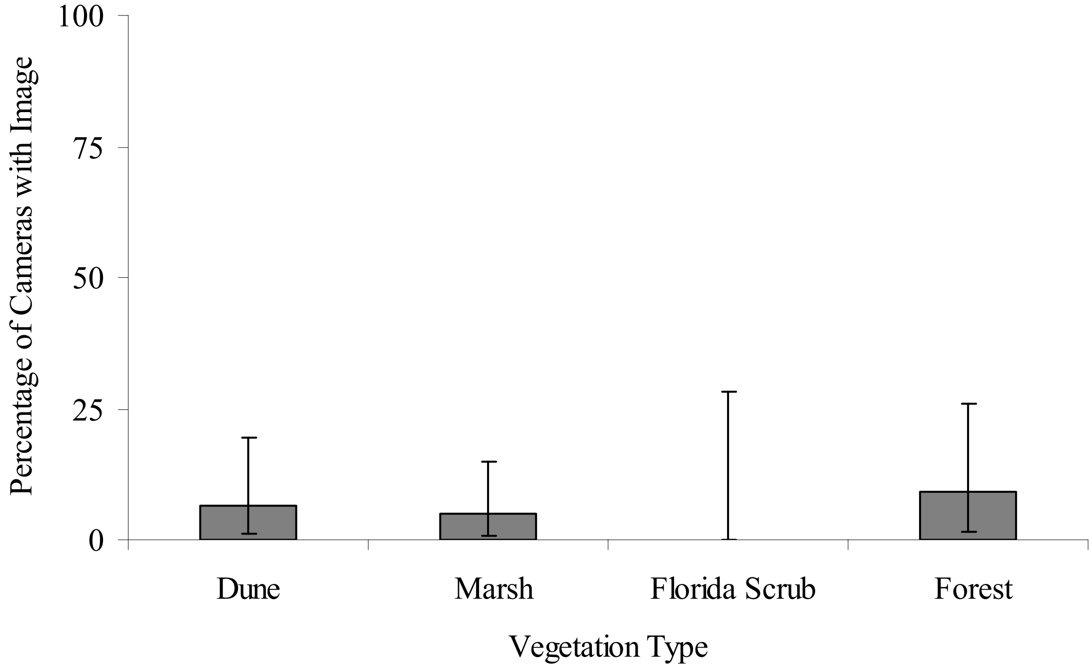


Figure 3.3. Percentage and 90% confidence intervals of cameras with captured images of raccoons on Cat, East Ship, West Ship, Horn, and Petit Bois Islands, Gulf Islands National Seashore, Mississippi, USA.
*Raccoon sign was also observed on East Ship, but no pictures were taken**.**

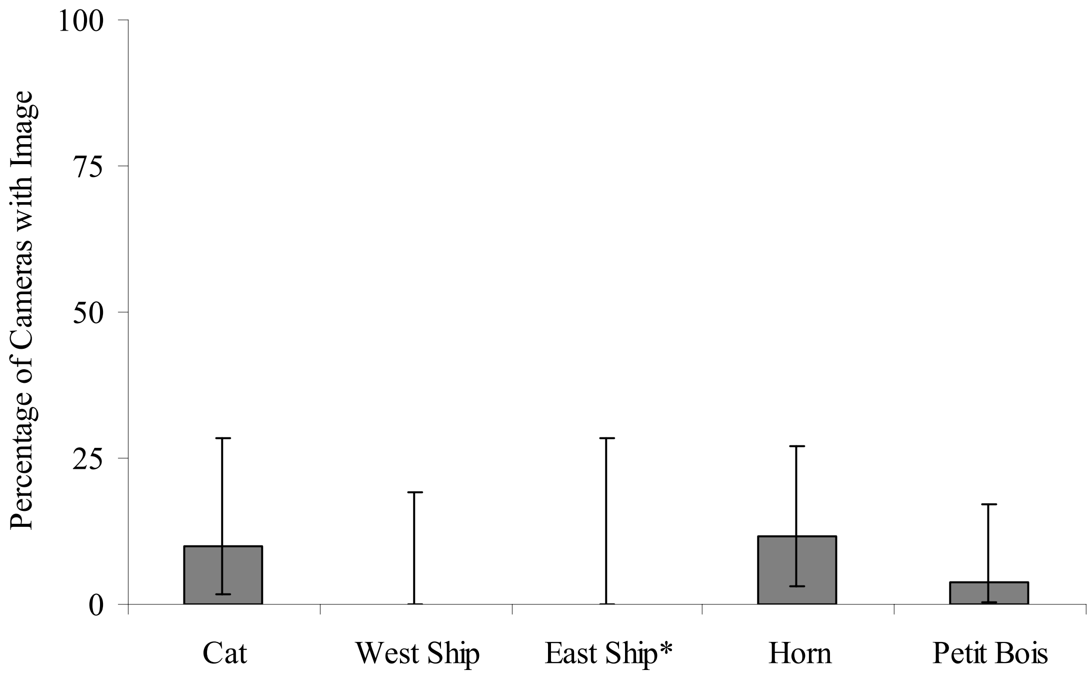


Figure 3.4. Percentage and 90% confidence intervals of cameras with captured images of raccoons in each vegetation type, Gulf Islands National Seashore, Mississippi, USA.

In 2007 the live trapping yielded 10 black rats on Horn Island and 1 on West Ship Island. I trapped these black rats in upland forest (5), marsh (4), relic dune (1), and dune (1; West Ship) vegetation types (Fig 3.5). In addition, I trapped 15 rice rats on Horn Island; 14 in marsh, and 1 in upland forest vegetation (Fig 3.5). I recorded both black rats and rice rats along the length of Horn Island.

Black rats were trapped most often in forest vegetation, while rice rats were trapped most often in marsh vegetation (Fig. 3.5). Annual trap success by island (captures/trap night) for rice rats (when present) was higher than trap success for black rats (Table 3.2).

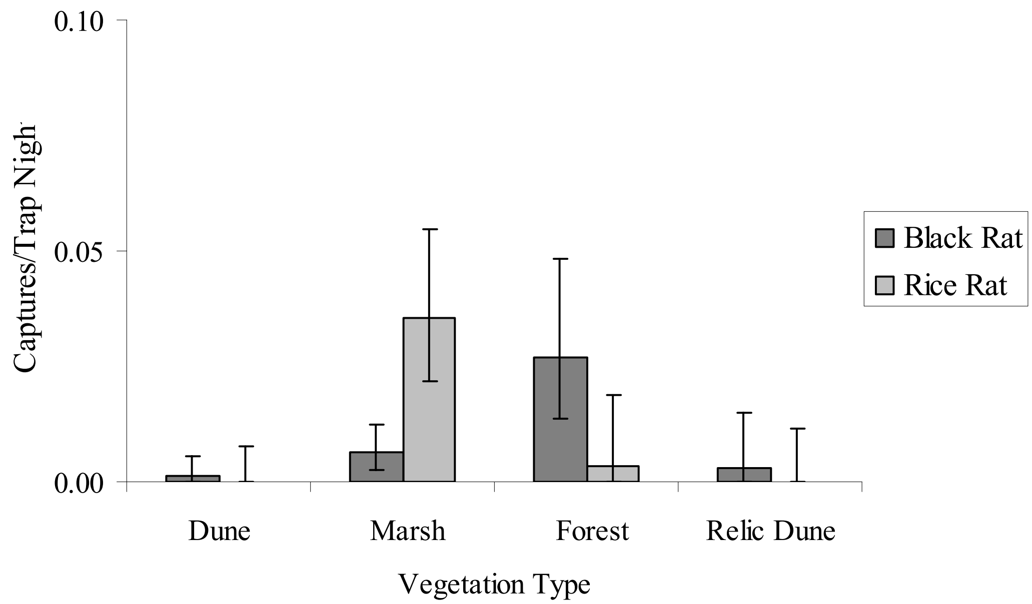


Figure 3.5. Captures/trap night with 90% confidence intervals for black rats and rice rats by vegetation type, Gulf Islands National Seashore, Mississippi, USA.

Table 3.2. Trap success (captures/trap night) for black and rice rats by year and island.

Black Rat			Rice Rat		
Island	Year	Success	Island	Year	Success
Horn	1988[a]	1.57%	Horn	1988[a]	3.57%
West Ship	1988[a]	3.33%	Cat	2005	5.69%
Cat	2005	0.39%	Horn	2006	0.00%
Horn	2006	1.00%	Cat	2006	0.00%
Horn	2007	0.88%	Horn	2007	1.34%
West Ship	2007	0.18%	Cat	2007	0.00%

[a] From Esher et al. 1988.

I recorded rabbit and nutria sign in the sign transects in similar proportions across each vegetation type on Horn Island (Fig. 3.6, 3.7). I did not record raccoons in the sign transects, and though I observed nutria sign on Petit Bois, the nutria did not traverse those sign transects.

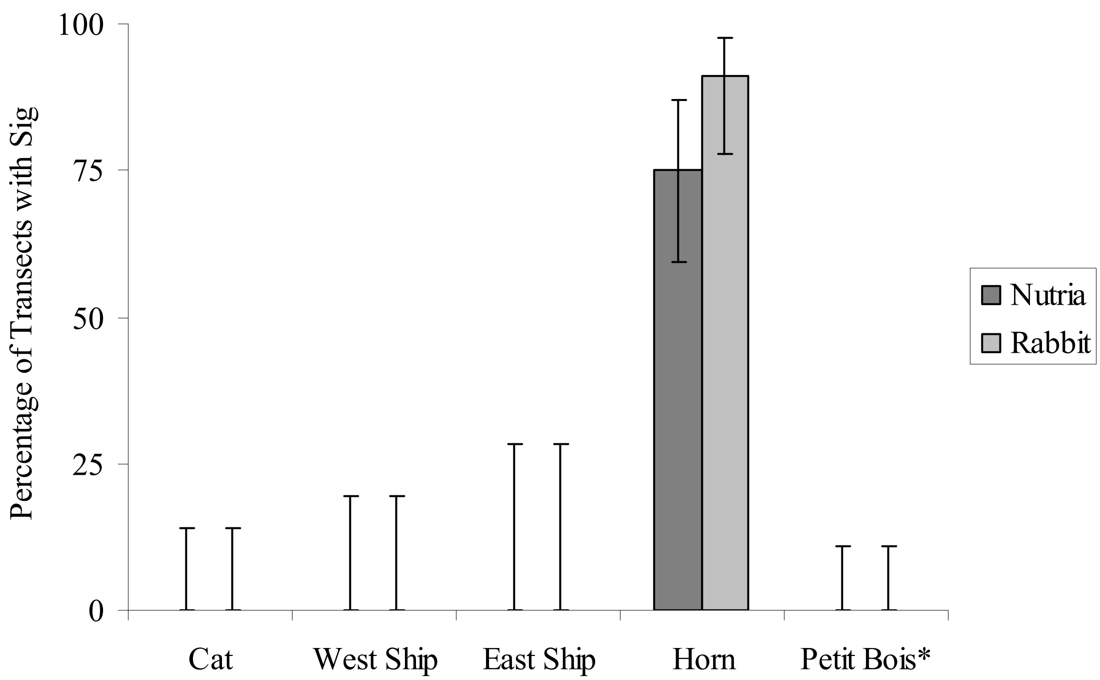


Figure 3.6. Percentage and 90% confidence intervals of transects with nutria and rabbit sign on Cat, West Ship, East Ship, Horn, and Petit Bois Islands, Gulf Islands National Seashore, Mississippi, USA.

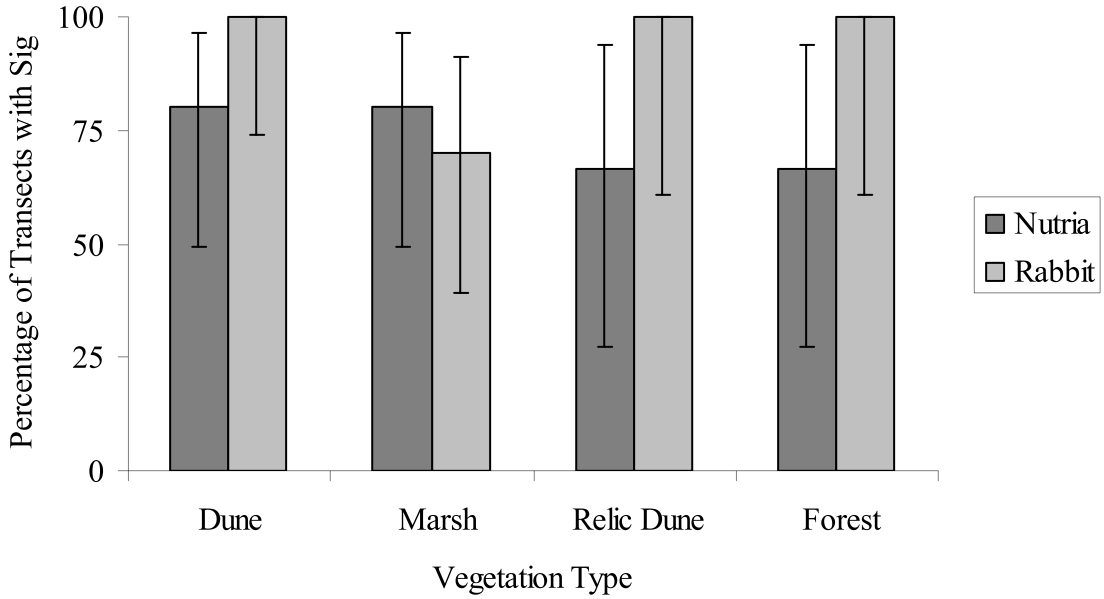


Figure 3.7. Percentage and 90% confidence intervals of transects with rabbit and nutria sign by vegetation type on Horn Island, Gulf Islands National Seashore, Mississippi, USA.

DISCUSSION

The retention of mammalian populations after the storm differed considerably by island. For example, Horn and Petit Bois Islands retained all of species regularly recorded on the islands prior to the hurricane. On the other hand, of the 7 species recorded on Cat Island prior to Katrina, only raccoons remained after the storm. Nonetheless, it is possible that raccoons were not the only species remaining on Cat Island. My sampling efforts were restricted to the western end of the island owned by the NPS. This portion of the island did not include 2 very important vegetation types (i.e., salt marsh and dunes). Rice rats trapped on the island in June 2005 were only trapped in salt marshes on the privately owned portion of the island. This is also where most of the cotton-tailed rabbit activity had been observed (Kemper et al., Texas A&M University, unpublished report).

Each species varied in distribution between islands. All mammals recorded except the river otter were found on Horn Island. Raccoons were widespread after Hurricane Katrina, inhabiting all but 1 island. Rabbits were only found on Horn Island and nutria were found on Horn and Petit Bois Islands. All 3 of these species showed little difference in the use of vegetation types on the islands (Figs. 3.4 and 3.7). Their ability to utilize multiple vegetation types probably allowed these species to recover from the hurricane more quickly than vegetation-specific species. Small mammals on the other hand appeared to select for different vegetation types on the islands. Black rats were found primarily in forest vegetation on Horn Island and around buildings on West Ship Island (Fig 3.5). Rice rats were even more selective and found primarily in marshes, their preferred habitat (Wolfe 1985a). Rice rats inability to utilize other vegetation types on the island could have made them more susceptible to disturbances, possibly explaining their absence from the islands in 2006.

Other factors that might have influenced post-Katrina distributions of mammals were the sizes of the islands and their distances from other mammal populations (MacArthur and Wilson 1967). I consider this influence unlikely because the 2 largest islands, Cat Island and Horn Island, were similar in size and approximately the same distance from the mainland, yet each island responded to the hurricane differently. Only 1 mammal species (of 7) was recorded on Cat Island after Katrina while 5 (of the 5 species recently known) remained on Horn Island. A possible explanation for this difference might be the height and duration of the storm surge on Cat Island compared to Horn Island (they were about 30 km and 60 km east of the storm center, respectively).

There were 3 possible instances of colonization on the islands after Katrina. I did not record rice rats on Horn Island 2006, but captured 15 individuals in 2007; however, it is also possible that they were undetected in 2006. On West Ship Island I recorded black rats and river otter in 2007, both of which had not been recorded in 2006. I am cautious about calling the black rat records a colonization event because West Ship was not surveyed specifically for mammals before the storm or in 2006. Richmond (1968:223) mentioned that the river otter was "apparently quite common" on Horn Island, but did not include them in the species list he published. Esher (1988) recorded otter tracks on Horn Island and East Ship Island and photographed an individual river otter on Horn Island, but I could not find any recent records of otters on West Ship Island. I believe that the river otter was a true colonization event.

To conclude, I recommend the NPS continue to monitor the islands to gain an understanding the response of the mammalian community following a natural disturbance. For future monitoring of mammalian populations, I recommend a design similar to surveys conducted in 2007 with some modifications. I had limited success using bait and passive infra-red triggered digital cameras and would not recommend them as a primary sampling technique due to the cost and time involved. The sandy substrate of the islands made sign counts on transects particularly useful. I recommend this methodology be expanded in future studies. Baiting the transects or plots would likely increase visitation by most of the insular species. To provide a reliable estimation of changes in the species richness of the islands, surveys should be conducted at least every 2 years. I also recommend conducting surveys at the same time each year, preferable during the late summer or early fall when population numbers peak, thereby increasing the probability of detection (Lotze and Anderson 1979, Wolfe 1985b).

CHAPTER IV

CONCLUSIONS

Following the landfall of Hurricane Katrina in August of 2005, I studied the changes in the herbaceous ground cover and the density of woody plants in Gulf Islands National Seashore (GUIS) in Mississippi from the winter of 2005 to the summer of 2007. Growth from existing plants and seed banks quickly revegetated the islands after the storm. The regeneration of most woody species and the universal increase in live ground cover seems to indicate that the vegetation of the islands was not irreversibly impacted. I also studied changes in the composition of mammal populations in GUIS from the winter of 2005 to the summer of 2007. Prior to the storm 11 terrestrial mammal species were recorded in studies of the barrier islands. In the 2 years following Hurricane Katrina, I recorded only 1 of the 7 species on Cat Island, 5 of the 9 species on Horn Island and 2 species each on East Ship, West Ship, and Petit Bois Islands (which previously had 4, 4, and 2 each). I also recorded at least one colonization event by river otter, a species not recently recorded on the islands.

VEGETATION

Growth from existing plants and seed banks quickly revegetated the islands of GUIS after the Hurricane Katrina. The amount of live ground cover increased and bare ground decreased on each island and in every vegetation type. This appears to indicate an increase in the overall plant biomass that I attribute to re-growth in areas that were stripped of vegetation or buried in sand during the storm. East Ship was particularly hard hit by Hurricane Katrina and bare ground on East Ship Island did not significantly decrease, even though live cover did increase. This study only measured recovery of established vegetation of the islands. I recommend adding plots on the western ends of the islands as they form to measure vegetation establishment on these quickly changing land forms.

Most woody plant species also showed a net increase in density, with the exception of pine and Florida rosemary. On Cat Island, the only island with vegetation data from before the storm, all recorded species of trees increased in density after the storm. However, only oak and yaupon reached or surpassed the pre-storm density, primarily due to a huge increase in new stem growth. Cat Island seemed to be least impacted of the islands (based on percentage of pines lost and island area lost), even though it was closest to the eye of Hurricane Katrina. One explanation for this is the buffering action of the dense woody vegetation on the island.

Several factors aside from hurricane intensity affect the recovery of vegetation post-disturbance. One aspect that should be considered is the amount of rainfall available to the islands following the storm. The islands were subjected to drought conditions for the several months following the storm with rainfall averages far below normal into 2007 (Edwards and Fuchs 2008). Rainfall not only encourages vegetative growth, but also decreases salt-stress in the islands plants as it leaches salts from the soils and creates a freshwater lens on the islands (Eleuterius, 1979). I believe that the vegetation on the islands would have showed greater improvement under average rainfall conditions. The regeneration of most woody species and the universal increase in live ground cover seems to indicate that the vegetation of the islands was not irreversibly impacted.

MAMMALS

Prior to the storm 11 terrestrial mammal species were recorded in studies of the barrier islands. In the 2 years following Hurricane Katrina, I recorded only 1 of the 7 species on Cat Island, 5 of the 9 species on Horn Island and 2 species each on East Ship, West Ship, and Petit Bois Islands (which previously had 4, 4, and 2 each). The retention of mammalian populations after the storm differed by island, but did not seem to follow the rules of the island biogeography theory (MacArthur and Wilson 1967). Populations of mammals that used multiple vegetation types (raccoons, nutria, and rabbits) seemed to show more tolerance to hurricane disturbance than more specialized species (marsh rice rats and black rats). There were 3 possible instances of colonization on the islands after Katrina. Rice rats on Horn Island and black rats and river otter on West Ship Island.

I recommend continuing research to better understand the responses of the mammalian communities following natural disturbances. For future monitoring I recommend a design similar to surveys conducted in 2007 with some modifications. I would not recommend using infra-red triggered cameras as a primary sampling technique due to the cost and time involved. However, the sandy substrate of the islands made sign counts on transects particularly useful. I recommend expanding this methodology in future studies. To provide a reliable estimation of changes in the species richness of the islands, surveys should be conducted at least every 2 years. I also recommend conducting surveys at the same time each year, preferable during the late summer or early fall when population numbers peak, thereby increasing the probability of detection (Lotze and Anderson 1979, Wolfe 1985b). Overall this data forms a baseline of vegetation recovery after an intense hurricane for future comparison.

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APPENDIX A

LOCATIONS OF VEGETATION TRANSECTS IN UTM COORDINATES

Island	Plot	X-coordinate	Y-coordinate	Vegetation[a]
Cat	1	0296562	3345551	UP
	2	0296684	3345488	UP
	3	0296824	3345470	UH
	4	0296972	3345511	UH
	5	0297097	3345489	UP
	6	0297228	3345487	UP
	7	0297376	3345454	UP
	8	0297560	3345430	UH
	9	0297704	3345432	UP
	10	0297838	3345365	UP
	11	0297977	3345355	UH
	12	0298153	3345341	UP
	13	0298226	3345332	UP
	14	0298066	3345366	M
	15	0297920	3345353	UH
	16	0297799	3345403	M
	17	0297649	3345440	UH
	18	0297503	3345462	M
	19	0297325	3345508	UP
	20	0297183	3345533	M
	21	0297045	3345485	UH
	22	0296863	3345520	UP
	23	0296719	3345510	UH
	24	0296570	3345490	UH
	25	0296467	3345531	UP
	26	0296395	3345548	UP
	27	0296330	3345571	M
	28	0296265	3345597	UP
	29	0296184	3345635	M
	30	0296103	3345630	UP
	31	0295992	3345621	UH
	32	0295918	3345617	UP
	33	0295852	3345670	UH
	34	0295778	3345656	UH

	35	0295709	3345708	UP
	36	0295629	3345686	UP
	37	0295545	3345669	UP
	38	0295508	3345737	M
	39	0295419	3345722	UP
	40	0295351	3345734	UP
West Ship	41	0310178	3343559	M
	42	0310122	3343545	M
	43	0310055	3343541	D
	44	0309998	3343516	D
	45	0309931	3343527	M
	46	0309065	3343507	D
	47	0309802	3343517	D
	48	0309731	3343529	D
	49	0309670	3343560	D
	50	0309601	3343549	D
	51	0309540	3343582	D
	52	0310257	3343658	D
	53	0310323	3343655	D
	54	0310385	3343644	M
	55	0310469	3343649	M
	56	0310546	3343666	D
	57	0310614	3343696	M
	58	0310685	3343640	M
	59	0310738	3343687	M
	60	0310805	3343720	M
	61	0310879	3343689	D
	62	0310944	3343682	D
	63	0311143	3343631	M
	64	0311226	3343616	D
	65	0311305	3343623	D
	66	0311401	3343640	M
	67	0311477	3343615	D
	68	0311562	3343588	M
East Ship	69	0318024	3346093	D
	70	0318028	3346168	D
	71	0318063	3346229	D
	72	0318117	3346283	D

	73	0318160	3346328	D
	74	0318166	3346393	M
	75	0318253	3346417	UH
	76	0318303	3346432	UH
	77	0318362	3346392	D
	78	0318447	3346472	M
	79	0318492	3346415	UH
	80	0318568	3346402	D
Horn (Cross Island Trail)	81	0334531	3346989	FS
	82	0334587	3347045	M
	83	0334648	3347025	UH
	84	0334721	3347001	M
	85	0334787	3347033	D
	86	0334359	3347168	FS
	87	0334288	3347135	FS
	88	0334232	3347163	UP
	89	0334205	3347193	UP
	90	0334155	3347199	M
Horn (East of Big Lagoon)	91	0335867	3347340	FS
	92	0335927	3347310	UP
	93	0335979	3347257	M
	94	0336068	3347274	FS
	95	0336115	3347225	UH
	96	0336189	3347234	D
	97	0336245	3347191	UP
	98	0336310	3347192	FS
	99	0336368	3347156	UP
	100	0336427	3347147	UP
Horn (West of Horseshoe)	101	0340148	3345760	M
	102	0340191	3345721	FS
	103	0340244	3345706	FS
	104	0340299	3345668	FS
	105	0340362	3345652	FS
	106	0340439	3345664	D
	107	0340516	3345657	D
	108	0340564	3345603	FS
	109	0340628	3345583	FS
	110	0340692	3345576	FS

	111	0340773	3345546	UP
	112	0340843	3345523	FS
	113	0340900	3345511	FS
	114	0340937	3345455	UP
	115	0341011	3345457	UH
Horn (Arcturus Flats)	156	0343748	3345103	D
	157	0343797	3345067	D
	158	0343831	3344995	M
	159	3443912	3344988	S
	160	0343951	3344918	M
Petit Bois (West Tip)	116	0355676	3343038	D
	117	0355715	3342959	D
	118	0355774	3342944	M
	119	0355839	3342912	D
	120	0355895	3342870	M
	121	0355935	3342822	M
	122	0356034	3342851	M
	123	0356054	3342783	M
	124	0356142	3342780	M
	125	0356217	3342775	D
Petit Bois (Petit Bois Point)	126	0357968	3342283	M
	127	0358032	3342260	M
	128	0358125	3342213	D
	129	0358172	3342166	M
	130	0358240	3342156	D
	131	0358286	3342104	M
	132	0358358	3342077	M
	133	0358427	3342077	D
	134	0358479	3342029	D
	135	0358253	3341994	D
Petit Bois (Just East of Middle)	136	0360876	3341634	S
	137	0360974	3341665	D
	138	0361035	3341697	S
	139	0361118	3341712	S
	140	0361187	3341695	S
	141	0361255	3341683	S
	142	0361314	3341775	S
	143	0361385	3341741	S

	144	0361451	3341733	D
	145	0361510	3341759	S
Petit Bois (East End)	146	0362105	3342275	FS
	147	0362165	3342260	FS
	148	0362224	3342295	M
	149	0362263	3342218	FS
	150	0362303	3342185	M
	151	0362373	3342210	M
	152	0362435	3342212	UH
	153	0362473	3342271	UH
	154	0362531	3342280	UP
	155	0362587	3342252	UP

[a] Abbreviations: D, Dune; FS, Florida scrub; M, Marsh; S, Scrub; UH, Upland Hardwood; and UP Upland Pine.

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