

EFFECTS OF OFF-ROAD VEHICLES ON SMALL MAMMALS IN BIG CYPRESS
NATIONAL PRESERVE

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2009

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To my parents, David and Mary Jeffery, who have encouraged and supported me to do what I
enjoy

ACKNOWLEDGMENTS

I am very grateful to my committee members for taking the time and patience to work with me: Frank Mazzotti for the opportunity and support that I needed to be successful throughout my graduate career, Ken Rice for the encouragement and guidance when needed, and Doria Gordon for her inspiration and insightful suggestions.

Franklin Percival was especially helpful for direction and support while in Gainesville. Hardin Waddle was instrumental for stimulating conversations, helping me in the field and for mentoring me. I would also like to thank those that have helped me in the field: Meghan Riley, Deborah Kramp and Aletris Neils, various volunteers from Student for Conservation Association and VIP personnel from Big Cypress National Preserve. All methods for handling and marking small mammals have been approved by the University of Florida Institutional Animal Care and Use Committee (IACUC).

Big Cypress National Preserve staff provided an office, housing, logistics and granted research permit. Jim Snyder of the USGS, for sharing of his knowledge and for his support in Big Cypress National Preserve.

Finally, I thank my parents. With their continued encouragement, support, and most importantly, love, I was able to obtain my dream.

TABLE OF CONTENTS

	<u>page</u>
ACKNOWLEDGMENTS	4
LIST OF TABLES	7
LIST OF FIGURES	10
ABSTRACT.....	11
CHAPTER	
1 INTRODUCTION	12
Off-Road Vehicles	12
Types of ORVs	13
Swamp buggies	13
Street-Legal vehicles	14
All-Terrain vehicles.....	14
Airboats	14
Uses of ORVs	14
Ecology of Small Mammals in Southern Florida	15
<i>Sigmodon hispidus</i>	15
<i>Oryzomys palustris</i>	16
<i>Peromyscus gossypinus</i>	17
<i>Blarina carolinensis</i>	17
Potential Impacts to Wildlife	18
Habitat Modification	19
Species Composition and Structure.....	20
Alteration of Behavior	20
Objectives	21
2 RESPONSE OF VEGETATION TO OFF-ROAD VEHICLES	26
Introduction.....	26
Study Area	29
Methods	30
Results.....	32
Discussion.....	32
3 ECOLOGY OF SMALL MAMMALS IN BIG CYPRESS NATIONAL PRESERVE IN AREAS AFFECTED BY ORV USE	41
Introduction.....	41
Methods	42
Study Area	42

Site Selection	44
Small Mammal Surveys	44
Statistical Analysis	45
Results.....	48
Species Distribution and Abundance.....	48
Weight and Size Comparisons.....	49
Body Condition	51
Mark-Recapture.....	52
Discussion.....	54
4 CONCLUSIONS	90
Introduction.....	90
ORV Impacts on Wildlife.....	90
Habitat Modification	90
Species Composition and Structure.....	91
Small Mammals as an Indicator Species	92
Conclusions.....	93
LIST OF REFERENCES.....	94
BIOGRAPHICAL SKETCH	102

LIST OF TABLES

<u>Table</u>	<u>page</u>
2-1. Overall variation in height among three vegetation classifications (forb, graminoid, and shrub) and two impact levels (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) at Big Cypress National Preserve.	35
2-2. Variation in height among three vegetation classifications (forb, graminoid, and shrub) and two impact levels (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) in pine habitat at Big Cypress National Preserve.	36
2-3. Variation in height among three vegetation classifications (forb, graminoid, and shrub) and two impact levels (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) in prairie habitat at Big Cypress National Preserve.	37
2-4. Variation in vegetative percent ground cover between habitats (pine and prairie) and impacts (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) (Percent cover data was arcsin transformed for analysis).	38
2-5. Variation in vegetative vertical cover among pine habitats and impacts (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV).	39
2-6. Variation in vegetative vertical cover among prairie habitats and impacts (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV).	40
3-1. Combinations of the 3 site covariates and one sampling covariates that were used in the occupancy analysis for each species. Each set of site covariates was modeled along with each set of sampling covariates for a total of 16 models for each species.	63
3-2. List of 25 models analyzed in program MARK for captures of cotton rat, marsh rice rat, and cotton mouse in Big Cypress National Preserve. Explanation defines each model in terms of the effects of time (t) and ORV group (g), on apparent survival (Φ) and capture probability (p).	64
3-4. Number of captures by hispid cotton rat, marsh rice rat, cotton mouse and short-tailed shrew on impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)) treatment areas. Individuals captured more than once within the same trapping event were not counted.	66
3-5. Total captures and individual captures of hispid cotton rat, marsh rice rat, cotton mouse and short-tailed shrew by off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) areas.	67
3-6. Total captures of hispid cotton rat, marsh rice rat, cotton mouse, and short-tailed shrew by pine and prairie habitats.	68

3-7. Mean \pm SD captures of hispid cotton rat, marsh rice rat, cotton mouse, and short-tailed shrew by impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)), habitat (pine and prairie), and sex (male and female).....	69
3-8. Mean weight \pm SD of adult, non-pregnant hispid cotton rat, marsh rice rat, and cotton mouse by impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)), habitat (pine and prairie), and sex (male and female).....	70
3-9. Mean length \pm SD of hispid cotton rat, marsh rice rat, and cotton mouse by impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)), habitat (pine and prairie), and sex (male and female).....	71
3-10. Linear regressions of ln(body weight) over ln(right hind foot))of hispid cotton rat, marsh rice rat, and cotton mouse.	72
3-11. Mean body condition indices (± 1 SD) of hispid cotton rat, marsh rice rat, and cotton mouse by impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)), habitat (pine and prairie), and sex (male and female).....	73
3-12. Number of detections by cotton rat, marsh rice rat, and cotton mouse and proportion of sites at which a detection occurred (naïve occupancy) during small mammal surveys.....	74
3-13. Program PRESENCE model selection results for the hispid cotton rat, including Akaike’s Information Criterion (AIC) and the delta AIC and AIC weights for all models with any weight.	75
3-14. Program PRESENCE beta estimates, standard errors (S.E.), and lower and upper 95% confidence intervals for the hispid cotton rat. The best model and second best model are shown.	76
3-15. Program PRESENCE model selection results for the marsh rice rat, including Akaike’s Information Criterion (AIC) and the delta AIC and AIC weights for all models with any weight.	77
3-16. Program PRESENCE beta estimates, standard errors (S.E.), and lower and upper 95% confidence intervals for the marsh rice rat. The best model and second best model are shown.	78
3-17. Program PRESENCE model selection results for the cotton mouse, including Akaike’s Information Criterion (AIC) and the delta AIC and AIC weights for all models with any weight.	79
3-18. Program PRESENCE beta estimates, standard errors (S.E.), and lower and upper 95% confidence intervals for the best model of the cotton mouse.....	80
3-19. The number of individuals marked, recaptured and the return rate (proportion of marked individuals recaptured at least once) for the hispid cotton rat, marsh rice rat,	

and cotton mouse in off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) areas.	81
3-20. Model selection table for Cormack-Jolly-Seber closed population mark-recapture model of the cotton rat, including Quasi-likelihood Akaike's Information Criterion for small sample sizes (QAICc), model weights based on QAICc, the number of parameter in each model, and the model deviance. Model structure includes the effects of time (t), and off-road vehicle (ORV) group (g) on apparent survival (Φ) and capture probability (p).....	82
3-21. Estimates, standard error (S.E.), and 95% confidence interval (C.I.) of the beta values for the off-road vehicle (ORV) effect on apparent survival (Φ) and capture probability (p) on the cotton rat, marsh rice rat, and cotton mouse.	83
3-22. Model selection table for Cormack-Jolly-Seber closed population mark-recapture model of the marsh rice rat, including Quasi-likelihood Akaike's Information Criterion for small sample sizes (QAICc), model weights based on QAICc, the number of parameter in each model, and the model deviance. Model structure includes the effects of time (t), and off-road vehicle (ORV) group (g) on apparent survival (Φ) and capture probability (p).	84
3-23. Model selection table for Cormack-Jolly-Seber closed population mark-recapture model of the cotton mouse, including Quasi-likelihood Akaike's Information Criterion for small sample sizes (QAICc), model weights based on QAICc, the number of parameter in each model, and the model deviance. Model structure includes the effects of time (t), and off-road vehicle (ORV) group (g) on apparent survival (Φ) and capture probability (p).	85

LIST OF FIGURES

<u>Figure</u>	<u>page</u>
1-1. Image of a swamp buggy commonly used in Big Cypress National Preserve, Ochopee, Florida.....	22
1-2. Image of a typical street-legal 4×4 used in Big Cypress National Preserve, Ochopee, Florida.....	23
1-3. Image of an all-terrain vehicle (ATV) commonly used in Big Cypress National Preserve, Ochopee, Florida.....	24
1-4. Image of an airboat commonly used in Big Cypress National Preserve, Ochopee, Florida.....	25
3-1. Total number of captures for hispid cotton rat, marsh rice rat and cotton mouse from October 2004 to September 2005.....	86
3-2. Apparent survival (Φ) and 95% confidence interval of cotton rat by off-road vehicle (ORV) group and total rainfall for the 10 monthly survival intervals. Estimates for cotton rats are averaged across models as no model had a majority of QAICc weight (Burnham and Anderson 1998).....	87
3-3. Apparent survival (Φ) and 95% confidence interval of marsh rice rat by off-road vehicle (ORV) group for the 10 monthly sampling intervals. Estimates for marsh rice rats are averaged across models as no model had a majority of QAICc weight (Burnham and Anderson 1998).....	88
3-4. Survival (Φ) and 95% confidence interval of cotton mouse for the 10 monthly sampling intervals.....	89

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

THE EFFECTS OF OFF-ROAD VEHICLES ON THE SMALL MAMMALS OF BIG
CYPRESS NATIONAL PRESERVE

By

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May 2009

Chair: Frank J. Mazzotti
Cochair: Kenneth G. Rice
Major: Interdisciplinary Ecology

Effects of off-road vehicles (ORV) on the environment have been debated as many public lands have restricted or closed areas to off-road vehicles. The use of ORVs in Big Cypress National Preserve has prompted managers to evaluate their use and impacts on natural resources. For this thesis, I studied small mammal and vegetation response to off-road vehicles. The vegetation structure of ORV areas was different from that in non-ORV areas. I found that percent cover and average graminoid height in ORV areas were significantly less than those in non-ORV areas. Abundance of small mammals was different for each species. Hispid cotton rats had higher abundance in non-ORV areas than in ORV areas; marsh rice rats showed no difference in abundance between areas; and cotton mice showed higher abundance in ORV areas than in non-ORV areas. Occupancy of the three species of small mammals was estimated in relation to ORV use. Off-road vehicle use was a significant factor in site occupancy for hispid cotton rats, while percent cover and habitat type were better indicators for cotton mice. Slight differences in survival between ORV and non-ORV areas were not significant. Small mammals showed some relationship to ORV use and with additional research could be good indicators of ORV impacts.

CHAPTER 1 INTRODUCTION

Accelerating population growth in southern Florida has increased recreational pressure on Big Cypress National Preserve (BCNP) (National Park Service 2000). Land managers are confronted with a difficult situation of protecting wildlife and habitat while demands for recreational access to public lands have increased (Cordell and Bergstrom 1991; English et al. 1993; Knight and Gutzwiller 1995). It has been difficult for off-road vehicle (ORV) enthusiasts to find areas in which it is legal to ride. Large expanses of public and private lands are no longer available for ORV use in southern Florida. In north Florida, many areas are open to ORV use including Ocala National Forest, Osceola National Forest, Apalachicola National Forest, and Croom Motorcycle Area in Withlacoochee State Forest. Big Cypress National Preserve is the only large tract of public land remaining in southern Florida in which ORV enthusiasts can legally ride. The large area of prairie and pine habitats within BCNP make it an ideal place to hunt, but this also exposes these habitats to ORV use. There is little known about impacts of ORVs on wildlife, especially small mammals, in BCNP. For this reason I discuss the ecology of small mammals in southern Florida, historical uses of ORVs in BCNP, what types of ORVs are used, and potential consequences of ORV use on wildlife. Finally, I describe my research in BCNP and outline the rest of the thesis.

Off-Road Vehicles

The use of motorized vehicles to explore the Big Cypress Swamp region began in the 1920s in association with logging, farming, oil exploration, and development of the Tamiami Trail (Tebeau 1997). Recreational use of ORVs was not common until the 1940s. By the 1950s, logging activities produced ORV trails which remained even after logging (Duever et al. 1986).

An increase in hunting increased use of these trails and expanded the trail system to over 1,100 km by 1973 (Duever et al. 1986).

On October 11, 1974, Big Cypress National Preserve was created (16 USC 698) “in order to assure the preservation, conservation, and protection of the natural, scenic, hydrologic, floral and faunal, and recreational values of the Big Cypress Watershed in the State of Florida and to provide for the enhancement and public enjoyment thereof.” The recreational values of Big Cypress Watershed include the use of ORVs. Widespread ORV use on many federal lands concerned environmentalists in the 1970s and prompted research. The majority of the research was focused on sandy coasts (Steiner and Leatherman 1981, Wolcott and Wolcott 1984, Anders and Leatherman 1987) and arid landscapes of the southwest (Vollmer et al. 1976, Eckert et al. 1979, Webb 1983). Executive Orders were enacted in 1972 (Order # 11644) and 1977 (Order # 11989) for control of ORV use. These executive orders allow closures of ORV trails that cause harm to an ecosystem.

Types of ORVs

Several types of ORVs are used in BCNP including swamp buggies, street-legal 4×4s, all-terrain vehicles, and airboats. Trail bikes, track vehicles, and vehicles with chains on the tires are prohibited from use within the Preserve (National Park Service 2000). All vehicles must pass a detailed safety and compliance inspection performed by the Preserve before a permit is issued (National Park Service 2000).

Swamp buggies

There are many varieties of swamp buggies, all of which are constructed from a four-wheel drive automotive frame (Figure 1-1). Completed buggies usually have an elevated platform constructed over an engine and frame. Tires vary from aircraft to street-legal brands and must meet a minimum width of nine inches (National Park Service 2000). Swamp buggies can access

every part of the Preserve except for areas designated for airboats or environmentally sensitive habitats. Swamp buggies account for approximately 30 percent of ORV permits in BCNP (National Park Service 2000).

Street-Legal vehicles

Street-legal vehicles are four-wheel drive vehicles that are commercially manufactured and sold. Street-legal vehicles must also have a minimum tire width of nine inches (Figure 1-2; National Park Service 2000). Street-legal vehicles are limited to the Bear Island Unit of the Preserve and account for approximately 18 percent of ORV permits in BCNP (National Park Service 2000).

All-Terrain vehicles

All-terrain vehicles (ATVs) are small, commercially manufactured vehicles that are designed for off-highway use (Figure 1-3). The ATV is 50 inches or less in width and has a total dry weight of less than 900 lbs. ATVs account for approximately 39 percent of ORV permits in BCNP (National Park Service 2000).

Airboats

Airboats are commercially manufactured or hand built (Figure 1-4). They consist of a fiberglass or aluminum hull powered by an aircraft or automotive engine that drives an aircraft propeller. Airboats are restricted to Zone 4 which is a deep water area (National Park Service 2000). Airboats account for approximately 13 percent of ORV permits in BCNP (National Park Service 2000).

Uses of ORVs

Hunting and hunting-related activities, such as preseason scouting, are predominant uses of ORVs within the Preserve (National Park Service 2000). Non-hunting activities include camping, pleasure driving, fishing, sightseeing, wildlife viewing and photography, socializing,

picnicking, and swimming (National Park Service 2000). The Preserve utilizes ORVs for law enforcement, research, and resource management.

Ecology of Small Mammals in Southern Florida

Small mammal communities often respond rapidly to changes in plant composition (Kaufman et al. 1983) and habitat structure (Abramsky 1978; Kaufman et al. 1983). Because small mammals occupy vital positions in food webs (Kaufman et al. 1998), they are useful indicators of biological change (Dale and Beyeler 2001). Small mammals can also respond quickly to disturbance (Clark et al. 1989). Small mammals are ubiquitous and prolific; they can be used by managers as a tool for assessing conditions across landscapes (Dale and Beyeler 2001). I selected *Sigmodon hispidus* (hispid cotton rat), *Oryzomys palustris* (marsh rice rat), *Peromyscus gossypinus* (cotton mouse), and *Blarina carolinensis* (short-tailed shrew) as study animals because they are commonly found in pine and prairie habitats that are found throughout BCNP.

Sigmodon hispidus

The hispid cotton rat is a medium-sized rodent with a tail shorter than its body. Ears are blackish, medium sized, rounded and buried in the neck fur. The upper pelage has a coarse, grizzled appearance and is a combination of brown, black, and light tan banded hairs. The belly is grayish or light brown. The tail is sparsely haired and weakly bicolored, black above and light brown below. Hispid cotton rats are one of the most common mammals in Florida and are abundant statewide (Brown 1997). This species is found throughout the southern United States as well as Central and South America. Hispid cotton rats occur in a wide variety of open and semi-open habitats. They are most abundant in old fields composed of dense grasses. In south Florida, hispid cotton rats occupy both prairie and upland habitats (Bigler and Jenkins 1975; Smith and Vrieze 1979; Mazzotti et al. 1981). During the dry season, hispid cotton rats are present in dry

prairie and upland habitats (Bigler and Jenkins 1975; Smith and Vrieze 1979). But during the wet season, hispid cotton rats were found more frequently in upland habitats because of increased water levels (Bigler and Jenkins 1975; Smith and Vrieze 1979).

Hispid cotton rats make well-defined runways through grasses which are good indicators of presence. A small bulbous nest is constructed of dry grass or fibers stripped off the stems of larger plants. It is usually placed underground in a shallow tunnel, but occasionally the nest is built on the surface in dense vegetation. Hispid cotton rats eat leaves, stems, roots, and seeds of many grasses, sedges, legumes, and other herbaceous plants. They also consume some insects and bird eggs, and will even feed on carcasses.

Oryzomys palustris

The marsh rice rat is a small-sized rodent with a slender, poorly haired tail that is about equal to the size of its body. The upper pelage is light brown slightly scattered with black. The color is darkest down the middle of the back with more brown on the sides. The underparts are grayish white and the feet are white. The tail is bicolored, brownish above and grayish white below. The body fur is coarse and fairly long. The ears are medium sized and round, and extend beyond the fur. Marsh rice rats are found in the southeastern United States. They are most abundant in freshwater marshes, saltwater marshes, and wet grassy meadows. They are sometimes found along wet ditches and the open edges of lakes and streams and are very good swimmers.

In south Florida, marsh rice rats are abundant in freshwater prairies and sloughs (Smith and Vrieze 1979; Mazzotti et al. 1981). In the wet season, marsh rice rats can commonly be found in prairie habitats (Smith and Vrieze 1979; Mazzotti et al. 1981). During the dry season, marsh rice rats abandon the prairie habitats for more mesic sites (Smith and Vrieze 1979). Marsh rice rats are active mostly at night and to some extent during the day. They eat seeds of grasses and

sedges, tender green plants, berries, fruits, fungi, snails, insects, crustaceans, and bird eggs (Brown 1997). Marsh rice rats make extensive runway systems where the vegetation is thick enough (Brown 1997). Their nests are grapefruit-sized spherical masses suspended in thick vegetation over water. Feeding platforms of matted vegetation are sometimes constructed in marshy environments.

Peromyscus gossypinus

The cotton mouse is a fairly large deer mouse. The upper pelage can vary from chestnut brown to dark brown or grayish brown. The middle of the back is darker than the sides. The underparts are white and there is no orange wash down the sides where the white meets the dark upper pelage. The tail is equal to or slightly longer than the body. It is sparsely haired and distinctly bicolored with the upper side brown and the underside white. The ears are large, rounded and gray. Cotton mice occur throughout Florida and are most abundant in mature hardwood forests (Brown 1997). They the most abundant mouse found in Florida (Brown 1997). In south Florida, cotton mice are most abundant in upland habitats (Smith and Vrieze 1979; Mazzotti et al 1981). In the dry season, cotton mice were primarily found in upland habitats, but some were caught in prairie habitats (Smith and Vrieze 1979). During the wet season, cotton mice are found in upland habitats (Bigler and Jenkins 1975; Smith and Vrieze 1979; Mazzotti et al. 1981). Cotton mice are active at night and often nest in logs, hollow stumps and holes in the ground. They also climb trees and build a spherical nest of leaves and plant fibers in hollow cavities. Food includes acorns, nuts, and seeds of trees, as well as snails, slugs, spiders, and insects. They have also been known to eat several types of mushrooms and other fungi.

Blarina carolinensis

The southern short-tailed shrew is an insectivorous rodent that has degenerate eyes and small ears hidden by fur. Short-tailed shrews range is in the southeastern United States and is

found throughout Florida, except for the Keys. Short-tailed shrews are most common in wooded areas, but are sometimes found in old fields, brushy areas and forest openings. Their fur is velvet like and grey, and their tails are short and barely reach beyond the extended hind foot. Their metabolic rate is high and they spend most of their time foraging for food. They have a heart rate of 160 beats per minute while respiration is around 150 breaths per minute (Brown 1997).

The diet of short-tailed shrews consists of mice, small snakes, snails, slugs, insects, spiders, and earthworms. This species is considered one of the most aggressive shrews and will attack and kill prey much larger than itself (Brown 1997). It has a submaxillary salivary gland that produces a neurotoxin and a hemotoxin that is introduced through a bite. The poison causes the prey's breathing and heart rate to slow, and the prey is then either eaten or stored.

Short-tailed shrew nests are comprised of dried grasses and leaves and are usually built in stumps, logs, or underground. The nests are six to eight inches in diameter and may have several openings. Breeding primarily occurs from early spring to late fall with two or three litters producing two to eight young. The gestation period is 21 days and the young are weaned at four weeks and start to breed at three months.

Potential Impacts to Wildlife

Human intrusions into wildlife habitats can cause various types and levels of changes in wildlife and habitats (Hammitt and Cole 1998). Wildlife can respond to ORVs in different ways depending upon type of activity, behavior of recreationists, frequency and magnitude of ORV use, timing, and location (Knight and Cole 1995). Interactions may be direct (Cole and Knight 1990) or indirect (Skagen et al. 1991; Pfister et al. 1992). Direct interactions involve various levels of disturbance, harassment, and harvesting of species, while indirect interactions modify habitat and cause stress (e.g. noise) (Hammitt and Cole 1998).

Habitat Modification

Vegetation can be classified into three types of strata; ground cover, shrubs and saplings, and mature trees (Hammit and Cole 1998). Ground cover is directly affected where ORV use breaks and crushes plants. Most plants exhibit reduced abundance, height, vigor, and reproductive capacity in impacted sites (Hammit and Cole 1998). Cole (1985) found a linear relationship between certain vegetation type covers and amount of use. Cover loss is increased rapidly with initial increases in use. Low lying shrubs and saplings are part of the ground cover and are susceptible to trampling. McEwen and Tocher (1976) found 76 saplings per acre compared to 338 per acre in adjacent unused section. Possibly the most serious effect is its long term impact on recruitment. Tree reproduction is negligible as a result of trampling (Hammit and Cole 1998). Major impacts on mature trees result from vehicular impacts. Roots are exposed from erosion due to vehicular traffic (personal observation). Trees with exposed roots are more at risk of wind throw in major wind events, such as hurricanes.

Habitat change can affect behavior, distribution, survivorship and reproduction of wildlife (Hammit and Cole 1998). Not only do ORVs cause physical damage to animals through the collapse of burrows and tunnels, they also reduce animals' means to escape extreme temperatures. Snowmobiles compact snow on which mice, shrews, and voles rely for its insulating properties (Schmid 1971; Stace-Smith 1978). Removal of shrubs and hazardous trees from campgrounds eliminates sources of food and shelter for birds and small mammals (Webb 1968). ORV use at the beach mixes dry upper sand with wet lower sand eliminating a natural moisture barrier and increasing desiccation of the sand (Brodhead and Godfrey 1979). This lack of moisture dried out gills of the Ghost Crab (*Ocypote quadrata*) causing mortality (Steiner and Leatherman 1981).

Species Composition and Structure

Population declines of the desert tortoise (*Gopherus agassizii*) (Bury 1980) and Couch's spadefoot (*Scaphiopus couchi*) (Berry 1980) have been linked to ORVs. Likewise, beluga whales' (*Delphinapterus leucas*) abundance declined in the St. Lawrence Estuary due to increased boating activity over several years (Caron and Sergeant 1988). In the Netherlands, negative relationships between intensity of recreation and population density were recorded for eight of 13 avian species; in areas where recreational use was common, 11 of the 12 most common species exhibited lower numbers than those in areas with fewer visitors (Van der Zande and Vos 1984). Similarly, in the west Netherlands where primary songs were affected by disturbances, birds appeared reluctant to establish territories (Reijnen et al. 1994). Adult bald eagles were more sensitive to disturbance than younger birds and preferred areas of lower human activity (Stalmaster and Newman 1978). Townsend's solitaires (*Myadestes townsendi*) exhibited reduced numbers as far as away as 100 m from trails (Miller et al., 1998).

Alteration of Behavior

Disturbance can cause behavioral changes among wild animals that range from slight modifications to extirpation (Hammit and Cole 1998). Wildlife may react to disturbance by elevated metabolism, lowered body weight, reduced fetus survival, and withdrawal from suitable habitat (Geist 1971; Moen 1976). White-tailed deer (*Odocoileus virginianus*) moved farther away from trails as snowmobile activity increased (Dorrance et al. 1975). Displacement of deer from suitable habitat during stressful winter conditions may lead to changes in their energy budget, which could be detrimental (Dorrance et al. 1975). Florida panthers (*Puma concolor corys*) were found farther from ORV trails during the hunting season in BCNP, which may be linked to prey behavior or disturbance (Janis and Clark 2002). ORV disturbance at beaches reduced reproduction and recruitment in ghost crabs (Steiner and Leatherman 1981). Bald eagles

Haliaeetu leucocephalus) avoid using areas of high activity and were not as successful in feeding attempts where existing human activities were present (Stalmaster and Newman 1978). Feeding was the activity most sensitive to human disturbance. Birds that were disturbed by ORVs did not return to feeding sites until several hours after the disturbance (Stalmaster and Newman 1978). Cetaceans such as bottlenose dolphins (*Tursiops truncatus*), killer whales (*Orcinus orca*) and harbor porpoises (*Phocoena phocoena*) increased swimming speed (Kruse 1991), changed surfacing patterns (Janik and Thompson 1996), adjusted dive length (Evans et al. 1992) and altered foraging habitat selection (Allen and Read 2000) in response to boats.

Objectives

Objectives of this study were to determine if ORV use influenced small mammal population and community structure and to inform managers in BCNP about the impacts of ORVs on small mammals. Chapter 2 describes influences that ORVs had on the vegetative communities that make up small mammal habitat in BCNP. Chapter 3 describes population responses of small mammals to ORVs, and applies the method of site occupancy estimation (MacKenzie et al. 2002) to describe distribution of the three small mammal species in BCNP. Chapter 4 discusses the overall usefulness of small mammals as indicators of ORV impacts in southern Florida, and provides recommendations for monitoring of small mammals in BCNP.



Figure 1-1. Image of a swamp buggy commonly used in Big Cypress National Preserve, Ochopee, Florida.



Figure 1-2. Image of a typical street-legal 4×4 used in Big Cypress National Preserve, Ochopee, Florida.



Figure 1-3. Image of an all-terrain vehicle (ATV) commonly used in Big Cypress National Preserve, Ochopee, Florida.



Figure 1-4. Image of an airboat commonly used in Big Cypress National Preserve, Ochopee, Florida.

CHAPTER 2 RESPONSE OF VEGETATION TO OFF-ROAD VEHICLES

Introduction

Big Cypress National Preserve (BCNP) was established in 1974 to ensure preservation, conservation, and protection of natural scenic, floral and faunal, and recreational values of the Big Cypress Watershed in southern Florida. BCNP was the first national preserve integrated into the National Park Service and its establishment helped to protect the hydrology of the southern Everglades ecosystem. BCNP is comprised of a mixture of pinelands, hardwood hammocks, prairies, mangrove forests, and cypress strands and domes (Duever et al. 1986). Many visitors take advantage of various recreational activities including hiking, nature viewing, canoeing, camping, hunting, and operating off-road vehicles.

Off-road vehicles (ORVs) are used in many recreational activities, and as a result, there can be impacts to the surrounding environment. A number of studies have attempted to quantify damage caused by ORVs. ORVs have been shown to affect vegetation by reducing plant cover and height, decreasing species diversity, and altering community composition (Bates 1935, Chappell et al. 1971, Trew 1973, Liddle and Greig-Smith 1975, Boorman and Fuller 1977). Research on the effects of ORV use on vegetation has been conducted in several habitat types. Impacts on dunes include reduction of total number of species, species diversity and total vegetation cover (Brodhead and Godfrey 1977, Hosier and Eaton 1980). Grasslands have exhibited slow recovery and growth and reduced vegetative cover from impacts (Foresman et al. 1976, Wilshire et al. 1978, Webb 1983). Bulk density and macropore space decreased in desert scrub habitats from impacts (Davidson and Fox 1974, Vollmer et al. 1976, Bury et al. 1977, Lathrop 1978). Snow compaction and decreased subnivian airspace from snowmobiles damaged samplings in the tundra (Neumann and Merriam 1972, Wooding and Sparrow 1978,

Emers et al. 1995). Off-road vehicles striped vegetation and reduced soil moisture in chaparrals (Wilshire et al. 1978). Habitat fragmentation occurs when habitat loss or anthropogenic influences divide an area of relatively contiguous habitat into smaller, fractured tracts. Fragmentation changes the amount of habitats, isolates patches from other patches of the same habitats, and alters adjoining habitats by changing their spatial characteristics (Garrison 2005). However, few studies have examined the response of vegetation to ORV impacts in Florida's ecosystems.

Wheeled ORVs, which are familiar in Florida swamps and marshes, are a common mode of transportation because they can traverse remote wetland areas. Rapid population growth and resulting increase in recreation pressure in southern Florida have led to concern about damage to natural resources. Land managers are confronted with a difficult and controversial situation of protecting wildlife and habitat while juggling demands for increasing recreational access to public lands (Cordell and Bergstrom 1991, English et al. 1993, Knight and Gutzwiller 1995) including BCNP.

ORVs were used in the Big Cypress Swamp region before the creation of BCNP; therefore that tradition was incorporated into the enabling legislation. The enabling legislation allows use of ORVs, but stipulates that ORV use will be controlled in a manner that will not harm resources of BCNP. Concerns over potential impacts on wetland ecosystems have been escalating because of increased use of ORVs. Possible negative effects include disturbance of wildlife, vegetation, soils, habitat fragmentation and changes in hydrology. ORV use can lead to habitat fragmentation by tire ruts, isolating patches of vegetation. In addition, there have been conflicts among recreationists, hunters, and environmentalists over perceptions of BCNP's natural resource use policy. These conflicts prompted BCNP to develop an ORV use management plan

to assess potential outcomes of various management alternatives. One major concern is effects of ORV travel on vegetation. Pine and prairie habitats are relatively easy to traverse with ORVs compared to cypress and hammock habitats. Cypress domes and strands have high density of trees and cypress knees that could cause damage to ORV drive train, while hammocks are typically composed of hardwood species that grow to large sizes that cannot be pushed over by ORVs permitted by BCNP. Prairie and pine habitats are ideal locations for finding game species, and as a result, hunters using ORVs utilize these habitats heavily.

The only study to examine ORV use in BCNP habitats was conducted by Duever et al. in 1981 and 1986. Duever et al. (1981) detailed experiments conducted with four major ORV types (3-wheeled all-terrain cycles (ATCs), airboats, tracked vehicles, and swamp buggies) used in BCNP and examined their impacts on four major vegetation associations (marshes with sand, marl and peat substrates; cypress; and pine habitats). Experimental lanes were created in each of the habitats and impact levels were determined by the number of passes by a vehicle. One pass by a vehicle was categorized as a light impact, medium impact sites were categorized by multiple passes that impacted vegetation but not soil, and heavy impact sites were categorized by multiple passes that severely impacted vegetation and created ruts in the soil. Dwarf cypress was the habitat type found to be most sensitive to wheeled ORV impacts, while pine was most resistant. All impacted habitats were significantly different from control plots (Duever et al. 1981). Vegetation recovery rates for the first year varied from less than 25 percent to 50 percent, depending on the habitat and the type of vehicle used (Duever et al. 1981). After six years, there was still visible damage in most habitats (Duever et al. 1986). My study differs from Duever's in that I quantify the response of vegetation in response to ORV use by examining percent ground cover and vertical cover.

Since the original studies by Duever and others, ORV use in BCNP has persisted, increased, and become very controversial. The National Park Service was sued by the Florida Biodiversity Project, U.S. Department of Interior, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, U.S. Department of the Army and the U.S. Army Corps of Engineers in 1995 for failure to implement an ORV management plan. The purpose of the current study is to investigate impacts to vegetation structure in response to ORV use in BCNP. Based on previous studies (Duever et al. 1981 and 1986), we hypothesize that ORV use reduces percent ground cover, height, and vertical cover of vegetation.

Study Area

BCNP is located in southwest Florida. The Big Cypress regional climate is affected by both tropical and temperate influences (Duever et al. 1986). The region is characterized by hot, humid summers and mild, dry winters. Southwest Florida has been classified as a tropical savanna due to its temperature and rainfall (Hela 1952).

The landscape of BCNP contains 295,000 ha of a heterogeneous mixture of pine forests, prairies, cypress dome/strands, marshes, and isolated hardwood hammocks (Duever et al. 1986). Pine forests are open areas that are composed primarily of South Florida slash pine (*Pinus elliottii* var. *densa*) and are usually bordered by wet prairies. A fire frequency of three to seven years is required to prevent succession from pine forest to hardwood hammock (Hofstetter 1984). Pine forests are elevated from a few centimeters to a meter or more above the surrounding lowlands, which results in a gradient in hydroperiod. The variety *densa* developed longer taproots and smaller needle size than the northern variety of *elliottii* in response to different water conditions (McMinn and McNab 1971). Variety *densa* is also highly fire tolerant and young seedlings sprout needles at the root collar below the burned growing tip (Ketcham and Bethune 1963). Cabbage palms (*Sabal palmetto*) are often abundant in pine forests. They tolerate

flooding by producing adventitious roots (Brown 1973) and have an embedded bud and a fire-resistant trunk (Myers 1977). Saw palmettos (*Serenoa repens*) are often associated with pine forests and are well adapted to fire but do not withstand inundation as well as cabbage palms. Hardwood shrubs and trees can be found scattered throughout pine forests where fire has not been present. Ground cover is usually dominated by grasses such as bluestem (*Andropogon floridanus*) and panic grass (*Panicum hemitomon*). Sedges, rushes, and composites may also be present.

Prairie communities are dominated by herbaceous vegetation and grow along a hydroperiod gradient. They have mixed grasses, sedges, and other herbaceous plants with few trees. Prairies may be seasonally inundated or infrequently inundated depending upon elevation. Prairie habitats are maintained by fire and burn about every one to three years to prevent the invasion of woody vegetation (Wade et al 1980). Common species include maidencane (*Panicum hemitomon*), blackhead rush (*Schoenus nigricans*), muhly (*Muhlenbergia batatifolia*), and scattered sawgrass (*Cladium jamaicensis*). Maximum water levels rarely exceed 20 cm and are inundated approximately 50-150 days per year (Duever et al. 1975).

Methods

The study was conducted between October 2004 and September 2005. Study sites were located in BCNP near the Concho Billie ORV access area and Upper Wagonwheel Road (Collier County Road 837). The Concho Billie ORV access site has been open to ORVs since the inception of BCNP, and we designated it as the ORV area in our study. Upper Wagonwheel Road has been closed to ORVs for more than 20 years and was designated as the non-ORV area.

A total of eight sample sites were randomly chosen from aerial maps that had at least 100 m of pine and an adjacent 100 m of prairie habitats. In October 2004, four sites were established: two in ORV and two in non-ORV areas. In January 2005, four more sites were established: two

in ORV and two in non-ORV areas. At each sample site, a 200 m transect was established with 100 m of the transect in pine habitat and 100 m in adjacent prairie habitat. Sample points were located every 10 m along the transect for a total of 21 points per transect.

Vegetation groups were categorized as graminoids (sedges and grasses), forbs (non-graminoids) or shrubs. Non-vegetation groups were categorized as bare ground or litter. At each sample point, a meter stick was used to measure average plant height to the nearest millimeter for each vegetation group. Percent ground cover was measured using a 1 m × 1 m quadrat made of PVC. Percent ground cover was used to estimate the amount of ground covered by vegetation within the quadrat. Bare ground was recorded when no vegetative group was touched. Twine was laced to create 100 intersections 10 cm apart creating a one m² quadrat. A wire was lowered at each intersection and the vegetation group first touched was recorded. Percent cover plots were measured 1 m from the sample location using random compass readings created from a random point generator ranging from 1 to 360. Percent ground cover was calculated by summing the total number of intersections at which each plant group occurred and dividing by 100.

A cover board (Nudds 1977) was used to assess vertical cover. A board 2.5 m in height and 30.48 cm wide was marked alternately with white and black bands at 0.5 m intervals. The board was divided into five categories (0-20%, 21-40%, 41-60%, 61-80%, and 81-100%). The vertical cover was assessed at each location by viewing the board from 15 m away in a randomly chosen direction. All vegetation measurements were recorded during the dry season (January through March).

Analysis of variance was used to determine if there were any differences in percent ground cover, vertical cover and plant height between ORV and non-ORV sites. All percent values were arcsine-transformed prior to analysis because the data were not normally distributed (Zar 1984).

Results

Variation in vegetation height differed depending upon habitat type and ORV use. Overall graminoid and shrub height was significantly higher in non-ORV areas than in ORV areas (Table 2-1). Height values for forbs were not significantly different between ORV and non-ORV areas. In pine habitats, graminoid height was significantly higher in non-ORV areas than in ORV sites (Table 2-2). Forb and shrub heights were not significantly different from one another in non-ORV and ORV pine sites. In prairie habitats, forb height was significantly higher in non-ORV areas than in ORV areas (Table 2-3). Shrub height was significantly higher in ORV areas than in non-ORV areas (Table 2-3). There was no significant difference in graminoid height in prairie habitats.

Percent ground cover was significantly lower in ORV than in non-ORV areas (Table 2-4). ORV areas showed an 11.19 percent decrease in mean percent cover from non-ORV areas. Percent ground covers in pine habitats in ORV areas were significantly lower than in non-ORV areas. ORV areas showed a 13.01 percent decrease in mean percent ground cover from non-ORV areas (Table 2-4). Percent ground covers of prairie habitats in ORV areas were significantly lower than non-ORV areas. An 8.51 percent decrease in mean percent ground cover in ORV from non-ORV prairie habitats was significant (Table 2-4). Vertical cover of pine vegetation in the 0.0m to 0.5m and 1.0m to 1.5m height classes were significantly higher in non-ORV than ORV sites (Table 2-5). There were no significant differences found in any other vertical cover comparisons (Table 2-5 and Table 2-6).

Discussion

The objectives of this study were to investigate impacts ORVs have on vegetation communities. I hypothesized that forb, graminoid, and shrub heights would be lower in ORV sites than in non-ORV sites due to the increased traffic from vehicles. I found that different

vegetation types respond differently to ORV impacts. Overall graminoid height was higher in non-ORV sites than in ORV sites. In prairie habitats, forb height was higher in non-ORV sites than ORV sites. On the other hand, in pine habitats, graminoid heights and prairie shrub heights were higher in ORV sites than in non-ORV sites. Duever et al. (1981) found that initial ORV impact was significantly decreased plant height from the control group; after one year without ORV use, they found that pine habitat had recovered completely and marl marsh had recovered except for heavily impacted sites. A possible explanation for my finding that the graminoid height was higher in ORV pine sites is that constant trampling from ORVs may cause the pine forest floor to revert to an early successional stage. Shrub heights in ORV sites in prairie habitats might be higher due to ORV users. Off-road vehicle operators traveling through marl prairies would want to travel through a path of least resistance and avoid anything that would slow down their momentum. Off-road vehicle operators would avoid hitting shrubs and would trample surrounding vegetation, which may benefit shrubs.

My results also supported the hypothesis that percent ground cover in ORV sites would be less than in non-ORV sites. This finding applied to both pine and prairie sites. This is consistent with Duever et al.'s (1981) finding that percent ground cover in pine and marl prairie was significantly lower in ORV-impacted sites than in control sites. Duever et al. (1981) also found that increased use of ORVs decreased the percent ground cover in marl prairies, but did not find any clear trends in the pine habitats. Reduced ground cover could impact wildlife. Many species rely on cover from vegetation to hide from predators.

I hypothesized that vertical cover would be lower in ORV sites than non-ORV sites. Vertical structure is important to wildlife as it provides both hiding cover and thermal cover. The 0.0-0.5m and 1.0-1.5m height classes showed a difference between ORV and non-ORV sites.

Long-term monitoring plots could be established in current ORV use areas, recovering ORV use areas, and non-ORV use areas. Monitoring plots would help resource managers understand the effects of ORVs on vegetative communities and recovery of vegetation from ORV impacts.

During this study, I did observe that ORV sites had a loss of continuous habitat from ORV ruts. These ruts may lead to habitat fragmentation. Habitat fragmentation is a set of mechanisms (i.e. ORV use) leading to the discontinuity in spatial distribution of resources and conditions present in an area at a given scale that affects occupancy, reproduction, and survival of particular species (Franklin et al. 2002). Habitat fragmentation from ORVs may reduce size of natural patches and increase distance between patches. Fragmentation effects can be magnified by edge effects with remaining habitats (Lindenmayer et al. 1999). Duever et al. (1981) documented soil displacement and rut depth from ORVs in their experiment and documented its effects on vegetation. Ruts created by ORVs can alter depth and period of inundation of areas, resulting in the loss of vegetation and increased ponding in ruts and artificial depressions (Duever et al. 1981). But effects on wildlife are unknown. Larger animals, such as the Florida panther (*Puma concolor coryi*) and the American alligator (*Alligator mississippiensis*), use ORV trails to travel and may benefit from ORV trails because it helps them transverse dense habitat (personal observation). However, effects of ORV ruts on smaller animals may be more detrimental and may influence behavior patterns. Managers should take into consideration the impacts ORVs have on vegetation. The decrease ground cover would leave many smaller species susceptible to larger predators. The results of this study raise additional questions for future research: To what extent does ORV use fragment pine and prairie habitats? Does the species composition change from non-ORV to ORV areas?

Table 2-1. Overall variation in height among three vegetation classifications (forb, graminoid, and shrub) and two impact levels (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) at Big Cypress National Preserve.

Vegetation Type	Impact	n	Mean Height	F-Value	p-value
Forb	ORV	87	199.00	0.00112	0.9
	Non-ORV	88	198.43		
Graminoid	ORV	87	528.69	4.08	<0.05
	Non-ORV	88	578.00		
Shrub	ORV	45	280.35	2.48	0.1
	Non-ORV	36	275.14		

Table 2-2. Variation in height among three vegetation classifications (forb, graminoid, and shrub) and two impact levels (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) in pine habitat at Big Cypress National Preserve.

Vegetation Type	Impact	n	Mean Height	F-Value	p-value
Forb	ORV	38	3.50	0.0227	0.8
	Non-ORV	32	3.64		
Graminoid	ORV	43	501.16	6.25	<0.05
	Non-ORV	44	594.64		
Shrub	ORV	34	614.02	1.04	0.3
	Non-ORV	33	509.80		

Table 2-3. Variation in height among three vegetation classifications (forb, graminoid, and shrub) and two impact levels (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) in prairie habitat at Big Cypress National Preserve.

Vegetation Type	Impact	n	Mean Height	F-Value	p-value
Forb	ORV	30	1.84	6.86	<0.05
	Non-ORV	40	3.14		
Graminoid	ORV	44	556.23	0.011	0.9
	Non-ORV	44	559.32		
Shrub	ORV	11	146.68	4.49	<0.05
	Non-ORV	3	40.48		

Table 2-4. Variation in vegetative percent ground cover between habitats (pine and prairie) and impacts (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) (Percent cover data was arcsin transformed for analysis).

Habitat	Impact	n	Mean Percent Cover	F-Value	p-value
Overall	ORV	88	75.13	13.64	<0.001
	Non-ORV	88	84.16		
Pine	ORV	44	72.34	10.26	<0.01
	Non-ORV	44	83.16		
Prairie	ORV	44	77.91	4.41	<0.05
	Non-ORV	44	85.16		

Table 2-5. Variation in vegetative vertical cover among pine habitats and impacts (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)).

Layer	Impact	n	Mean Cover	F-Value	p-value
0.0-0.5	ORV	44	2.25	2.88	0.1
	NonORV	47	4.00		
0.5-1.0	ORV	18	1.25	0.628	0.5
	NonORV	17	2.00		
1.0-1.5	ORV	14	3.50	3.857	0.1
	NonORV	20	5.00		
1.5-2.0	ORV	4	1.00	0.0588	0.8
	NonORV	5	1.25		
>2.0	ORV	5	1.25	1.174	0.3
	NonORV	2	0.50		

Table 2-6. Variation in vegetative vertical cover among prairie habitats and impacts (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)).

Layer	Impact	n	Mean Cover	F-Value	p-value
0.0-0.5	ORV	31	7.75	0.338	0.6
	NonORV	35	8.75		
0.5-1.0	ORV	13	3.25	0.338	0.6
	NonORV	9	2.25		
1.0-1.5	ORV		0		
	NonORV		0		
1.5-2.0	ORV		0		
	NonORV		0		
>2.0	ORV		0		
	NonORV		0		

CHAPTER 3
ECOLOGY OF SMALL MAMMALS IN BIG CYPRESS NATIONAL PRESERVE IN AREAS
AFFECTED BY ORV USE

Introduction

Big Cypress National Preserve (BCNP) was established to include recreational ORV use (16 USC 698). Off-road vehicles (ORVs) are commonly used throughout the Preserve for recreation, especially hunting. As a result of fragmentation, once contiguous habitat has increased into small patches delimited by tire ruts. Duever et al. (1981) demonstrated that ORVs altered vegetation composition and hydrology. Fragmentation of natural habitats and vegetation changes has potentially negative effects on natural populations of small mammals such as change of behavior or change in body condition. There is evidence that ORV use altered the behavior of the endangered Florida panther in BCNP (Janis and Clark 2002). Understanding these changes has important implications for land-use policies that promote long-term survival and persistence of natural populations.

Small mammals may be an ideal taxonomic group for addressing questions of impacts of ORV use to wildlife populations in BCNP. Detailed information regarding biology and natural history of small mammals at the organismal, population, and community levels is readily available (Chase et al. 2000; Mares and Ernest 1995). Small mammals are easily marked to monitor their movements, behavior, and study life history parameters such as survival and occupancy. Live-trapping studies have revealed dispersal behavior and an understanding of why a particular species selects a particular habitat (Gaines and McClenaghan 1980). Small mammals live in relatively small areas and have short lives. They typically disperse upon reaching adulthood and exhibit behavioral responses to environmental and anthropogenic changes. I selected pine and prairie habitats because these habitats are used by ORV users the most (Duever

et al. 1981). Pine and prairie habitats are also easily traversed than cypress and hammock habitats because of low density of trees and less obstacles.

The objective of this study was to determine: 1) if ORV or habitat use influence small mammal abundance, 2) if ORV or habitat use changes body condition of small mammals, 3) does ORV use change survival of small mammals, 4) does occupancy change in ORV use areas. I hypothesized that captures of *Sigmodon hispidus* (hispid cotton rat), *Oryzomys palustris* (marsh rice rat), and *Peromyscus gossypinus* (cotton mouse) in non-ORV sites are greater than in ORV sites because changes in vegetation would not make suitable habitat. Abundances and body condition of hispid cotton rats and cotton mice should be higher in pine habitats, while that of marsh rice rats are higher in prairie habitats because those are their preferred habitats. I also predict that body condition of all the small mammal species will be greater in non-ORV sites than in ORV sites because the ORV sites may not have the necessary vegetation for cover and food. Males should have a higher body condition than females regardless of ORV presence because females will have young to take care of. Occupancy of all species will be greater in non-ORV sites than ORV sites, as non-ORV sites are more continuous habitat. Finally, I hypothesize that survival and capture probabilities of hispid cotton rats, marsh rice rats, and cotton mice are lower in ORV than in non-ORV sites due to sparse vegetation in ORV sites based on my findings in Chapter 2.

Methods

Study Area

Big Cypress National Preserve is located in southwest Florida. The Big Cypress regional climate is affected by both tropical and temperate influences (Duever et al. 1986). The region is characterized by hot, humid summers (30-35°C) and mild, dry winters (19-24°C). Southwest

Florida has been classified as a tropical savanna due to its temperature and rainfall (148.8 cm/year) (Hela 1952).

The landscape of BCNP contains 295,000 ha of a heterogeneous mixture of pine forests, prairies, cypress dome/strands, marshes, and isolated hardwood hammocks (Duever et al. 1986). Pine and prairie habitats are the most abundant communities in BCNP and are most used by ORV enthusiasts (National Park Service 2000). Pine forests are open areas that are composed primarily of South Florida slash pine (*Pinus elliottii* var. *densa*) and are usually bordered by wet prairies. A fire frequency of three to seven years is required to prevent succession from pine forest to hardwood hammock (Hofstetter 1984). Pine forests are elevated from a few centimeters to a meter or more above the surrounding lowlands, which results in a gradient in hydroperiod. The variety *densa* developed longer taproots and smaller needle size than the northern variety of *P. elliottii* in response to different water conditions (McMinn and McNab 1971). Variety *densa* is also highly fire tolerant and young seedlings sprout needles at the root collar below the burned growing tip (Ketcham and Bethune 1963). Cabbage palms (*Sabal palmetto*) are often abundant in pine forests. They tolerate flooding by producing adventitious roots (Brown 1973) and have an embedded bud and a fire-resistant trunk (Myers 1977). Prairie habitats are maintained by fire and burn about every one to three years to prevent the invasion of woody vegetation (Wade et al 1980). Saw palmettos (*Serenoa repens*) are often associated with pine forests and are well adapted to fire but do not withstand inundation as well as cabbage palms. Hardwood shrubs and trees can be found scattered throughout pine forests where fire has not been present. Ground cover is usually dominated by grasses such as bluestem (*Andropogon floridanus*) and panic grass (*Panicum hemitomon*). Sedges, rushes, and composites may also be present.

Prairie communities are dominated by herbaceous vegetation and grow along a hydroperiod gradient. They have mixed grasses, sedges, and other herbaceous plants with few trees. Prairies may be seasonally inundated or infrequently inundated depending upon elevation. Common species include maidencane (*Panicum hemitomon*), blackhead rush (*Schoenus nigricans*), muhly (*Muhlenbergia batatifolia*), and scattered sawgrass (*Cladium jamaicensis*). Maximum water levels rarely exceed 20 cm and are inundated approximately 50-150 days per year (Duever et al. 1975).

Site Selection

A total of eight sample sites were randomly chosen from aerial maps that had at least 100 m of pine adjacent to 100 m of pine habitats. ORV sites were established in areas where ORV use is permitted and non-ORV sites were established in areas where ORVs are excluded for at least 20 years. On October 2004, four sites were established: two in ORV and two in non-ORV areas. On January 2005 four more sites were established: two in ORV and two in non-ORV. At each sample site, a 200 m transect was established with 100 m in pine habitat and 100 m in prairie habitat.

Small Mammal Surveys

We captured four species of small mammal in BCNP: hispid cotton rat, marsh rice rat, cotton mouse, and southern short-tailed shrew (*Blarina carolinensis*). Captures of southern short-tailed shrews were not included in the analysis because of their low numbers. Rodents were live trapped from October 2004 to September 2005 using Sherman live traps (3 × 3.5 × 9 inch) baited with sunflower seeds. A total of 44 traps were set on each transect with two traps set every 10 m (n=176 traps). When temperatures were forecasted below 20 degrees Celsius, cotton was provided to prevent hypothermia. The absence/presence of standing water was recorded for each trap location at a wooden stake. During the wet season, traps were placed on 30cm × 30 cm

Styrofoam® floats. Sampling of the original four sites occurred every other week. When four new sites were established in January 2005, at which point sampling frequency decreased to once per month. During each sampling session, sites were trapped for three or four consecutive nights depending upon weather. Traps were closed after the morning inspection to ensure that no animals were caught and exposed to the afternoon heat. Traps were reopened before sunset. When the traps were not in use, they were removed from the study area and were thoroughly cleaned with bleach to remove uneaten food and prevent transmission of disease and parasites.

When animals were captured, they were carefully removed from the trap and placed into a bag to avoid harm and reduce stress. The captured animals were identified by species, age (adult/juvenile), sex (male/female), and reproductive status. Males were considered reproductive if they had descended testes and females were considered reproductive if they were pregnant, had a perforated vagina, or had lactating mammary glands. Measurements of head-body length, head length, and right hind foot length were measured with a ruler to the nearest millimeter. Each individual was weighed using a hanging scale to the nearest gram.

Captured animals were individually marked on both ears using National Band and Tag Company Small Mammal Ear Tag #1005-1 (<http://www.nationalband.com/1005b.htm>). All animals were released as soon as possible after capture at the original capture site.

Statistical Analysis

Comparisons of capture numbers in ORV/non-ORV sites and pine/prairie habitat were made using a Chi² test. Mean weight, mean length, and body condition in ORV/non-ORV sites and pine/prairie habitat were made using Wilcoxon Rank Sign test

Body condition was assessed by regressing body weight against a right hind foot length. Data were transformed using a natural log to meet assumptions of the regression analysis. Body condition was assessed using Fulton's K:

$$K = 10^4 \cdot W/L^3,$$

where W = weight (g), L^3 = skeletal measurement length (mm) and “3” is used to assume growth is isometric. Isometric growth is when growth occurs at the same rate for all parts of an organism so that its shape is consistent throughout development. The key assumptions are that condition is independent of length, that the measure used for length is an accurate measure of structural size, that length measurements are not subject to error, and that the relationship between body size and mass is linear (Green 2001). The condition index was compared using Wilcoxon Rank Sign test for the observational groups from each species (ORV vs. Non-ORV, male vs. female, pine vs. prairie). Only non-pregnant adults were used in the body condition analysis. Pregnant females may show better body condition as the fetus may increase the weight of the female. There is little information on when juvenile rodents stop suckling and the addition of female milk to the diet of juveniles may bias the body condition analysis of juvenile individuals. Individuals were considered adults when their hind foot measurements were greater than 28 mm for hispid cotton rats (Cameron and Spencer 1981), 28 mm for marsh rice rats (Wolfe 1982), and 16 mm for cotton mice (Wolfe and Linzey 1977). I selected $\alpha = 0.1$ for all statistical testing to help better understand the biological changes that could be happening.

Detection probabilities for all small mammal species were assumed *a priori* to be less than one. By estimating detection probabilities, it was possible to estimate the true site occupancy rate of each species, while taking into account effects of environmental variables on behavior of the animals. Detection rates were not assumed to be constant. However, if a species was present, a detection probability greater than zero was assumed. Also, sites were assumed to be closed to changes in occupancy between subsequent samples.

The single season model in program PRESENCE was used to look at the impacts of ORVs on small mammal site occupancy rates and detection probabilities (MacKenzie et al. 2002; MacKenzie et al. 2006). The single season model assumes that sites are closed to changes in occupancy and that the detection of a species at a site is independent of detections from other sites. This method also assumes that species are not falsely detected, but species may or may not be detected when present. This method was considered appropriate for the small mammal species due to low dispersal and difficulty of detection. Sample sites were defined by using the trap locations from the eight 200 m transects, resulting in 176 sample sites. Presence/absence was recorded for each sample site when the traps were checked each day.

Site-specific covariables that could directly affect the estimate of occupancy (ψ) were ORV use (ORV/Non-ORV site), habitat type (pine/ prairie), and percent ground cover (see Chapter 2 for methods). A sampling occasion covariate that could affect detection probability (p) was presence of standing water. For each species, we considered 16 models that were combinations of the covariables thought to be biologically important (Table 3-1). The best model was chosen as the one with the lowest value for Akaike's information criterion (AIC) or the model with the best fit for the fewest parameters (Burnham and Anderson 1998). The effect of ORV use on species occupancy was established using model selection to determine the AIC weight of all models including the ORV use covariate and by examining the beta estimates for ORV use in the models.

Mark-recapture data were analyzed by using the Cormack-Jolly-Seber closed population recapture model performed in program MARK (White and Burnham 1999) to estimate survival for the three species. Individuals of all species were divided into two groups for analysis: ORV and non-ORV areas. A series of 26 models representing different hypotheses about the effects of

time and group on apparent survival (Φ) and capture probability (p) were fit for all species (Table 3-2).

Goodness of fit was assessed by estimating \hat{c} (variance inflation factor) using the parametric bootstrap method in program MARK (White and Burnham 1999) on the most general model, $\Phi_{g^*}p_{g^*}$. Model selection was conducted using the information-theoretic approach of Burnham and Anderson (1998) with the Quasi-likelihood Akaike's Information Criterion adjusted for over dispersion of data and small sample sizes (QAICc).

Results

Species Distribution and Abundance

From October 2004 to September 2005, I sampled on 14,784 trap nights at eight sites. Trapping yielded 412 individuals from four different species (Table 3-3). I had 1,293 recaptures of these individuals for a total of 1,710 captures. Most captures were cotton rats (57.5%) followed by marsh rice rats (29.1%), cotton mice (12.8%) and short-tailed shrews (0.6%) (Table 3-4). Hispid cotton rat captures peaked in April during the beginning of the wet season (Figure 3-1). Marsh rice rat and cotton mouse captures peaked in March after heavy rain events (Figure 3-1). Captures decrease in all small mammal species after a major rain event in May (Figure 3-3).

The hispid cotton rat was captured the most frequently, with 118 and 83 individuals captured, respectively, in ORV and non-ORV sites (Table 3-5). The hispid cotton rat also had the highest captures in pine habitats with 312 captures (Table 3-6). The marsh rice rat was the second most abundant species, with 75 individuals captured in ORV-impacted areas and 81 individuals captured in non-ORV areas (Table 3-5). The marsh rice rat was also the most frequent species in the prairie habitat with 190 captures and the second most abundant in pine

habitats with 72 captures (Table 3-6). The cotton mouse was the third most abundant species, with 46 individuals captured in ORV sites and five individuals captured in non-ORV sites (Table 3-5). Cotton mouse captures in pine habitats were 57 and in prairie habitats were 35 (Table 3-6). Short-tailed shrew captures in pine habitats were 4 and none were found in prairie habitats (Table 3-6). I exclude short-tailed shrews from the analysis due to their low numbers.

Mean hispid cotton rat captures in ORV sites (n=268) were significantly lower than in non-ORV sites (n=152, $\chi^2=32.038$, p -value <0.001) (Table 3-7). However, mean marsh rice rat captures showed no significant differences between ORV (n=101) and non-ORV sites (n=107 $\chi^2=0.173$, p -value = 0.7). In contrast, mean cotton mice captures were significantly higher in ORV sites (n=82) than in non-ORV sites (n=10, $\chi^2=56.348$, p -value <0.001) (Table 3-7). Mean hispid cotton rat captures in pine habitats (n=321) were significantly higher than in prairie habitats (n=99, $\chi^2=117.3$, p -value <0.001) (Table 3-7). On the other hand, mean marsh rice rat captures in prairie habitats (n=184) were significantly higher than in pine habitats (n=24, $\chi^2=123.1$, p -value <0.001) (Table 3-7). Conversely, mean cotton mice captures in pine habitats (n=57) were significantly higher than in prairie habitats (n=35, $\chi^2=5.621$, p -value = 0.02) (Table 3-7). Mean hispid cotton rat male captures (n=232) were not significantly higher than female captures (n=233, $\chi^2=6.565$, p -value = 0.3) (Table 3-7). Mean marsh rice rat male captures (n=150) were not significantly greater than female captures (n=94, $\chi^2=8.565$, p -value = 0.3) (Table 3-7). Mean cotton mouse male captures (n=59) were not significantly different from female captures (n=39, $\chi^2=10.915$, p -value = 0.09) (Table 3-7).

Weight and Size Comparisons

The mean weight of adult, non-pregnant hispid cotton rats was 113.96 ± 7.59 g (mean \pm SD). Male hispid cotton rats had significantly higher mean weights (125.55 ± 8.57 g, $p < 0.001$) than females (97.32 ± 10.76 g) (Table 3-8). The mean weights of hispid cotton rats for the

ORV/non-ORV and pine/prairie comparisons were not significantly different (Table 3-8). The mean adult head-body length of adult hispid cotton rats was 125.08 ± 3.98 mm. The mean adult head-body length of male hispid cotton rats (129.78 ± 4.59 mm, $p < 0.001$) was significantly higher than that of female hispid cotton rats (117.84 ± 7.64 mm) (Table 3-9). The mean adult head-body lengths of hispid cotton rats for the ORV/non-ORV and pine/prairie comparisons were not significantly different (Table 3-9).

The mean weight of adult, non-pregnant marsh rice rats was 56.77 ± 5.88 g. Male marsh rice rats' mean weight (62.61 ± 7.43 g, $p < 0.01$) was significantly higher than that of females (48.61 ± 7.59 g) (Table 3-8). The mean weights of marsh rice rats for the ORV/non-ORV and pine/prairie comparisons were not significantly different (Table 3-8). The mean adult head-body length of adult marsh rice rats was 103.89 ± 5.98 mm. The mean adult head-body lengths for the males (107.06 ± 8.35 mm, $p = 0.08$) were significantly larger than females (101.28 ± 6.78 mm). Marsh rice rat lengths in ORV/non-ORV, and pine/prairie comparisons were not significantly different (Table 3-9).

The mean weight of adult, non-pregnant cotton mice was 27.76 ± 3.09 g. There were no significant differences in average weights for male/female, ORV/non-ORV, and pine/prairie comparisons (Table 3-8). The mean head-body length of adult cotton mice was 83.68 ± 4.25 mm. There were significant differences in average head-body length for the male/female and pine prairie comparisons (Table 3-9). Male lengths (84.65 ± 4.99 mm, $p = 0.1$) were significantly larger than females (80.26 ± 7.64 mm). Cotton mice in pine habitats (84.60 ± 5.39 mm, $p = 0.1$) were longer than prairie habitats (81.21 ± 5.73 mm).

Body Condition

The regression of $\ln(\text{weight})$ on $\ln(\text{hind foot length})$ for hispid cotton rats, marsh rice rats, and cotton mice yielded significant regressions (Table 3-10). For all three species, the mean condition index was independent of ORV presence and habitat type (Table 3-11). Hispid cotton rat mean condition index score for females was significantly lower than that for males; female and male condition indices were equivalent for both marsh rice rats and cotton mice (Table 3-11).

A total of 176 sites were visited for a total of 48 sampling visits from October 2004 to September 2005. Of the 176 sites, 88 were located in prairie habitat and 88 were located in pine habitat. Also, of the 176 sites, 88 were located in ORV areas and 88 were located in non-ORV areas. Hispid cotton rats, marsh rice rats, and cotton mice were detected between 78-132 times, and naïve occupancy rates (proportion of sites at which a detection occurred) varied from 44 to 75 percent (Table 3-12).

The best model is recognized by using the lowest AIC value (Burnham and Anderson 1998). The two best models for the cotton rat included ORV use, habitat and percent cover as a site covariate (Table 3-13). ORV use had a negative beta estimate for occupancy in the second best model but the 95% confidence interval overlaps 0 and is not significant (Table 3-14). The best model had a habitat beta of 1.4233 (S.E. = 0.4233) and the second best model had a habitat beta estimate of 1.4298 (S.E. = 0.4283), indicating a positive association with pine habitats (Table 3-14). The best model had percent cover beta estimate of 0.8812 (S.E. = 0.2804) and the second best model had a percent cover beta estimate of 0.9906 (S.E. = 0.3521) indicating a positive association with higher horizontal vegetative percent cover (Table 3-14). Detection probability beta estimate for the cotton rat was -2.335 (S.E. = 0.1661), which suggests a strong negative detection with presence of standing water.

The two best models for the rice rat included ORV use, habitat, and percent cover as site covariates (Table 3-15). The best model had an ORV use beta estimate of 0.7212 (S.E. = 0.3732) but the 95% confidence interval overlaps 0 and is not significant; this is because we did not have a large enough sample size to detect a trend (Table 3-16). The best model had a habitat beta estimate of -2.6835 (S.E. = 0.4127) and the second best model had a habitat beta of -1.9206 (S.E. = 0.3847), indicating a positive detection with prairie habitat (Table 3-16). The best model had a percent cover beta estimate of 1.684 (S.E. = 0.4028) and the second best model had a beta of 1.9526 (S.E. = 0.3947), indicating a positive association with higher horizontal vegetative percent cover.

The best model for the cotton mouse included ORV use, habitat, and horizontal vegetative percent cover as site covariates (Table 3-17). The ORV use had a beta estimate of 2.7672 (S.E. = 0.5600), indicating a strong association with ORV use (Table 3-18). Habitat had a beta estimate of 1.0869 (S.E. = 0.5060), which indicates a positive association with pine habitat (Table 3-18). Percent cover had a beta estimate of -2.0566 (S.E. = 0.4980), indicating a negative association with horizontal vegetative percent cover (Table 3-18).

Mark-Recapture

During the sampling period, a total of 447 cotton rats, 218 marsh rice rats, and 97 cotton mice were captured. These captures included recaptures of 205 individual cotton rats, 157 individual marsh rice rats, and 51 individual cotton mice. The return rates (proportion of marked individuals recaptured at least once) for the cotton rat and the cotton mouse were higher in ORV areas than in non-ORV areas (Table 3-19). The return rates for the marsh rice rat were lower in ORV areas than in non-ORV areas (Table 3-19).

The parametric bootstrap of the most general Cormack-Jolly-Seber model for the cotton rat produced an estimate of $\hat{c} = 1.3206$. Three models had delta QAICc values less than 2 (Table 3-

20). Two of the three best models included ORV group effect on survival. Models that included ORV group effect on survival had 71.58% of the QAICc weight among the set of candidate models, and models that included ORV group effect on capture probability had 61.76% of the model weight.

The estimated beta for the best model that had ORV group effect on survival in cotton rats was 0.7567 (S.E. = 0.1817; Table 3-21). There was a mean decrease in survival of 7.98% from the non-ORV areas to the ORV areas (Figure 3-2). The estimate beta for the best model that included ORV effect on capture probability in cotton rats was 1.5163 (S.E. = 0.2951). Cotton rat recapture probability in non-ORV areas was 8.35% higher than that in ORV areas. It is interesting to note that survival numbers decreased dramatically after August. The drop of survival coincides with Hurricane Katrina (Category 1) which went through southern Florida August 23, 2005.

For the marsh rice rat, the estimate of \hat{c} from the parametric bootstrap was 1.699. Four models had delta QAICc values less than 2 (Table 3-22). Two of the top four models included ORV effect on survival and on capture probability. Models that included the ORV effect on survival for the marsh rice rat received 43.59% of the QAICc weight, and models that included the ORV effect on capture probability accounted for 45.85% of the total weight.

The estimated beta for the best model that included ORV effect on survival in the marsh rice rat was -0.6200 (S.E. = 0.4045), which indicates a slightly negative effect of ORV use (Table 3-21). But the 95% confidence interval includes 0, which means we did not have a large enough sample size to detect a trend. There was a mean decrease in survival of 5.47% from the non-ORV areas to the ORV areas (Figure 3-3). The estimate of beta for the best model that included ORV effect on capture probability of the marsh rice rat was -1.2581 (S.E. = 0.7744),

which indicates a negative effect of ORV use (Table 3-21). But the 95% confidence interval for this parameter also includes 0, which means we did not have a large enough sample size to detect a trend. Marsh rice rat recapture probabilities were 8.38% higher in non-ORV areas than ORV areas.

For the cotton mouse, the estimate of \hat{c} from the parametric bootstrap was 1.7045. Only the model $\Phi(.)p(.)$ had a delta QAICc value less than 2, and therefore had strong support (Table 3-23). Two of the remaining top three models had ORV effect on survival and capture probability. Models that included the ORV effect on survival for the cotton mouse received 27.89% of the QAICc weight, and models that included ORV effect on capture probability accounted for 25.27% of the total weight.

The estimated beta for the best model that had ORV effect on survival was -0.2866 (S.E. = 0.8184), which indicates a negative effect of ORV use (Table 3-21; Figure 3-4). But the 95% confidence interval includes 0, which means we did not have a large enough sample size to detect a trend. The estimate of beta for the best model that included ORV effect on capture probability of the cotton mouse was -0.1419 (S.E. = 1.5411), which indicates a negative effect of ORV use (Table 3-21). But the 95% confidence interval for this parameter also included 0, which means we did not have a large enough sample size large enough to detect a trend.

Discussion

This study addresses the lack of baseline data concerning the effects of ORVs on small mammals in BCNP. I captured four species of small mammals while trapping in pine and prairie habitats. Hispid cotton rats were the most abundant species and appear to be habitat generalists, as they were found at all the trapping sites. Marsh rice rats were the dominant species found in prairie habitats, while they were only captured in pine habitats that were flooded. The increase of water levels may reduce the amount of ground cover and suitable nesting refugia in the prairie

habitats, driving the marsh rice rats into the pine habitats. Cotton mice were mostly found in pine habitats, but were also captured in prairie habitats during the dry season. Short-tailed shrews were captured only in pine habitats.

Capture comparisons of species based on ORV use showed mixed results. I expected captures and densities in ORV sites to be lower than in non-ORV sites. I found that small mammal species respond differently to ORV impacts. I did find that mean hispid cotton rat captures and densities were higher in non-ORV sites than in ORV sites, supporting my hypothesis. Mean cotton mice captures and densities displayed the opposite effect, with ORV sites having higher captures than non-ORV sites. Mean marsh rice rat captures, on the other hand, showed no difference between ORV and non-ORV sites.

As discussed in Chapter 2, habitat fragmentation may affect species' behaviors, dispersal abilities, life history, trophic level, social relationships, and overall responses to change in habitat size, connectivity, and type of habitat matrix (Hammitt and Cole 1998). Hispid cotton rats are habitat generalists, but they display preferences for grassland or early successional habitats high in vegetative cover (Lidicker et al. 1992, Cothran et al. 1991). The reduced patch size and increased distance between habitat patches caused by ORVs seem to have an effect on hispid cotton rat captures. Diffendorfer et al. (1995) found a 40% decrease in abundance in hispid cotton rats in fragmented habitats compared to continuous habitats. There is also an increase of transient hispid cotton rats observed in fragmented habitats (Diffendorfer et al. 1995). This can lead to animals staying for a short period of time and leaving quickly, making for an unstable population. Significant genetic differentiation has been documented for populations of white-footed mice (*Peromyscus leucopus*) 500 m apart (Mossman and Waser 2001), and Allegheny woodrats (*Neotoma magister*) living within 2–3 km (Castleberry et al. 2002). Genetic diversity

may be lost is a population that experiences a long-term bottleneck of low population size (Monty et al. 2003). A loss of genetic heterozygosity in a population may lead to the expression of deleterious genes that can result in lower survival rates and hastens population declines (Frankham 1995; Lacy 1993; O'Brien et al. 1985).

Constant use of ORVs in prairie habitats reduces vegetative cover (Chapter 2) preferred by hispid cotton rats and reduces their cover to travel between habitat patches. Hispid cotton rats also exhibit sexual segregation in specific habitat requirements during all life stages (Lidicker et al. 1992). Female hispid cotton rats are territorial and may be limited by breeding sites in ORV-impacted sites. Habitat fragmentation could lead to a smaller proportion of sexually active females reducing the overall population.

Cotton mice, on the other hand, have higher captures in ORV sites, which suggest that they may be more tolerant of fragmented habitats. With cotton mice smaller body size and home range, movements within habitat patches that were created by ORV use may not be affected. *Peromyscus maniculatus* also showed a positive response to a habitat fragmentation experiment conducted by Diffendorfer et al. (1995). He found that abundances were three times higher in fragmented sites. Increased habitat and reduced competition from the larger rodents abandoning the smaller fragments is theorized for the increase in abundances (Diffendorfer et al. 1995). Cotton mice females can endure an increase in density when space is limited, this display of tolerance may explain why we find more cotton mice in ORV impacted areas (Wolff 1994). Hispid cotton rats have lower captures in fragmented ORV sites presumably because the smaller patches do not have enough habitat to sustain individuals. Cotton mice may therefore reach their highest densities on smaller, fragmented patches of habitat. I found that hispid cotton rats and cotton mice mean captures in pine habitats were significantly higher than in prairie habitats,

supporting my hypothesis. Hispid cotton rats are well adapted to survive in many different types of habitat and have been observed swimming. Hispid cotton rats on tree islands in the Everglades showed little movement in hardwood hammocks and high dispersion in prairie habitats during interface of wet and dry seasons (Smith and Vrieze 1975). This suggests that hispid cotton rats prefer the higher elevation habitats of pine and hammock habitats. Cotton mice often nest in logs and holes in the ground, and they are one of only two Florida mice species to frequently nest in trees. Prairie habitats do not offer the same foraging and nesting opportunities as pine habitats for the cotton mouse. As expected, marsh rice rats were predominantly found in prairie sites. Smith and Vrieze (1975) observed the same pattern in Everglades with the marsh rice rats moving to hardwood hammocks in the wet season. This species is an adept swimmer often spending most of its foraging time in the water. It can readily dive and is capable of swimming underwater to forage or escape predation.

Hispid cotton rat males were found to be significantly longer than females, contrary to my hypothesis. A possible explanation might be that hispid cotton rats are sexually dimorphic (Cameron and Spencer 1981). Males may grow larger to compete for females and territory. There were no differences in length between ORV and non-ORV sites contrary to my hypothesis. This might be because the suitability of habitat in ORV and non-ORV sites may not inhibit growth.

Hispid cotton rats, marsh rice rats and cotton mice showed no differences in body condition between ORV and non-ORV sites. These findings contradict my original expectations that body condition of small mammal species would be better in non-ORV sites. A possible explanation might be the ideal free distribution theory. This theory states that if several habitat types (e.g., disturbed vs. undisturbed) are available but differ in their basic suitability, then each

individual is free to settle where their expected fitness is highest. If the population is distributed in accordance with this theory, densities will be highest in the most suitable habitat and lowest in the least suitable, resulting in a decreased competition for scarce resources. The distribution and densities of the population might have created an equilibrium that would not affect body condition. My data supports this theory for the hispid cotton rat as I saw higher capture numbers in non-ORV sites, but body condition was not affected.

Another possibility is that the disturbance at ORV sites keeps the habitat in early successional stage, producing more food. Undisturbed sites may offer a stable food source that is higher in quality but lower in quantity. On the other hand, disturbed sites may offer food in the form of early successional plants that are lower in quality, but higher in quantity. This dynamic relationship may account for why I did not see any differences in body condition between ORV and non-ORV sites. My data showed that cotton mice had higher counts in ORV than non-ORV sites, but body condition was not affected, this may be due to the smaller body size and home range of the cotton mice.

I did find a difference in body condition for the hispid cotton rat between habitats. Cotton rats in pine habitats had significantly higher body condition than prairie habitats. Contrary to my hypothesis, I found that there were no differences in body condition index scores between pine and prairie habitats for rice rats and cotton mice. I predicted that cotton mice would have a better condition index score in pine habitats than in prairie and that marsh rice rats would have a better condition index score in prairie habitats than in pine habitats. Rodents are very adaptable to their surrounding environment. They are able to adjust to different food sources in a variety of habitats. Even though we observed the rodents in their secondary habitats, they were able to maintain their body condition.

Male hispid cotton rats body condition index scores were significantly higher than female. Males may be more selective in the food they eat. Higher quality food could be in short supply and males could be willing to travel great distances to obtain it. Smith and Vrieze (1975) observed female cotton rats moved farther than males. Females may have to travel great distances because of their young. In order to get the required amount of nutrition to feed the young, longer distances would have to be traveled to get the proper food quality. Traveling long distances for higher quality food could produce significantly different body condition from gathering lower quality food at a short distance.

Marsh rice rats and cotton mice had no significant difference in body condition index scores between males and females. This finding does not support my hypothesis. Marsh rice rats and cotton mice have smaller home ranges than hispid cotton rats and may be able to find enough nutrition within their limited territory, thus not showing a difference in body condition.

The results from the site occupancy analysis indicate that ORV use is not a strong predictor of occupancy for the cotton rat and marsh rice rat, but it may be a strong predictor for the cotton mouse. Two of the three species included the ORV use covariate in the best model for occupancy, and the sum of the model AIC weight was highest for those models that included ORV use. This indicates that occupancy for some species may depend more on ORV use than on habitat or horizontal vegetative percent cover.

I predicted that these small mammals would be negatively influenced by ORV use due to ground level disturbance of vegetation. Two of the three species of rodents had beta values for ORV use that were positive, indicating positive associations with ORV use. One species, however, the cotton rat, was negatively associated with ORV use. Although this is counter to the original prediction, altered hydrology and morphology might explain the difference in response

to ORV use. The marsh rice rat is a medium-sized rodent that is associated with water (Brown 1997). ORVs can alter the hydroperiod of areas, resulting in the creation of artificial depressions and the increase of ponding in ruts (Duever et al. 1981). The marsh rice rats may take advantage of the increased temporal and spatial extent of standing water for consumptive purposes. The cotton mouse is a small-sized rodent that may thrive in areas where ORVs have created a fragmented habitat because of a potential competitive release from cotton rats.

For all species, horizontal vegetative percent cover was an important predictor in site occupancy. This may be due to the fact that small mammals are regular prey for many species. The cotton rat and marsh rice rat had positive beta values indicating positive associations with horizontal vegetative percent cover. Without proper cover, nesting and foraging areas would be exposed to predation and weather. The cotton rat and the marsh rice rat may take advantage of the increased vegetative cover to evade predators, to have sufficient cover to rear young, to forage, or a combination of these factors (e.g., rear young and forage).

For all species, habitat was an important predictor in site occupancy. The cotton rat prefers dry habitat that is composed of dense grasses, and is common in brush and palmettos where some grass is present, although we did catch any in the marsh fringes during high water (Cameron and Spencer 1981). The marsh rice rat prefers habitats that are wet and seldom occur in dry areas (Wolfe 1982). I observed the marsh rice rat in both the prairie and pine habitats, but they were in the pine habitat only when there was high water or the pine habitat was flooded. The cotton mouse prefers wooded habitats as it is very arboreal and nests in logs and hollow stumps (Wolfe and Linzey 1977).

Hurricane Katrina had an impact on survival of hispid cotton rats in both ORV and non-ORV sites. There was a drop of captures post-hurricane, but it is unclear if the decline is from the

hurricane or normal population fluctuations. After Hurricane Andrew in 1992, Everglades white-tailed deer populations in five wildlife management areas had a 67% decline in population and had a 13 fold decrease in fawn production (Labisky et al. 1999). A major natural event such as a hurricane could put more pressure on an already stressed small mammal population in BCNP. Swilling et al. (1998) found that the effects of Hurricane Opal (1995) on beach mice (*Peromyscus polionotus ammobates*) were delayed until the next summer. Beach mice populations decreased 30% from pre-hurricane levels and utilized more transitional habitat (Swilling et al. 1998). The population of the small mammals in BCNP could also show a lag effect from Hurricane Katrina, where effects may not be seen for many months. Significant red-cockaded woodpecker (*Picoides borealis*) nesting cavities were destroyed in BCNP after Hurricane Andrew (Loope et al. 1994). Although Hurricane Katrina was a category 1 hurricane and did not cause much damage in BICY, a major hurricane could devastate small mammal populations in ORV areas.

There is clear evidence of impacts from ORV use, but the long-term implications are unclear. The number species of small mammals did not change between ORV and non-ORV areas, but there were changes of species composition. Similar results were observed by Waddle (2006) for anurans. Three of the four anurans studied had a negative relationship with ORV use, but the southern toad (*Bufo terrestris*) had a positive relationship. The southern toad prefers longer hydroperiod as their tadpoles require a longer developmental period. The ruts and modified hydrology caused by ORV use created a beneficial habitat for the southern toad (Waddle 2006).

This is a concern for species that rely upon small mammals as prey. The Florida panther has been shown to move away from ORV use areas during hunting season due to prey avoiding

hunters (Janis and Clark 2002). Another example is Bobcats (*Lynx rufus*). Bobcats could be affected by the shift of species composition caused by ORV use. Preying on the larger hispid cotton rat would give more energy per effort than preying on cotton mice. In ORV areas where hispid cotton rats are not abundant, bobcats would have to prey on the smaller cotton mouse. The bobcat would have to capture multiple cotton mice to get the same nutritional requirements for a hispid cotton rat.

It is not possible to determine the mechanisms that ORV use has on influencing the small mammal community due to the observational nature of this study. However, this study should help promote more research on the use of ORVs. Is there evidence that ORV use influences small mammal species? Does the species composition shift from non-ORV to ORV affect predator species? Long-term monitoring plots could be established in current ORV use areas, recovering ORV use areas, and non-ORV use areas using the techniques of this study to observe any changes in small mammal population structure. This study provides baseline data on small mammal species in BCNP that managers can use to make management decisions or to develop future research hypothesis.

Table 3-1. Combinations of the 3 site covariates and one sampling covariates that were used in the occupancy analysis for each species. Each set of site covariates was modeled along with each set of sampling covariates for a total of 16 models for each species.

Site Covariates	Sampling Covariates
Constant	Constant
ORV	Water
Habitat	
Percent Cover	
ORV, Habitat	
ORV, Percent Cover	
Habitat, Percent Cover	
ORV, Habitat, Percent Cover	

Table 3-2. List of 25 models analyzed in program MARK for captures of cotton rat, marsh rice rat, and cotton mouse in Big Cypress National Preserve. Explanation defines each model in terms of the effects of time (t) and ORV group (g), on apparent survival (Φ) and capture probability (p).

Model	Explanation
$\Phi(.) p(.)$	Survival and capture probability constant throughout study
$\Phi(.) p(g)$	Survival is constant; capture varies by ORV
$\Phi(.) p(t)$	Survival is constant; capture varies by time
$\Phi(.) p(g*t)$	Survival is constant; capture is an interaction of ORV and time
$\Phi(.) p(g+t)$	Survival is constant; capture is an additive effect of ORV and time
$\Phi(g) p(.)$	Survival varies by ORV; capture is constant
$\Phi(g) p(g)$	Survival varies by ORV; capture varies by ORV
$\Phi(g) p(t)$	Survival varies by ORV; capture varies by time
$\Phi(g) p(g*t)$	Survival varies by ORV; capture is an interaction of ORV and time
$\Phi(g) p(g+t)$	Survival varies by ORV; capture is an additive effect of ORV and time
$\Phi(t) p(.)$	Survival varies by time; capture is constant
$\Phi(t) p(g)$	Survival varies by time; capture varies by ORV
$\Phi(t) p(t)$	Survival varies by time; capture varies by time
$\Phi(t) p(g*t)$	Survival varies by time; capture is an interaction of ORV and time
$\Phi(t) p(g+t)$	Survival varies by time; capture is an additive effect of ORV and time
$\Phi(g*t) p(.)$	Survival is an interaction of ORV and time; capture is constant
$\Phi(g*t) p(g)$	Survival is an interaction of ORV and time; capture varies by ORV
$\Phi(g*t) p(t)$	Survival is an interaction of ORV and time; capture varies by time
$\Phi(g*t) p(g*t)$	Survival and capture are both an interactive effect on ORV and time
$\Phi(g*t) p(g+t)$	Survival is and interaction of ORV and time; capture is an additive effect of ORV and time
$\Phi(g+t) p(.)$	Survival is an additive effect of ORV and time; capture is constant
$\Phi(g+t) p(g)$	Survival is an additive effect of ORV and time; capture varies by ORV
$\Phi(g+t) p(t)$	Survival is an additive effect of ORV and time; capture varies by time
$\Phi(g+t) p(g*t)$	Survival is an additive effect of ORV and time; capture is an interaction of ORV and time
$\Phi(g+t) p(g+t)$	Survival and capture are both the additive effect of ORV and time

Table 3-3. Number of captures and recaptures for hispid cotton rats, marsh rice rats, cotton mice, and short-tailed shrews from 14,784 trap nights.

Number of Times Captured	Hispid cotton rat	Marsh rice rat	Cotton mouse	Short-tailed shrew
1	118	128	29	4
2	39	20	7	0
3	20	5	10	0
4	12	3	1	0
5	7	4	3	0
6	6	0	1	0
7	2	0	0	0
8	1	0	0	0
9	4	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
Number of Individuals	201	156	51	4
	Total Individuals	412		
	Total Recaptures	304		
	Total Captures	716		

Table 3-4. Number of captures by hispid cotton rat, marsh rice rat, cotton mouse and short-tailed shrew on impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)) treatment areas. Individuals captured more than once within the same trapping event were not counted.

Site	Impact	Hispid cotton rat	Marsh rice rat	Cotton mouse	Short-tailed shrew	Total	Proportion of Total
1	ORV	41	38	23	4	106	0.148
2	ORV	73	41	33	0	147	0.205
5	ORV	11	5	16	0	32	0.045
6	ORV	19	17	10	0	46	0.064
3	Non-ORV	98	32	3	0	133	0.186
4	Non-ORV	71	39	0	0	110	0.154
7	Non-ORV	52	17	4	0	73	0.102
8	Non-ORV	47	19	3	0	69	0.096
Total		412	208	92	4	716	
Proportion of Total		0.575	0.291	0.128	0.006		

Table 3-5. Total captures and individual captures of hispid cotton rat, marsh rice rat, cotton mouse and short-tailed shrew by off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) areas.

Total Captures		
Species	ORV	Non-ORV
Hispid cotton rat	166	281
Marsh rice rat	128	134
Cotton mouse	86	11
Short-tailed shrew	4	0

Individual Captures		
Species	ORV	Non-ORV
Hispid cotton rat	83	118
Marsh rice rat	81	75
Cotton mouse	46	5
Short-tailed shrew	4	0

Table 3-6. Total captures of hispid cotton rat, marsh rice rat, cotton mouse, and short-tailed shrew by pine and prairie habitats.

Species	Pine	Prairie
Hispid cotton rat	312	135
Marsh rice rat	72	190
Cotton mouse	59	34
Short-tailed shrew	4	0

Table 3-7. Mean \pm SD captures of hispid cotton rat, marsh rice rat, cotton mouse, and short-tailed shrew by impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)), habitat (pine and prairie), and sex (male and female).

ORV				
Species	ORV	Non-ORV	<i>p</i> -value	df
Hispid cotton rat	38.5 \pm 15.76	67.0 \pm 11.55	<0.001	1
Marsh rice rat	25.5 \pm 16.62	26.8 \pm 10.53	0.7	1
Cotton mouse	20.8 \pm 9.74	2.5 \pm 1.75	<0.001	1
Habitat				
Species	Pine	Prairie	<i>p</i> -value	df
Hispid cotton rat	40.5 \pm 24.68	12.3 \pm 7.81	<0.001	1
Marsh rice rat	4.6 \pm 5.21	21.5 \pm 10.73	<0.001	1
Cotton mouse	7.1 \pm 6.94	4.5 \pm 5.15	<0.05	1
Sex				
Species	Male	Female	<i>p</i> -value	df
Hispid cotton rat	52.88 \pm 26.71	62.88 \pm 7.81	0.1	1
Marsh rice rat	34.38 \pm 16.14	24.13 \pm 20.64	<0.05	1
Cotton mouse	16.75 \pm 16.79	10.75 \pm 11.31	0.06	1

Table 3-8. Mean weight \pm SD of adult, non-pregnant hispid cotton rat, marsh rice rat, and cotton mouse by impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)), habitat (pine and prairie), and sex (male and female).

Hispid Cotton Rat			
	Mean Weight \pm SD	n	<i>p</i> -value
ORV	111.84 \pm 9.49	134	0.1
Non-ORV	116.07 \pm 5.69	228	
Pine	113.10 \pm 14.69	271	0.12
Prairie	107.73 \pm 10.15	91	
Female	97.32 \pm 10.76	172	<0.001
Male	125.55 \pm 8.57	190	
Marsh Rice Rat			
	Mean Weight \pm SD	n	<i>p</i> -value
ORV	57.14 \pm 8.46	101	0.3
Non-ORV	54.12 \pm 5.08	106	
Pine	53.97 \pm 18.11	26	0.95
Prairie	57.58 \pm 5.77	181	
Female	48.61 \pm 7.59	84	<0.001
Male	62.61 \pm 7.43	122	
Cotton Mouse			
	Mean Weight \pm SD	n	<i>p</i> -value
ORV	29.50 \pm 3.26	75	0.2
Non-ORV	25.92 \pm 2.77	10	
Pine	27.72 \pm 2.62	52	0.5
Prairie	27.71 \pm 7.10	33	
Female	27.58 \pm 3.89	35	0.3
Male	28.33 \pm 3.10	50	

Table 3-9. Mean length \pm SD of hispid cotton rat, marsh rice rat, and cotton mouse by impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)), habitat (pine and prairie), and sex (male and female).

Hispid Cotton Rat			
	Mean Length \pm SD	n	<i>p</i> -value
ORV	123.37 \pm 4.90	134	0.18
Non-ORV	126.79 \pm 2.30	228	
Pine	125.72 \pm 5.91	271	0.4
Prairie	122.36 \pm 6.55	91	
Female	117.84 \pm 7.64	172	<0.01
Male	129.78 \pm 4.59	190	
Marsh Rice Rat			
	Mean Length \pm SD	n	<i>p</i> -value
ORV	104.43 \pm 6.21	101	0.4
Non-ORV	103.36 \pm 6.65	106	
Pine	102.49 \pm 13.91	26	0.3
Prairie	104.36 \pm 5.26	181	
Female	101.28 \pm 6.78	84	0.08
Male	107.06 \pm 8.35	122	
Cotton Mouse			
	Mean Length \pm SD	n	<i>p</i> -value
ORV	81.57 \pm 3.50	75	0.3
Non-ORV	85.11 \pm 5.44	10	
Pine	84.60 \pm 5.39	52	0.1
Prairie	81.21 \pm 5.73	33	
Female	80.26 \pm 7.64	35	0.1
Male	84.65 \pm 4.99	50	

Table 3-10. Linear regressions of ln(body weight) over ln(right hind foot))of hispid cotton rat, marsh rice rat, and cotton mouse.

Skeletal measurement	Slope	r^2	p-value
Cotton Rat	$y=3.28x-6.29$	0.438	<0.0001
Marsh Rice Rat	$y=1.79x-1.99$	0.266	<0.0001
Cotton Mouse	$y=1.06x+0.0889$	0.0640	<0.05

Table 3-11. Mean body condition indices (± 1 SD) of hispid cotton rat, marsh rice rat, and cotton mouse by impact (off-road vehicle (ORV) and non-off-road vehicle (Non-ORV)), habitat (pine and prairie), and sex (male and female).

ORV Impact				
Species	ORV	Non-ORV	df	<i>p</i> -value
Cotton rat	46.34 \pm 5.82	51.59 \pm 2.81	3	0.2
Marsh rice rat	24.11 \pm 3.12	21.68 \pm 2.21	3	0.3
Cotton mouse	12.01 \pm 1.30	11.26 \pm 1.21	2	0.6
Habitat				
Species	Pine	Prairie	df	<i>p</i> -value
Cotton rat	49.61 \pm 5.51	44.79 \pm 10.80	6	0.3
Marsh rice rat	26.88 \pm 6.93	22.42 \pm 2.74	4	0.2
Cotton mouse	11.69 \pm 1.31	11.94 \pm 1.77	5	0.8
Sex				
Species	Female	Male	df	<i>p</i> -value
Cotton rat	44.62 \pm 9.98	50.83 \pm 8.13	6	0.2
Marsh rice rat	21.43 \pm 4.29	23.81 \pm 2.96	5	0.2
Cotton mouse	12.37 \pm 1.50	11.52 \pm 1.36	5	0.2

Table 3-12. Number of detections by cotton rat, marsh rice rat, and cotton mouse and proportion of sites at which a detection occurred (naïve occupancy) during small mammal surveys.

Species	# Detections	Naïve Occupancy
Cotton Rat	132	75.57%
Marsh Rice Rat	105	59.66%
Cotton Mouse	78	44.57%

Table 3-13. Program PRESENCE model selection results for the hispid cotton rat, including Akaike's Information Criterion (AIC) and the delta AIC and AIC weights for all models with any weight.

Model	AIC	delta AIC	AIC weight
$\Psi(\text{Percent Cover, Habitat}),p(\text{Water})$	1809.7	0	0.6874
$\Psi(\text{ORV, Percent Cover, Habitat}),p(\text{Water})$	1811.43	1.73	0.2894
$\Psi(\text{ORV, Habitat}),p(\text{Water})$	1817.97	8.27	0.011
$\Psi(\text{Habitat}),p(\text{Water})$	1818.44	8.74	0.0087
$\Psi(\text{Percent Cover}),p(\text{Water})$	1821.07	11.37	0.0023
$\Psi(\text{ORV, Percent Cover}),p(\text{Water})$	1823.01	13.31	0.0009
$\Psi(\cdot),p(\text{Water})$	1825.27	15.57	0.0003

Table 3-14. Program PRESENCE beta estimates, standard errors (S.E.), and lower and upper 95% confidence intervals for the hispid cotton rat. The best model and second best model are shown.

Best Model				
Covariate	Beta Estimate	S.E.	Lower 95% C.I.	Upper 95% C.I.
Habitat	1.4233	0.4283	0.5838	2.2628
Percent Cover	0.8812	0.2804	0.3316	1.4308

Second Best Model				
Covariate	Beta Estimate	S.E.	Lower 95% C.I.	Upper 95% C.I.
ORV	-0.1936	0.3681	-0.9151	0.5279
Habitat	1.4298	0.4283	0.5903	2.2693
Percent Cover	0.9906	0.3521	0.3005	1.6807

Table 3-15. Program PRESENCE model selection results for the marsh rice rat, including Akaike's Information Criterion (AIC) and the delta AIC and AIC weights for all models with any weight.

Model	AIC	delta AIC	AIC weight
$\Psi(\text{ORV, Habitat, Percent Cover}), p(\cdot)$	1589.64	0	0.731
$\Psi(\text{Habitat, Percent Cover}), p(\cdot)$	1591.64	2	0.2689

Table 3-16. Program PRESENCE beta estimates, standard errors (S.E.), and lower and upper 95% confidence intervals for the marsh rice rat. The best model and second best model are shown.

Best Model				
Parameter	Beta Estimate	S.E.	Lower 95% C.I.	Upper 95% C.I.
ORV	0.7212	0.3732	-0.01027	1.4528
Habitat	-2.6835	0.4127	-3.4924	-1.8746
Percent Cover	1.684	0.4208	0.8592	2.5088
Second Best Model				
Parameter	Beta Estimate	S.E.	Lower 95% C.I.	Upper 95% C.I.
Habitat	-1.9206	0.3847	-2.6746	-1.1667
Percent Cover	1.9526	0.3947	1.1790	2.7262

Table 3-17. Program PRESENCE model selection results for the cotton mouse, including Akaike's Information Criterion (AIC) and the delta AIC and AIC weights for all models with any weight.

Model	AIC	delta AIC	AIC weight
$\Psi(\text{ORV, Habitat, Percent Cover}), p(\cdot)$	1000.72	0	0.8422
$\Psi(\text{ORV, Percent Cover}), p(\cdot)$	1004.07	3.35	0.1578

Table 3-18. Program PRESENCE beta estimates, standard errors (S.E.), and lower and upper 95% confidence intervals for the best model of the cotton mouse.

Covariate	Beta Estimate	S.E.	Lower 95% C.I.	Upper 95% C.I.
ORV	2.7672	0.56	1.6688	3.8656
Habitat	1.0869	0.506	0.09573	2.0781
Percent Cover	-2.0566	0.498	-3.0327	-1.0805

Table 3-19. The number of individuals marked, recaptured and the return rate (proportion of marked individuals recaptured at least once) for the hispid cotton rat, marsh rice rat, and cotton mouse in off-road vehicle (ORV) and non-off-road vehicle (Non-ORV) areas.

Species	Treatment	# Marked	# Recaptured	Return Rate
Cotton Rat	ORV	88	46	52.27%
	Non-ORV	121	58	47.93%
Marsh Rice Rat	ORV	83	14	16.87%
	Non-ORV	77	18	23.38%
Cotton Mouse	ORV	46	20	43.48%
	Non-ORV	5	2	40.00%

Table 3-20. Model selection table for Cormack-Jolly-Seber closed population mark-recapture model of the cotton rat, including Quasi-likelihood Akaike's Information Criterion for small sample sizes (QAICc), model weights based on QAICc, the number of parameter in each model, and the model deviance. Model structure includes the effects of time (t), and off-road vehicle (ORV) group (g) on apparent survival (Φ) and capture probability (p).

Model	QAICc	Delta QAICc	QAICc Weights	# Par	QDeviance
$\Phi(g^*t) p(\cdot)$	531.842	0	0.29977	19	148.5903
$\Phi(\cdot) p(g^*t)$	532.036	0.1939	0.27207	16	155.33299
$\Phi(g) p(g^*t)$	532.76	0.9183	0.1894	17	153.88531
$\Phi(g^*t) p(g)$	533.885	2.0432	0.10792	20	148.42883
$\Phi(t+g)p(\cdot)$	535.026	3.1844	0.061	13	164.77562
$\Phi(g^*t) p(t)$	537.107	5.2653	0.02155	26	138.18746
$\Phi(t+g)p(g)$	537.115	5.2733	0.02146	14	164.72445
$\Phi(t) p(g^*t)$	538.597	6.7548	0.01023	24	144.21006
$\Phi(t+g)p(t)$	539.099	7.2568	0.00796	20	153.64243
$\Phi(t+g)p(t+g)$	541.314	9.4724	0.00263	21	153.64221
$\Phi(\cdot)p(t+g)$	541.931	10.0896	0.00193	11	175.92973
$\Phi(g)p(t+g)$	542.078	10.2362	0.00179	12	173.95707
$\Phi(g^*t) p(g^*t)$	542.716	10.8742	0.0013	30	134.59058
$\Phi(t) p(\cdot)$	544.847	13.0053	0.00045	12	176.72616
$\Phi(t) p(g)$	545.827	13.9849	0.00028	13	175.57612
$\Phi(g) p(t)$	547.506	15.6643	0.00012	12	179.38521
$\Phi(t)p(t+g)$	548.908	17.0665	0.00006	20	163.4521
$\Phi(\cdot) p(t)$	549.152	17.3097	0.00005	10	185.25872
$\Phi(t) p(t)$	552.055	20.2136	0.00001	20	166.59917
$\Phi(g) p(\cdot)$	557.407	25.5652	0	3	207.9932
$\Phi(g) p(g)$	559.339	27.4976	0	4	207.88701
$\Phi(\cdot) p(\cdot)$	560.475	28.6332	0	2	213.0901
$\Phi(\cdot) p(g)$	561.672	29.8303	0	3	212.25836
$\Phi(g+t) p(g^*t)$	205.391	30.4477	0	26	49.792671
$\Phi(t) p(g^*t)$	205.652	30.7091	0	26	50.054092

Table 3-21. Estimates, standard error (S.E.), and 95% confidence interval (C.I.) of the beta values for the off-road vehicle (ORV) effect on apparent survival (Φ) and capture probability (p) on the cotton rat, marsh rice rat, and cotton mouse.

Species	Parameter	Beta	S.E.	Lower 95% C.I.	Upper 95% C.I.
Cotton Rat	Φ	0.7567	0.1817	0.3976	0.9449
	p	1.5163	0.2951	0.9449	2.0876
Marsh Rice Rat	Φ	-0.6200	0.4045	-1.4129	0.1728
	p	-1.2581	0.7744	-2.7759	0.2597
Cotton Mouse	Φ	-0.2866	0.8184	-1.8907	1.3174
	p	-0.1419	1.5411	-3.1624	2.8786

Table 3-22. Model selection table for Cormack-Jolly-Seber closed population mark-recapture model of the marsh rice rat, including Quasi-likelihood Akaike's Information Criterion for small sample sizes (QAICc), model weights based on QAICc, the number of parameter in each model, and the model deviance. Model structure includes the effects of time (t), and off-road vehicle (ORV) group (g) on apparent survival (Φ) and capture probability (p).

Model	QAICc	Delta QAICc	QAICc Weights	# Par	QDeviance
$\Phi(\cdot) p(g)$	174.943	0	0.31237	3	72.98424
$\Phi(g) p(\cdot)$	175.105	0.1617	0.28811	3	73.145939
$\Phi(\cdot) p(\cdot)$	175.442	0.4985	0.24346	2	75.541814
$\Phi(g) p(g)$	176.525	1.5818	0.14164	4	72.486676
$\Phi(g) p(t)$	183.506	8.5632	0.00432	11	64.31812
$\Phi(\cdot) p(t)$	183.577	8.6335	0.00417	10	66.618638
$\Phi(g) p(g+t)$	185.196	10.2527	0.00185	12	63.754602
$\Phi(\cdot) p(g+t)$	185.775	10.832	0.00139	11	66.586976
$\Phi(t) p(g)$	186.78	11.8365	0.00084	13	63.062065
$\Phi(t) p(\cdot)$	187.358	12.4151	0.00063	12	65.91702
$\Phi(g+t) p(\cdot)$	187.887	12.9436	0.00048	13	64.169162
$\Phi(g+t) p(t)$	188.934	13.9905	0.00029	17	55.871341
$\Phi(g+t) p(g)$	189.003	14.06	0.00028	14	62.98574
$\Phi(g+t) p(g+t)$	191.33	16.387	0.00009	18	55.869869
$\Phi(t) p(t)$	191.93	16.9863	0.00006	17	58.867126
$\Phi(g^*t) p(\cdot)$	195.766	20.8224	0.00001	21	52.956533
$\Phi(g^*t) p(g)$	197.426	22.4829	0	22	52.114477
$\Phi(t) p(g+t)$	197.588	22.6448	0	20	57.25474
$\Phi(\cdot) p(g^*t)$	198.527	23.5835	0	19	60.642879
$\Phi(g^*t) p(t)$	201.597	26.6542	0	26	45.999209
$\Phi(g) p(g^*t)$	202.133	27.1901	0	21	59.324288
$\Phi(g^*t) p(g+t)$	204.232	29.2888	0	27	45.990648
$\Phi(g^*t) p(g^*t)$	204.823	29.8796	0	28	43.908864
$\Phi(g+t) p(g^*t)$	205.391	30.4477	0	26	49.792671
$\Phi(t) p(g^*t)$	205.652	30.7091	0	26	50.054092

Table 3-23. Model selection table for Cormack-Jolly-Seber closed population mark-recapture model of the cotton mouse, including Quasi-likelihood Akaike's Information Criterion for small sample sizes (QAICc), model weights based on QAICc, the number of parameter in each model, and the model deviance. Model structure includes the effects of time (t), and off-road vehicle (ORV) group (g) on apparent survival (Φ) and capture probability (p).

Model	QAICc	Delta QAICc	QAICc Weights	# Par	QDeviance
$\Phi(\cdot) p(\cdot)$	107.885	0	0.51502	2	49.434354
$\Phi(g) p(\cdot)$	109.89	2.0049	0.189	3	49.310253
$\Phi(\cdot) p(g)$	110.006	2.1203	0.17841	3	49.425677
$\Phi(g) p(g)$	112.065	4.1794	0.06372	4	49.309945
$\Phi(g^*t) p(\cdot)$	115.256	7.3705	0.01292	10	38.402476
$\Phi(\cdot) p(t)$	115.496	7.6105	0.01146	8	43.553207
$\Phi(t) p(\cdot)$	115.583	7.6982	0.01097	8	43.640895
$\Phi(g) p(t)$	117.684	9.7984	0.00384	9	43.313673
$\Phi(g^*t) p(g)$	117.714	9.8291	0.00378	11	38.319981
$\Phi(g+t) p(\cdot)$	117.742	9.8571	0.00373	9	43.372329
$\Phi(\cdot) p(g+t)$	117.878	9.9926	0.00348	9	43.507867
$\Phi(g) p(g+t)$	120.167	12.2817	0.00111	10	43.313637
$\Phi(t) p(g)$	120.489	12.6033	0.00094	10	43.635216
$\Phi(\cdot) p(g^*t)$	121.141	13.2554	0.00068	11	41.746326
$\Phi(g+t) p(g)$	122.763	14.8777	0.0003	11	43.368629
$\Phi(g) p(g^*t)$	123.05	15.1645	0.00026	12	41.054579
$\Phi(g^*t) p(t)$	123.453	15.5682	0.00021	14	36.068665
$\Phi(t) p(t)$	125.703	17.8177	0.00007	13	41.045051
$\Phi(g^*t) p(g^*t)$	127.984	20.0992	0.00002	16	34.943859
$\Phi(g+t) p(t)$	128.161	20.276	0.00002	14	40.77646
$\Phi(t) p(g+t)$	128.22	20.3349	0.00002	14	40.83531
$\Phi(g^*t) p(g+t)$	128.996	21.1109	0.00001	16	35.955543
$\Phi(g+t) p(g+t)$	130.83	22.9447	0.00001	15	40.651702
$\Phi(t) p(g^*t)$	133.163	25.2777	0	16	40.122317
$\Phi(g+t) p(g^*t)$	134.873	26.9879	0	17	38.898625

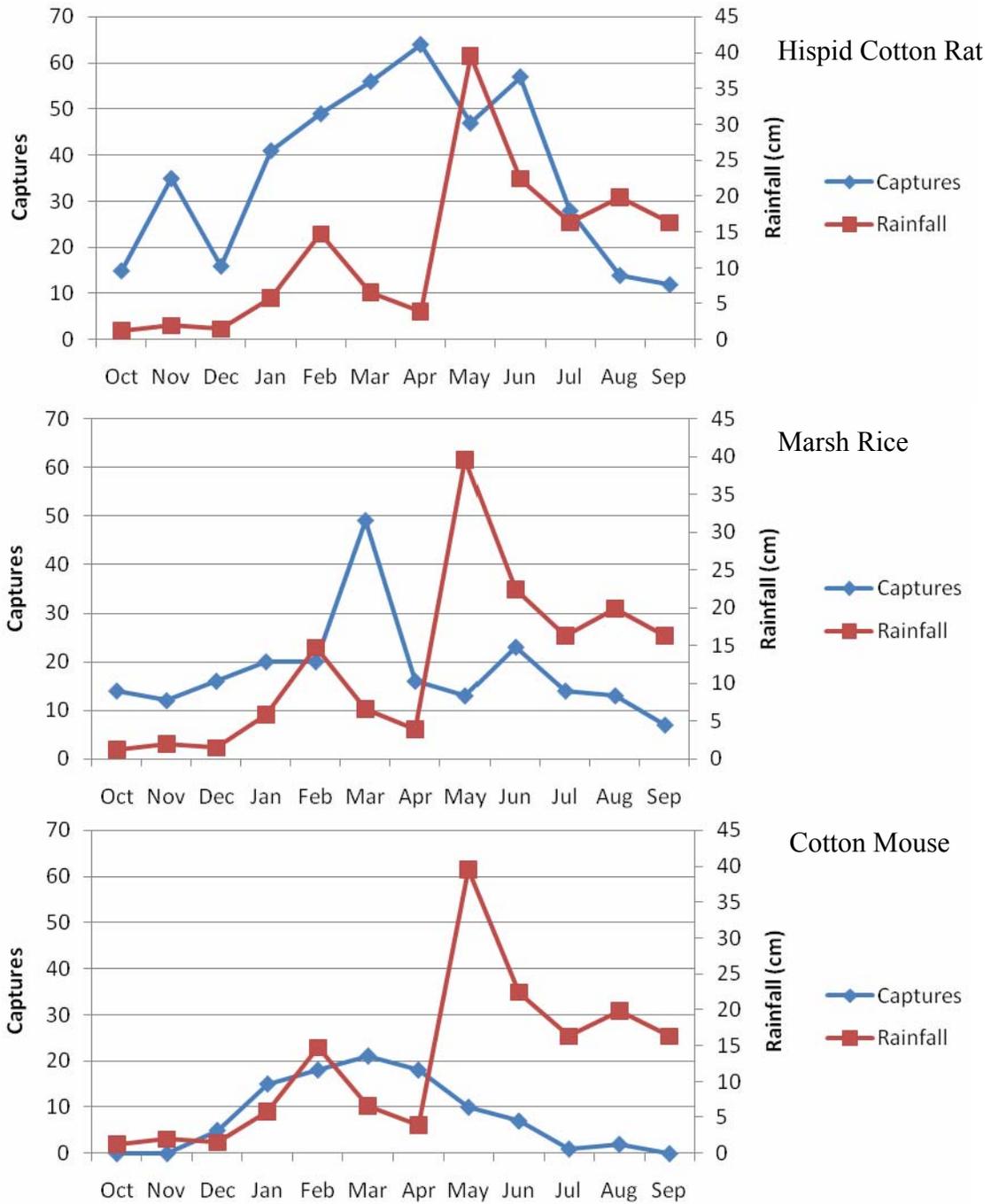


Figure 3-1. Total number of captures for hispid cotton rat, marsh rice rat and cotton mouse from October 2004 to September 2005.

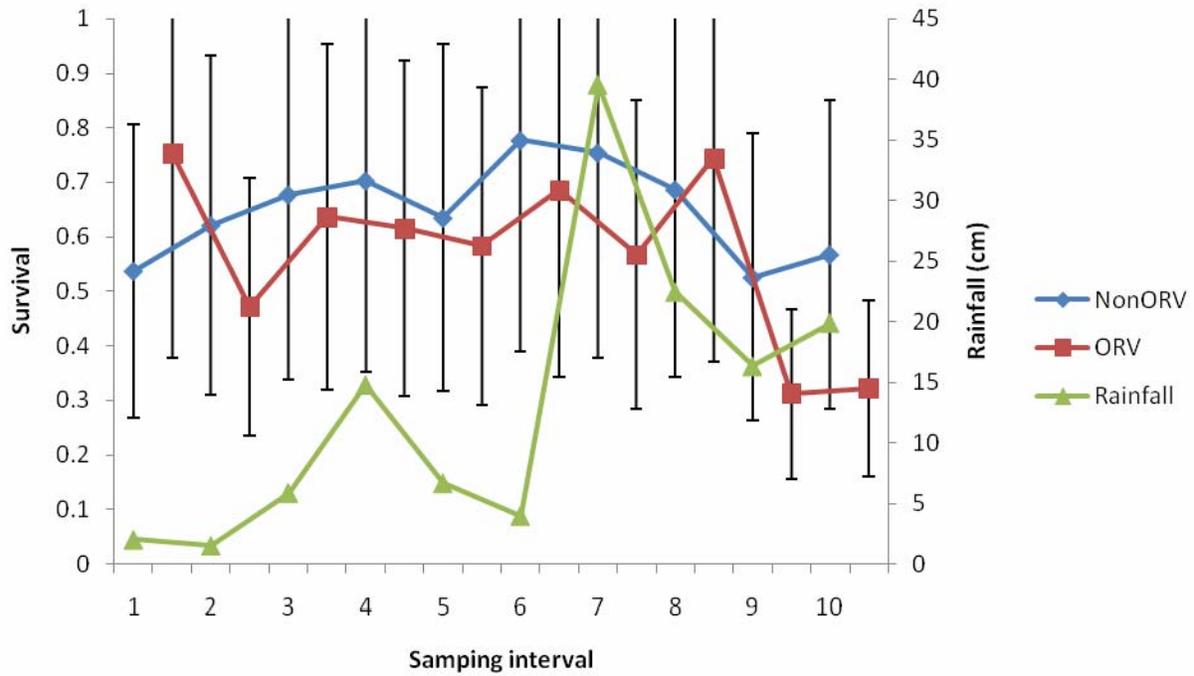


Figure 3-2. Apparent survival (Φ) and 95% confidence interval of cotton rat by off-road vehicle (ORV) group and total rainfall for the 10 monthly survival intervals. Estimates for cotton rats are averaged across models as no model had a majority of QAICc weight (Burnham and Anderson 1998).

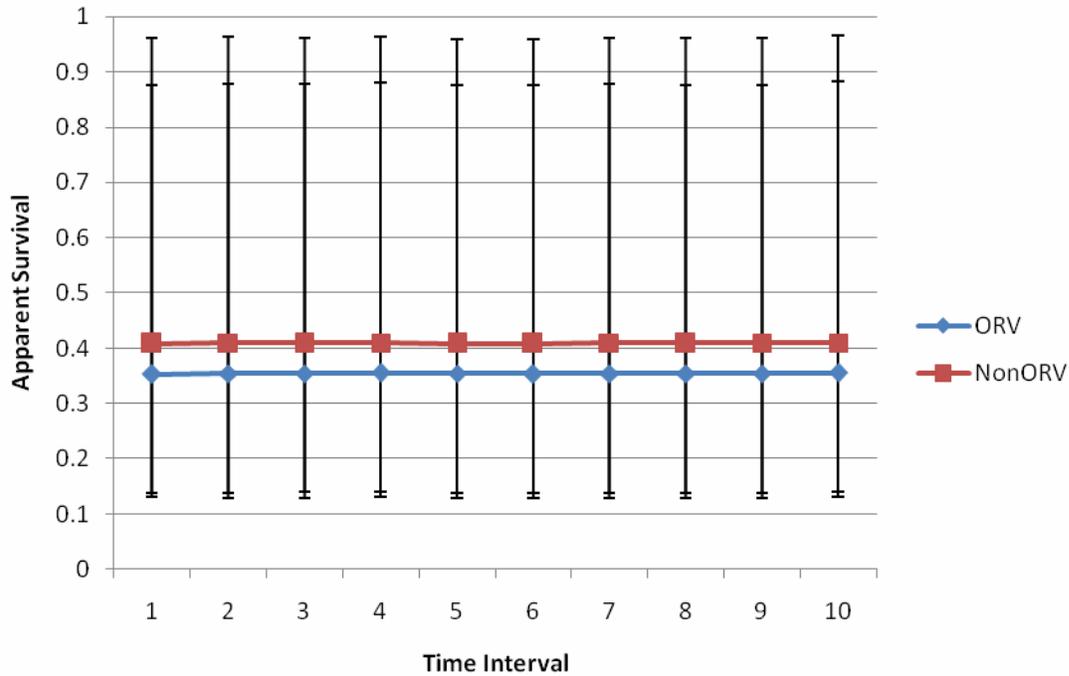


Figure 3-3. Apparent survival (Φ) and 95% confidence interval of marsh rice rat by off-road vehicle (ORV) group for the 10 monthly sampling intervals. Estimates for marsh rice rats are averaged across models as no model had a majority of QAICc weight (Burnham and Anderson 1998).

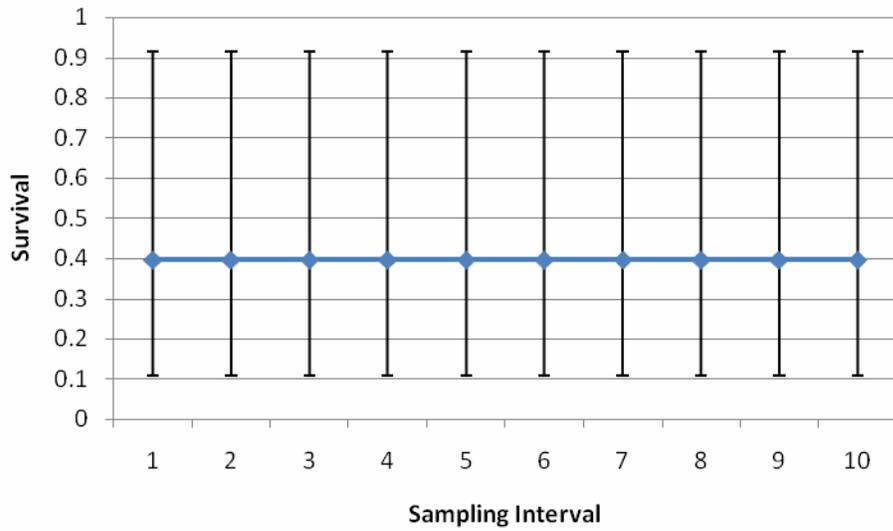


Figure 3-4. Survival (Φ) and 95% confidence interval of cotton mouse for the 10 monthly sampling intervals.

CHAPTER 4 CONCLUSIONS

Introduction

In the beginning of this thesis I outlined the potential harm ORVs may have on wildlife and explained why small mammals would be useful indicators of ORV impacts. In this chapter, I will address the major problems that ORVs cause for wildlife in BCNP and explain whether the results of this research support the use of small mammals as indicators of ORV impacts.

ORV Impacts on Wildlife

Habitat Modification

I observed in Chapter 2 that the direct impacts of ORVs have influenced characteristics of vegetative communities that make up small mammal habitat in BCNP. I found that vegetation height in ORV areas were significantly less than non-ORV areas. Duever et al. (1981) found similar results where there was a decreased trend in height with increased ORV activity. Duever et al. (1981) also showed little recovery in height after one year from the heavily impacted sites. The continual use of heavily used trails may delay recovery time from impacts or not recover at all. Recovery may also change species composition in vegetation. Duever et al. (1981) reported that *Panicum* species and *Muhlenbergia* species declined and *Utricularia* species increased from the increased water levels from ruts. The shift from aquatic grasses and sedges to submerged aquatic species could have a dramatic effect on how wildlife utilizes the area.

I also observed changes in percent cover, where ORV sites had less than non-ORV sites. Duever et al. (1981) also saw changes in percent cover as well in his experiment. While Duever et al. (1981) saw a decrease in marsh habitats, he did not see any difference in pine habitats. I observed a decrease in both marsh and pine habitats. The difference may come from the duration of impacts at experimental sites. Duever et al. (1981) experimented at sites where no impacts

were observed and conducted experiments on intensity of impacts. My sites were established in continuous ORV use areas. This shows that not only does intensity of impacts matter, but duration of impacts are important to monitor as well.

Ruts cutting through pine and prairie habitats have a potential to create habitat fragmentation. Ruts could create small patches of habitat that could affect wildlife. Ruts may decrease patch size and increase distances between habitats. Habitat fragmentation has adverse effects on wildlife populations that may influence local abundance (Fahrig and Paloheimo 1988), viability (Fahrig and Merriam 1985; Lande 1987; Roff 1974), and community organization (Holt 1985, 1993). On the other hand, the total species diversity in a landscape may increase when new patches of habitat are created from habitat fragmentation. Although we were not studying the effects of fragmentation of habitat by ORVs, examining the potential of fragmentation on small mammals should be considered. Studies could be designed for small mammal to examine effects of patch size, distances between patches, and movement.

Species Composition and Structure

There was a significant change in small mammal population structure in terms of abundances in disturbed areas. Disturbance preferences of the three small mammal species show three types of distribution patterns: ORV preference (cotton mouse), ORV avoidance (hispid cotton rat), and no preference (marsh rice rat). Waddle (2006) showed similar results with anurans where all species were present in ORV and non-ORV sites, three of four species preferred non-ORV areas and the remaining species preferred ORV areas. This suggests that examining species richness may not be the best method for monitoring impact of ORVs. Monitoring species assemblages could be a more efficient way. Species assemblages can serve as indicators for monitoring composition, structure, and function in natural areas (Kremen 1992). Monitoring species assemblages allows the most direct assessment of viable populations and

biodiversity. Monitoring at the population or community level can provide direct or indirect assessments of ecological change (Gilbert 1980). When monitoring populations are conducted within the context of known environmental change (i.e. ORV use), it can provide a base for management decisions (Kremen 1992). Species assemblages should provide a finer estimate of biotic response than single species. Assemblages that include species covering a wide range of movement and distribution could be expected to display a greater range of sensitivities to habitat modification or fragmentation over time (Terborgh 1974). Monitoring programs could use separate indicator species assemblages, such as small mammals and amphibians, to monitor different environmental impacts (Kremen 1992).

Small Mammals as an Indicator Species

An ideal indicator species must be abundant and/or cost effective to sample. Small mammals in southern Florida meet this requirement. They have niches and microhabitats that are small and easily sampled. Sampling small mammals using live trapping techniques, as described in Chapter 3, was an efficient way to sample several species at once.

Another requirement for an indicator species is that it provides early warning of natural responses to environmental impacts (Noss 1990; Munn 1993; Woodley 1996). Chapter 3 demonstrated that two of the three species of small mammals were sensitive to ORV use. Indicator species should indicate the cause of change rather than the existence of change (Herricks and Schaeffer 1985). The responses are useful for managers to predict changes of the whole system by monitoring community levels. Small mammals are suitable to detect changes over the BCNP ecosystem. They are found throughout the terrestrial habitats in BCNP and are the base of the food chain for many species. I believe this study has shown how small mammals responded to anthropogenic stresses in the short term.

Conclusions

I conclude that small mammals could serve as indicators of ORV effects. There is detailed information about their biology and natural history on the levels of population and community. Their roles and niches are well known in their habitats and ecosystems. Small mammals are easily marked for identification and we can follow their survivorship, reproduction, and population fluctuations from community to ecosystem levels. The spatial scale on which small mammals live is relatively small. They have short life spans and display behavioral responses to seasonal and environmental changes. In Chapter 3, I showed that species react differently to ORV impacts. While my study was for one year, there may be climatic effect on the small mammals. We need to determine what the real pattern is with multiple year study on small mammals. With the proper network of sites, local populations can be studied intensively and modeled appropriately to allow managers to track changes in population in relation to management decisions. At the landscape level, site occupancy modeling can be used on all small mammal species to monitor the changes in colonization and extinction of sites throughout the Big Cypress National Preserve.

My comparisons of ORV and non-ORV areas have raised a number of interesting questions. With the larger rodent species having lower captures in the ORV areas, how are predatory species responding to this change? How much and how fast are ORVs changing the vegetative community? To what extent is habitat fragmentation affecting local wildlife populations? I feel that more can be gained by the continued monitoring of the small mammal community, given that current data only spans one year. There may be population fluctuations due to hydrologic or seasonal changes over many years that this project did not observe. These and other research questions can be addressed using small mammals as indicator species.

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BIOGRAPHICAL SKETCH

Brian Jeffery was born in Ft. Lauderdale, Florida in 1977. Brian received his high school diploma from South Plantation High School in 1996. He then attended Florida International University and received his Bachelor of Science in environmental studies in 2001. While he was an undergrad, Brian worked as a student technician in the Aquatic Ecology Lab at FIU, working for Joel Trexler. After graduation, Brian joined FART (Florida Alligator Research Team) and then worked as a technician helping a graduate student doing alligator research in A.R.M. Loxahatchee National Wildlife Refuge for six months. In the beginning of 2002, Brian worked in Big Cypress National Preserve doing reptile and amphibian inventory. In 2004, Brian enrolled at the University of Florida to pursue a Master of Science in School of Natural Resources and Environment.