6-9-2000

THE EFFECTS OF SILVICULTURE AND PRESCRIBED BURNING ON HERPETOFAUNA IN FLORIDA SAND-PINE SCRUB

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CERTIFICATE OF APPROVAL

Master's Thesis

This is to certify that the Master's Thesis of

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with a major in Zoology has been approved
for the thesis requirement on June 9, 2000
for the Master of Science degree

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by

STIG RAVDAL

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
Department of Biology
University of South Florida

August 2000

Co-Major Professor: Henry R. Mushinsky, Ph.D.
Co-Major Professor: Earl D. McCoy, Ph.D.

ACKNOWLEDGMENTS

I would like to thank Dr. Henry R. Mushinsky for giving me the opportunity to pursue graduate studies and for his scholarly advice, patience and friendship. I would also like to thank Dr. Earl D. McCoy for his scholarly advice, patience and support. Thanks to Dr. Peter D. Stiling for scholarly advice and ideas that improved the research design.

Special thanks to George Navratil who assisted me in the field throughout the course of this study and gave me ideas to improve the research. I would also like to express my gratitude to my wife, Maria V. Cattell, who supported me and gave helpful suggestions to improve this manuscript. Special thanks to my friends and colleagues Karen Hill, Kevin Ernst, Little Ben Motten, Tiffany Doan for their many hours of field assistance.

This research was sponsored, in part, by the Disney Development Company.

TABLE OF CONTENTS

LIST OF TABLES	ii
LIST OF FIGURES	iii
ABSTRACT	v
INTRODUCTION	1
MATERIALS AND METHODS	8
Study Sites	8
Treatments	8
Herpetofaunal Sampling	11
Vegetation and Habitat Structure	14
Data Analysis	15
RESULTS	18
DISCUSSION	29
LITERATURE CITED	36

LIST OF TABLES

Table 1. Date of Logging and Prescribed Burning and Habitat Description by Study Site. 11

Table 2. Effects of fire (percent killed) on ground cover and litter, the shrub layer and canopy (tree-kill). 18

Table 3. Mean results of vegetation and structural variables measured at each trap in 1997 and 1998. Different letters in superscript indicate significant (a=0.05) difference between the treatments according to Tukey's HSD. 19

Table 4. Species, frequency of capture (with recaptures in parenthesis) and relative frequency of capture in percent. 20

Table 5. Spearman's rank correlation values relations among species, vegetation and structural variables. Signifiacnt and higly significant correlations are marked with one or two astrices respectively. Correlations that were within the 10% level are also reported in this table, the remaining correlations were not reported (n/a). 29

LIST OF FIGURES

Figure 1. Map showing part of Kissimme Florida, interstate highway 4, route 27 and 192. Study sites are marked with crosses; from the top MW-5, MW-7 and CW-1. 18

Figure 2. Diagram of the modified drift-fence pit-fall trap used in my study. 13

Figure 3. Species richness compared between treatments and the control using Hill's richness numbers N0, N1 and N2. 21

Figure 4. Species abundance curves for the treatments, control and pre -treatment study showing $\log_{10}$ of the relative importance of species along the Y-axis and the rank of species abundance on the X-axis. 23

Figure 5. Rarefaction curves for each treatment, undisturbed plots and pre-treatment study. The vertical axis shows the estimated number of species in the sample. The horisontal axis shows the sample sizes. 25

Figure 6. Species evenness in the harvest, burned and undisturbed plots calculated using using *J'* (*E*1) and Hill's modified ratio (*E*5). 26

Figure 7. Comparison of Shannon-Wiener diversity between treatments and undisturbed plots. 27

Figure 8. Non-metric multi-dimensional scaling of species as variables and the treatments as SUs. The species abbreviations are the first letter of the genus name and first three letters of the species epitath. 29

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Florida sand pine scrub is among the most endangered habitats in the United States and much of the remaining scrub is heavily influenced by management for timber production. In this study the effects of timber management practices on herpetofaunal community diversity and composition were investigated on experimentally manipulated plots near Orlando, Florida.

Plots at three sites were either harvested, burned, or treated as a control (unmanipulated). Herpetofauna were trapped using pit-fall drift-fence trapping arrays. Animals were counted, measured, marked and released from March 1996 to June 1998. During this time period 1489 reptiles and amphibians were caught from 31 different species. In general, the control plots were the most diverse and the burn plots were more diverse than the harvested plots. The treatments also influenced the composition of the communities found within them. Non-metric multi-dimensional scaling of species associations indicated that species assemblage found in the harvested site plots are different than those found in the burn and control plots. Harvested plots were dominated by several very common generalist species that are associated with open canopy cover. In addition to the species associations with open canopy cover, the burned and control plots contained species associated with denser canopy cover. The increased habitat structure of the burned and control plots may account for the greater herpetofaunal species diversity and evenness there. This study supports the contention that silvicultural practices have a greater affect on the diversity and structure of Florida sand pine scrub than does prescribed burning.

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INTRODUCTION

Florida sand pine scrub is a unique pyrogenic habitat that occurs on xeric, infertile upland areas. Many endemic species of plants and animals are found in this habitat (Christman 1988, Meyers 1990). Three general types of scrub are recognized; those that are found on the inland peninsula, those found on the coastal peninsula, and those found on the panhandle coast. The inland peninsula type is the most extensive and contains scrub that occurs along a complex of ridges recognized as ancient beaches and sand dunes, that transects the state from Clay and Putnam Counties in the North to Highlands County in the south (Myers 1990).

Scrub habitat is characterized by loose sandy substrate and sunny exposure. Typically, there is an overstory of *Pinus clausa*, although this may be absent, and an understory that consists of *Quercus myrtifolia* and/or *Q. inopina*, *Serenoa repens*, *Q. geminata*, *Lyonia feruginea*, and *Ceratiola ericoides*. These six species typically make up approximately 90% of the shrub layer (Myers 1990). The shrub layer varies from sparse to dense depending upon the frequency of fire, and is usually dominated by the three near-evergreen oak species. Rosemary (*C. ericoides*) balds may be common, and in inland scrubs, scrub palm (*Sabal etonia*) occurs side-by-side with saw palmetto or replaces it entirely (Myers 1990). Ground cover generally consists of *Licania michauxii*, *Rhynchospora megalocarpa*, *Galactia* spp., grasses (e.g., *Andropogon floridanum, Panicum patentifolium*), and lichens (e.g., *Cladonia* spp), and is typically distributed in patches with open areas of exposed, fine, white sand (Myers 1990).

More than 300 vascular plant species (not including weedy species) have been collected from scrub habitats in Florida. Of these, it is estimated that 10 to 40% are only found in scrub, depending on the species classification used, and several species are listed as endangered or threatened at the state and federal levels (Myers 1990, Richardson 1989). Sixty-five to seventy vertebrate species are regularly found in Florida scrubs. Christman (1988) lists 8 amphibian and 39 reptile species that include scrub in their home range. Nine species of vertebrates are considered obligate scrub denizens, including a few well-known species such as *Sceloporus woodi*, *Podomys floridana*, *Neoseps reynoldsi*, *Aphelocoma coerulescence*, and *Eumeces egregius lividus*. Additionally, the latter three species are federally listed as threatened species, and an endangered species, *Gopherus polyphemus,* frequently utilizes scrub habitat (Meyers 1990). Finally, there are more than 100 species of arthropods found in Florida scrub, including many that are found nowhere else (Deyrup 1989, Myers 1990, Richardson 1989).

According to a 1997 report by the Florida Game & Freshwater Fish Commission scrub habitat is one of the most rapidly disappearing habitat types in the country. Estimates suggest an 80% reduction of the original expanse of scrub statewide, and as much as a 95% reduction in central and southern Florida (Myers 1990, Peroni and Abrahamson 1986). Much of former scrub habitat has been converted into agricultural lands, primarily for citrus farming. Real estate development has also usurped some scrubs. Furthermore, because of the perceived worthlessness of scrub habitat, it has not received much conservation attention until recently. The largest contiguous Florida sand pine scrub is 84,000 hectares, found in Ocala National Forest (ONF), and it is managed by the U.S. Forestry Service for sustained timber production. The next largest scrub is a private ecological research site found on Archbold Biological Station and is only 1,720 hectares. Many of the remaining fragments of sand pine scrub are small, typically not more than a few hundred hectares (McCoy and Mushinsky 1994). The many small patches of scrub are managed for different objectives including commercial timber management, grazing, and recreation, further reducing the extent of pristine scrub habitat.

In Florida, wildfire may be the most important form of disturbance affecting terrestrial communities. It is known to influence floral and faunal communities (Abrahamson and Hartnett 1990, Mushinsky and Gibson 1991, Webber 1935). Species diversity and composition, as well as the physical structure and productivity of the communities, may be affected. The effect that a disturbance has on a community depends on its frequency, time of occurrence, synchrony, intensity and its spatial arrangement (Lugo and Zucca 1983, Mushinsky and Gibson 1991). The frequency, or periodicity, of the fires is critical. Both too long and too short a period between fires (depending on the particular habitat) may result in lower biodiversity (Mushinsky 1986). Organisms within these communities have adaptations that promote or resist fire or are fire dependent (Means and Campbell 1981). For example, sand pines have low branches that allow fire to climb into the canopy, and serotinous cones that open after exposed to high heat and that allow seeds to be spread immediately after a fire when the seedlings will suffer less competition from other vegetation (Myers 1990, Abrahamson 1984).

Florida scrub habitat typically burns every 30 - 60 years without human intervention (Myers 1990, McCoy and Mushinsky 1994). A periodicity of fire is necessary in order to retain the nature and integrity of scrub habitat. The periodic fires create conditions that tend to promote scrub species and maintain the scrub habitat. Without fire, scrub develops into a dense xeric hardwood forest, which may exclude several vertebrate species such as *A. coerulescence*, *G. polyphemus* and *S. woodi* (Abrahamson 1984, Connor 1996, Mushinsky and McCoy personal communication). When a fire occurs, sand pines if present, and virtually all the above-ground vegetation often is destroyed or burned back. Many species have underground root systems or rhizomes, or depend on seed banks in the soil, from which they can regenerate following a catastrophic fire (Abrahamson 1984, Peroni and Abrahamson 1986).

The frequency of fire in scrub is closely associated with the vegetative productivity. Catastrophic, or stand-replacing, high intensity fires, which sweep across large areas of scrub when there are severe burning conditions (dry and windy) occur when enough leaf litter has accumulated to fuel such a fire. More highly productive scrubs accumulate litter, and therefore fuel, more rapidly than less productive scrubs, thereby creating conditions that are conducive to large fires more frequently. In these more productive scrubs, fuel accumulation may be fast enough to support a fire within 20 -30 years, while in low productivity scrubs fuel accumulation may be so slow that the scrub rarely or never burns (Lugo and Zucca 1983, Myers 1990).

Scrub does not actually burn very well and is difficult to ignite because of the open sandy areas and lack of grasses and pine straw. When fire does occur, it usually spreads from an adjacent sand-hill or high-pine habitat that possesses fuels that are easily ignited. The fires are commonly caused by lightning strikes that cause fires in neighboring habitats that spread into scrub. Scrub can however, burn very intensely; Myers (1990) describes a 1935 wildfire that burned 14,000 hectares in 4 hours, crossed 91.5 meter wide fire breaks and generated spot fires 1.6 km ahead of the fire.

Currently, because of efficient forest fire prevention and scrub fragmentation, catastrophic fires are no longer common. Today most remaining scrub is managed for timber production, for cattle pastures, for recreation, and as parks. Prescribed burning in these managed areas is frequently used to remove litter, thereby reducing the risk of wildfire, and to control disease and pests (Greenberg *et al.* 1994a).

The majority of existing sand pine scrubs are managed for wood production. The processes involved in this industry likely have a large influence on scrub habitat today. Management of scrubs for timber production involves the use of 1) harvesting schedules that increase sand pine growth and wood production, 2) large-scale, cost-efficient, mechanized harvesting and 3) site preparation before re-seeding. The whole process begins at that time when the trees have reached a commercially valuable size. In large operations such as ONF, the forest has been divided into parcels that are logged approximately every 20 years (Greenberg *et al.* 1994a). Harvesting occurs throughout the year and does not coincide with the timing of natural disturbances.

Following harvesting, sites are prepared for seeding (Abrahamson and Hartnett 1990, Anderson and Tiebout 1993). Residual vegetation is removed by roller-chopping, disking, or windrowing which are all methods that mechanically destroy vegetation and disrupt the soils (Abrahamson and Hartnett 1990). Common silviculture practices are known to cause substantial disturbance to the habitat and, most, if not all, of the vegetation that has no commercial value (groundcover, shrubs and overstory) is destroyed. Typically, the top 10 to 40 cm of the soil horizon are severely disturbed (Abrahamson and Hartnett, 1990; Greenberg *et al.* 1994a).

Because silviculture is a widespread influence on the Florida sand pine scrub ecosystems it is important to understand what aspects of the ecosystem are affected by the harvesting. Studies have shown that timber management practices have an effect on community structure (Greenberg *et. al.* 1994a). Greenberg *et. al.* (1994b) have shown that the richness and diversity of herbaceous plants tends to increase in those habitats used for silviculture. Campbell and Christman (1982a) have suggested that the effects of mechanical harvesting may mimic the effects of wildfire on the vegetation structure and herpetofaunal assemblages. In their study of Ocala National Forest, Greenberg *et al.* (1994a, 1994b) showed that there were negligible differences in diversity and richness between sites that had been logged and sites that were subject to natural fire. Ocala National Forest however, had been subjected to timber management many years prior to their study. Therefore, all of the sites used in their study were likely affected by long term timber management which could have obscured differences between experimental treatments that may have been evident had the experiment been carried out in a healthy scrub habitat (E.D. McCoy personal communication).

The remaining fragments of Florida sand pine scrub habitats are heavily influenced by human activities. As a result of population influx to Florida, urban sprawl, agricultural and commercial development and associated infrastructure building (roads, communication and energy), scrubs are becoming fragmented and isolated. It is of great importance therefore that we understand the effects of the most substantial influences that we humans impose on the few largest remaining scrub communities. The purpose of my research is to determine if prescribed burning, and the typical silvicultural practices of clear cutting and roller-chopping affects the species richness and diversity of the herpetofaunal community in relatively undisturbed Florida sand pine scrub. My null hypotheses are: 1) Prescribed burning has no significant effect on the species richness and diversity of the herpetofaunal community in sand pine scrub and 2) Commonly used silvicultural practices have no significant effect on the species richness and diversity of the herpetofaunal community in sand pine scrub. To accomplish this goal, I sampled the herpetofaunal community of three sand pine scrub sites in Central Florida, for three years following logging and burning.

MATERIALS AND METHODS

Study Sites

Three study sites (MW5, MW7 and CW1) located no more than 6 kilometers apart in Orange and Oceola Counties in Central Florida were used in the study (Figure 1). At each of these sites, plots of scrub that were at least six hectares large and had not been recently disturbed (70+ years) were selected as my study sites. At each site, *Pinus clausa* provides the only canopy. The understory is composed of *Quercus geminata*, *Q. chapmanii*, *Q.myrtifolia*, *Lyonia ferruginea*, *Serenoa repens* and *Sabal etonia*. Patches of *Cladonia* spp. and bare sand typical of mature scrub, are common and balds of *Ceratiola ericoides* are present at two of the three sites (Table 1).

Treatments

Commercial harvesting and prescribed burning were the two experimental treatments used to study the effect of management practices on herpetofaunal communities. At each site the selected scrub plots were partitioned into three plots of equal size (1.5 to 2 hectares) and each of the two treatments were applied to one of the plots. The third plot was left untreated and used as a control. A combination of 1) the relative fire hazard to contiguous forest during prescription burning, 2) the ease of access for harvesting equipment, and 3) minimal disturbance by the forestry equipment to adjacent

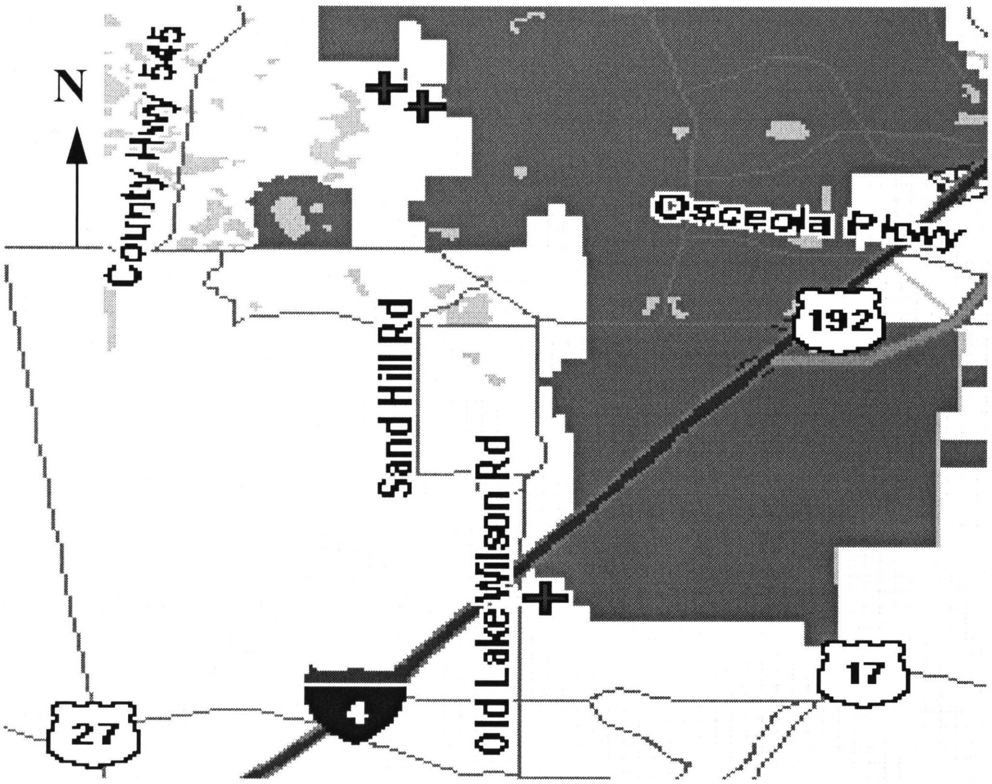

Figure 1. Map showing part of Kissimmee Florida, interstate highway 4, route 27 and 192. Study sites are marked with crosses; from the top MW-5, MW-7 and CW-1.

natural areas determined which treatment a plot received. In the "harvest" plots the sand pines were removed by a local logging crew consisting of four men, one feller-buncher, a skid, one tractor, and two trailers. The plots were harvested in two days and were then site-prepared using a large bulldozer pulling a roller-chopper behind it to destroy vegetation that would compete with sand pine seedlings. Unlike most typical harvests the plots were not re-seeded. The roller-chopper was 3 meters wide and 1.5 meters in diameter with fifteen 30 centimeter long blades along its circumference. After being filled with water it weighed approximately two metric tons. The bulldozer pulled the roller-chopper across the site multiple times leaving deep furrows in the "harvest" plots. As much as 98 percent of the above ground vegetation was destroyed, and mostly small plants such as grasses, herbs, and lichens were left in small patches all around the plot. In the harvest plots, the sand pines were stripped of their branches and loaded onto a “low-boy” for transport to the mill, leaving behind large piles of woody debris. In addition to the woody debris, oaks and other unwanted vegetation remaining in the plot were bulldozed into mounds that were up to 3 meters tall at site CW1. Finally, vegetation-free trails and deep furrows were cut into the soil where bunches of felled trees had been dragged across the site.

Prior to the prescribed burning, fire breaks about 7 meters wide were cut to prevent fire from spreading into adjacent tree stands. The prescribed burns were started by back-burning (burning against the wind) a safety zone on the downwind side of the plot to prevent the fire from leaping across the fire breaks. In a typical prescribed burn, the fire is started on the upwind side after the safety zone is created, and a strong head-fire burns fiercely and rapidly until it runs out of fuel when it reaches the safety-zone. At the two MW sites, however, the entire plots were mostly back-burned because the plots were relatively small and the humidity too high (55%) for a good fire. As a result of the low intensity of the fire at the MW sites, the canopy remained intact. At CW-1 the fire was successfully started upwind after a small but sufficient back-burn. A good head-fire was started and it traversed the plot in approximately 15 minutes. In several places, blazes reached into the canopy and burned the sand pine tree crowns. The harvest and burn schedule are listed in Table 1. The efficiency of the burn was assessed by determining sand pine mortality two weeks to one month after the burn. Ten transects in each burn plot were surveyed, and these proved to be sufficient to ensure that all trees had been accounted for. Trees were recorded as alive or dead, and used to calculate percent tree-kill. In addition to counting dead and living trees, the percentages of leaf-litter and shrubs affected by the burn were recorded to determine the extent of the ground- and brush fire.

Table 1. Date of Logging and Prescribed Burning and Habitat Description by Study Site.

Study Site	Date of Logging	Date of Prescribed Burn	Habitat Description
MW – 7	June 11, 1995	December 13, 1995	Sand pine, sand-live oak, palmetto scrub; w/ good canopy closure, semi-dense tree stand w/ bare patches.
MW – 5	June 13, 1995	July 14, 1995	Sand pine, sand-live oak, palmetto scrub, w/ rosemary; semi-dense tree stand, w/ good canopy closure w/ bare patches.
CW - 1	June 24, 1995	February 12, 1996	Sand pine, turkey/sand-live oak, rosemary balds, open tree stand w/ bare patches

Herpetofaunal Sampling

To census the herpetofauna, 10 pit-fall drift-fence traps were installed in each plot between December 1995 and February 1996. The trap arrays were distributed evenly throughout each plot, maximizing the distance between traps (8 to 15 meters apart). At each trap location, a single drift-fence pit-fall trap (trap array) was installed in a randomly chosen direction. The trap array design used in the study was modified from Campbell and Christman's (1982b) four winged open cross trap array (Gibbons and Semlitsch 1981). Each trap array consisted of a single wing made from 2 meters of 50 cm wide aluminum roof valley flashing which was buried about 20-30 cm into the ground to keep it in a vertical position. At each end of the fence, a 19 L white plastic bucket was buried flush with the ground to capture any organism moving along the fence. To ensure that burrowing organisms could not avoid the fence by burrowing under it, a slit approximately 20 – 30 cm was cut vertically in the side of the bucket to allow 2cm of flashing to protrude into the bucket (Figure 2). Twenty 2-mm holes were drilled in the bottom of each bucket for drainage during heavy precipitation. The bucket lids were propped up against the flashing at an angle to provide shade. A slit cut in the bucket lid allowed it to hang on the end of the fence, thus keeping it in place over the bucket. A 2-4 cm layer of sand on the bottom, as well as any debris that accumulated in the bucket, provided shelter for burrowing organisms.

Trap arrays were "opened" by uncovering the buckets. The trapping period varied between years because of experiences gained during the first season. In the first year of the study, the traps were open from February 26 to October 20, 1996. In 1997, however, the traps were open from February 13 to June 13 and then again from August 20 to October 23, because the previous season revealed that there was little activity during the summer months of June, July and August. In 1998, traps were open from February 22 to May 24, when the field portion of the study was concluded. Traps were checked weekly.

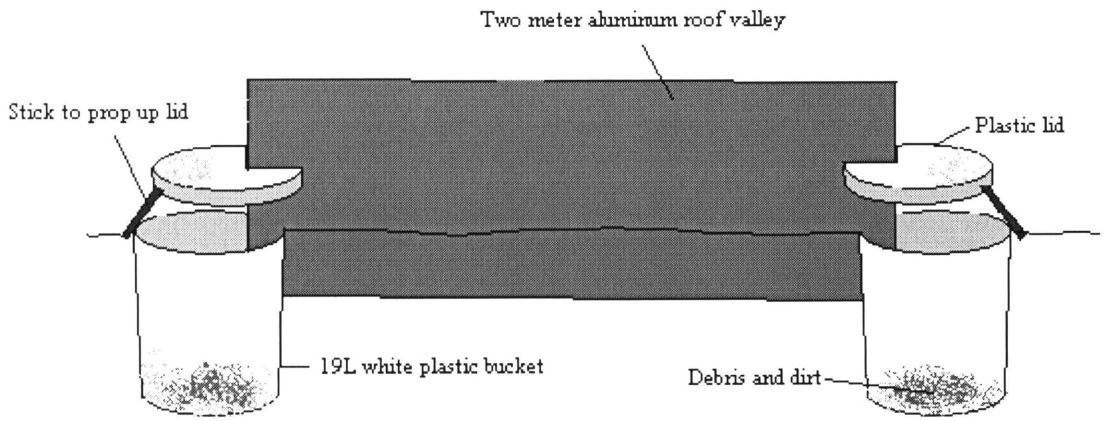

Figure 2. Diagram of the modified drift-fence pit-fall trap used in my study.

Captured animals were uniquely marked by toe clipping or branding with a medical cauterizer. Unique marks were created by coding digits on each foot. Starting from the first outside digit on the left hind foot, numbers were assigned as follows: 1, 2, 4, 7 and 9. The right hind foot represented tens, and the left front foot hundreds. The need to use the fourth limb never arose. Unique identifying numbers could be assigned to an individual by combining the different digits. For anurans a modified numbering scheme was used for the front foot with only four digits. An 8 was used in place of the 7 and there was no fifth digit. I removed no more than two digits per appendage. Furthermore, for species such as *Cnemidophorus sexlineatus* and other lizards with a long second or third digit, numbers that would require the removal of those digits were never assigned. Because recapture rates were low compared with the total number of captures (<<10%) in 1996 and lower still in 1997, no unique marks were used in the 1998 census. In 1998, instead of individual markings, a mark was used that would distinguish an organism as having been caught previously that year. Snakes were marked by cauterizing the ventral scales. A different marking scheme was used for this purpose: The ventral scales were coded starting at the second pre-anal scale and moving anteriorly assigning the numbers 1, 2, 4, 7, 9, 10, 20, 40, 70 and 90. Unique identifying numbers were created by combining scales with different numbers assigned. Only a small number of snakes were caught, however, and very few numbers were used. In addition to marking the organisms that were captured, the following measurements for all captures were taken and recorded in the field: Total length, snout-vent length (tibia-tarsus length for anurans), weight and sex.

Vegetation and habitat structure

In March of 1997 and 1998, a 2 x 2 meter quadrat was placed 1.5 meters from the fence on either side of the 90 pit-fall drift-fence traps. The quadrat was used to estimate the following structural variables at each trap location: percent bare ground, percent litter and average depth of the litter. The measurements from each quadrat were averaged for each trap location. In March of the following year, measurements were taken using a densiometer held 1.5 meters above ground at each trap location, to measure percent canopy cover. Densiometer readings for each cardinal direction (N, E, S, W) were taken at each location and averaged to yield a measurement used in the vegetation analysis.

Data Analysis

Differences in the effect of fire on canopy, shrubbery and the litter layer at each site were tested using a Kruskal-Wallis ANOVA on ranks. One-way ANOVA were used to compare treatment effects on certain habitat characteristics (canopy, bare ground, litter and litter-depth). Where it was necessary the data were arcsine square root transformed. Tukey's HSD was used to compare variables. Differences in species richness among treatments were tested using a Kruskal-Wallis ANOVA on ranks classified by treatment.

Species diversity was compared among treatments using one of the more commonly used diversity indices, Shannon-Wiener diversity index:

$$H' = -\left\{ \sum_{i=1}^{S} \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right] \right\}, \; S = \text{number of species}$$

Shannon-Wiener index is common in the literature and the biases of this index are known and can be taken into consideration when interpreting the results. Species diversity was compared among treatments using Hill's diversity numbers because their units are in number of species which is easy and intuitive to compare, and they are based on indices with known behaviors (Ludwig and Reynolds 1988). These are:

$$\mathrm{N0} = S,$$

$$\mathrm{N1} = e^{\mathrm{H}'},$$

$$\mathrm{N2} = \frac{1}{\lambda}$$

where *H'* is the Shannon-Wiener index, and λ is Simpson's index:

$$\lambda = \sum_{i=1}^{S} p_i^2 \left(p = \frac{n_i}{N}, \text{ and } i = 1,2,3,\ldots,S\right)$$

Estimates of species richness for each treatment and the undisturbed plots were calculated using Hurlbert's method of rarefaction. This method uses actual sample size and species number to estimate species richness at a given smaller sample size (Ludwig and Reynolds 1988), allowing for comparisons of species richness at equal sample sizes between the treatments. To justify the use of rarefaction the log of species' relative importance was plotted against species rank for each treatment. The resulting curves were compared visually to determine that abundance patterns were similar.

To determine the prevalence of numerical dominance by one or several species within different treatments, the treatments were compared using several evenness indices. The first evenness index used is Pielou's *J'* (Ludwig and Reynolds 1988):

$$J' = \frac{H'}{\ln(S)} \text{ or } E1 = \frac{\ln(\mathrm{N1})}{\ln(\mathrm{N2})}$$

This index is relatively sensitive to the addition of rare species to the sample when the sample contains very few species. Even with its drawbacks it is a commonly used index, and no samples in this study were particularly species poor. The second evenness index used was the modified Hill's ratio which approaches zero as a single species becomes increasingly dominant in the sample (Ludwig and Reynolds 1988): $E5 = N2/N1$, where N1 and N2 are Hill's diversity numbers. Several authors have shown that this evenness index has desirable characters for example it is not sensitive to rare species in the sample (Ludwig and Reynolds 1988). Numerical dominance was also investigated by examining species' relative frequencies expressed as a percent. Spearman's rank correlation was used to determine if correlations could be found among individual species and the vegetation and structural variables described above.

RESULTS

Substantial variation existed in the effects that the different treatments had on the vegetation. Post-treatment visual inspection indicated that the harvest plots were most altered. At each of the three replicate harvest plots, there was 100 percent tree mortality and 100 percent reduction of the understory vegetation. Marked differences were found in the extent of the damage caused by the presecribed burns at the MW-5, MW-7 and CW-1 sites in July, December and Febuary respectively. Ground cover and shrubby vegetation were reduced most at CW-1 and least at MW-5 (Table 2). The effect of the fire on the canopy cover was also the greatest at CW-1.

Table 2. Effects of fire (percent killed) on ground cover and litter, the shrub layer and canopy (tree-kill).

Measurement	MW-5	MW-7	CW-1
Ground cover / Litter	75.3	93.2	97.8
Shrubbery	22.8	53.5	81.2
Canopy	35	31.6	54.7

Further investigation of structural variables in 1997 and 1998 showed that the undisturbed plots had the most and the harvest plots had the least canopy (Table 3). There was a significant difference in canopy cover among treatments ($F_{2,87} = 54.2$, $P < 0.001$). The amount of bare ground was significantly greater in the harvest compared with the other two treatments ($F_{2,87}$ =38.85, P< 0.001). Percent litter did not differ among the treatments ($F_{2,87}$ = 25.002, P< 0.558). Litter-depth was also significantly greater in the harvest compared with the other two treatments ($F_{2,87}$ = 0.587, P< 0.001).

Table 3. Mean results of vegetation and structural variables measured at each trap in 1997 and 1998. Different letters in superscript indicate significant (a=0.05) difference between the treatments according to Tukey's HSD.

Measurement	Burn	Undisturbed	Harvest
% Canopy	51.7^{a}	66.6^{b}	0^{c}
% Bare Ground	8.9^{a}	5^{a}	32.1^{b}
% Litter	82.8^{a}	78.8^{a}	49.8^{a}
Litter-depth (cm)	2.4^{a}	2.8^{a}	3^{b}

Over a period of three years, 1531 vertebrates were captured. Captured animals included 740 reptiles of 22 species, 749 amphibians of 9 species and 42 small mammals. *Bufo terrestris* and *Cnemidophorus sexlineatus* were the most abundant species, accounting for 29% and 20% of all captures, respectively. The preceding percentages include unique captures as well as recaptures; however, recapture rates were very low. Five species including *Eumeces inexpectatus*, *Gastrophryne carolinensis*, *Neoseps reynoldsi*, *Scaphiopus holbrookii* and *Tantilla relicta,* each accounted for 7 to 10% of all captures (Table 4). Of the remaining species none accounted for more than 5% of all captures (see Table 4). The overall trap mortality for amphibians and reptiles was less than 10%. Several species that were caught were not used in data analyses because of their ability to leave the bucket at will (Table 4). In addition to organisms that could leave the bucket at will, incidental captures of *Gopherus polyphemus* were not included in the analyses, because drift-fence pit-fall trapping is not an appropriate method for capturing this species (McCoy and Mushinsky 1994). A few additional species were observed but never trapped at the sites: *Drymarcon corais*, *Crotalus adamanteus*, *Masticophis flagellum* and *Opheodrys aestivus*.

Table 4. Species, frequency of capture (with recaptures in parenthesis) and relative frequency of capture in percent.

Species	# Caught	% of Total	Remarks
Acris gryllus	1	< 1	Not used in analyses
Anolis carolinensis	10	< 1	Not used in analyses
Bufo quercicus	2	< 1	
B. terrestris	444(9)	29	
Cemophora coccinea	12	< 1	
Cnemidophorus sexlineatus	309(61)	20	
Coluber constrictor constrictor	6	<1	
Diadophis punctatus	3	< 1	
Elaphe guttata	2	< 1	
Eleutherodactus planirostris	3	< 1	Not used in analyses
Eumeces inexpectatus	114(13)	7	
Gastrophryne carolinensis	152(1)	10	
Gopherus polyphemus	10	< 1	Not used in analysis
Graptemys scripta	1	< 1	
Heterodon simus	3	< 1	
Micrurus fulvius	1	< 1	
Neoseps reynoldsi	131	9	
Ophisaurus ventralis	1	< 1	
Rana catesbiena	6	< 1	
R. grylio	4	< 1	
R. utricularia	9	< 1	
Rhineura floridana	2	< 1	
Scaphiopus holbrookii	117(2)	8	

Table 4. Species, frequency of capture (with recaptures in parenthesis) and relative frequency of capture in percent.

Species	# Caught	% of Total	Remarks
Sceloporus woodi	9	< 1	
Scincella lateralis	12	< 1	
Seminatrix pygea	1	< 1	
Tantilla relicta	110(4)	7	
Terrapene carolina	1	< 1	
Thamnophis sirtalis	2	< 1	
Blarina carolinensis	34	2	
Mice & rats	7	< 1	Various species of mice and small rats

Species richness did not differ significantly among experimental treatments when tested using a Kruskal-Wallis ANOVA classified by treatments (Fig. 3). Hill's N1, a richness index that takes into account the relative abundance of each species, yielded a different trend. Undisturbed plots had more *abundant* species (averaging 8.5 species) than the burn plots and harvest plots which had numerical averages of 7.6 and 5.8 abundant species, respectively (Figure 3). Hill's N2 yielded a similar but more pronounced result. The undisturbed plots had a numerical average of 7.6 *very abundant* species whereas the burn and harvest treatments had numerical averages of 5.8 and 4.2 *very abundant* species, respectively (Figure 3). Overall the harvest treatment had the fewest number of abundant and very abundant species.

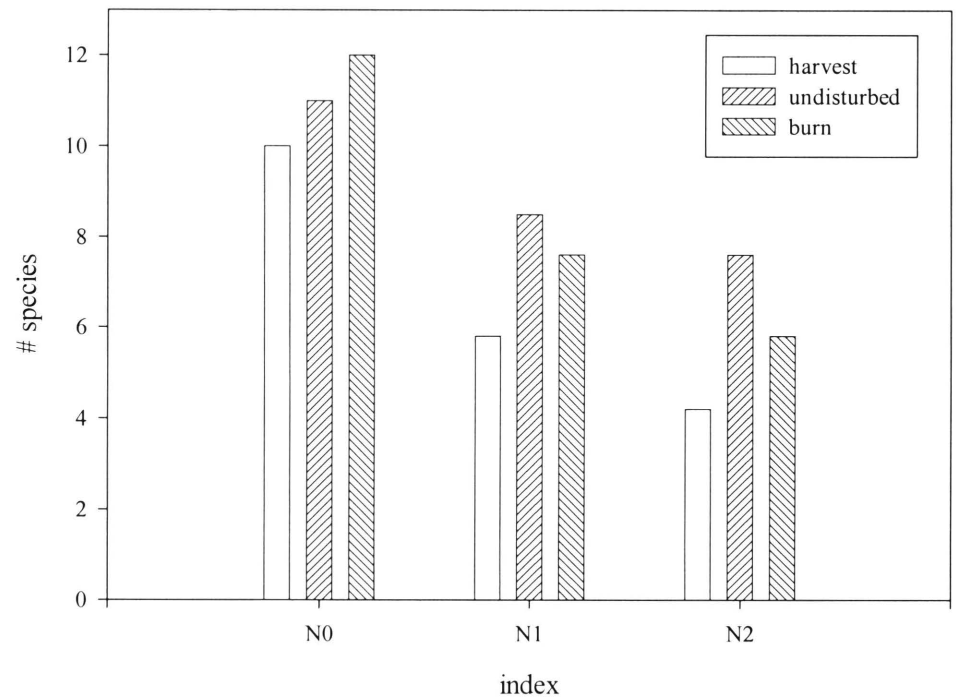

Figure 3. Species richness compared between treatments and the control using Hill's richness numbers N0, N1 and N2.

The number of animals captured varied among the burn, harvest and undisturbed plots (N = 461, 442, 574, respectively). To account for the differing sample sizes, Hurlbert's method of rarefaction was applied to the data (Ludwig and Reynolds 1988). Rarefaction takes sample size, as well as the number of species, into account when estimating species richness. Visual inspection of the species abundances curves in figure 4 indicate that the species abundance distributions are similar in each of the treatment plots, the undisturbed plots and in pre-treatment study and appear to follow a log-normal distribution.

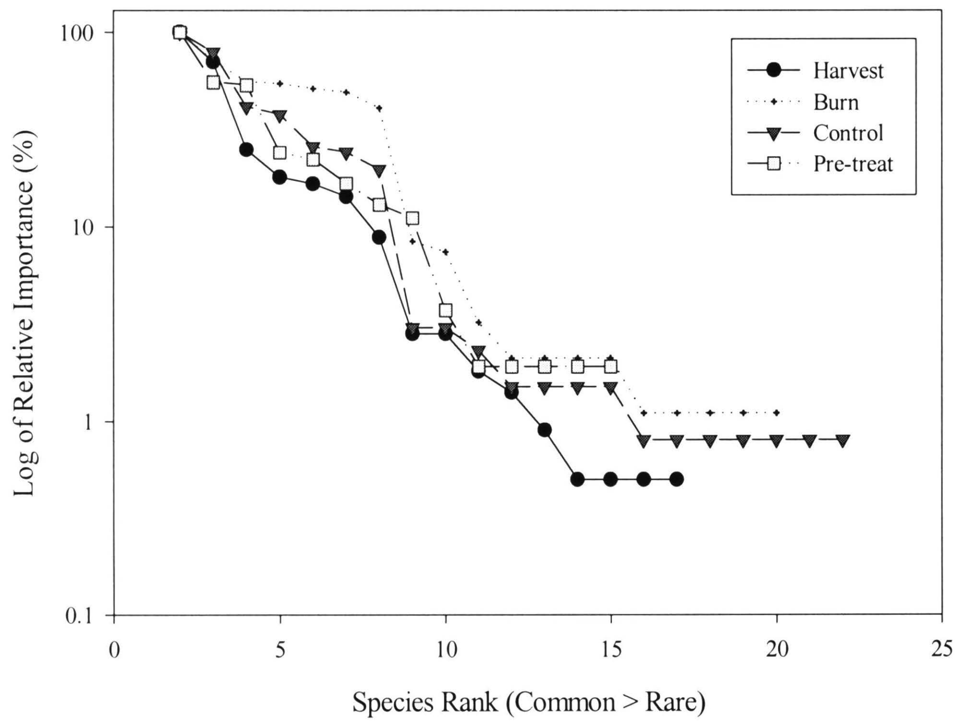

Figure 4. Species abundance curves for the treatments, control and pre-treatment study showing $\log_{10}$ of the relative importance of species along the Y-axis and the rank of species abundance on the X-axis.

A fit to a log-normal curve was not explicitly tested, however the log-normal distribution is commonly found in communities, such as this one, where most of the species have intermediate abundances and few species have very low or very high abundances (Sugihara 1980). If the assumed log-normal distributions are correct, then the assumption that the populations have similar species distributions is met, and I am justified in applying the rarefaction technique to the samples.

Rarefaction also indicated that the harvest treatment was the least species rich (Figure 5). The burn treatment was on average the most species rich when sample size is taken into account. The gray squares in Figure 5 represent the results from a pre-treatment study at the same three sites in Kissimee, Florida, conducted by a Tampa based consulting firm. Comparison between the data from the pre-treatment study and the current study would have been difficult without the use of rarefaction because the sample sizes used were less than half those used in this investigation. By applying Hurlbert's rarefaction method however, it was possible to make comparisons of the pretreatment study with my study. The resultant rarefaction curve indicate that the pre-treatment study is most similar to the undisturbed plots used in this study, suggesting that the herpetofaunal community of the undisturbed plots has not changed because of the treatments. In addition to the similarity with the preliminary study, the greater steepness of the curve for the burn treatment also indicates that the relative evenness of the treatment is greater than the harvest, and the undisturbed treatment was intermediate.

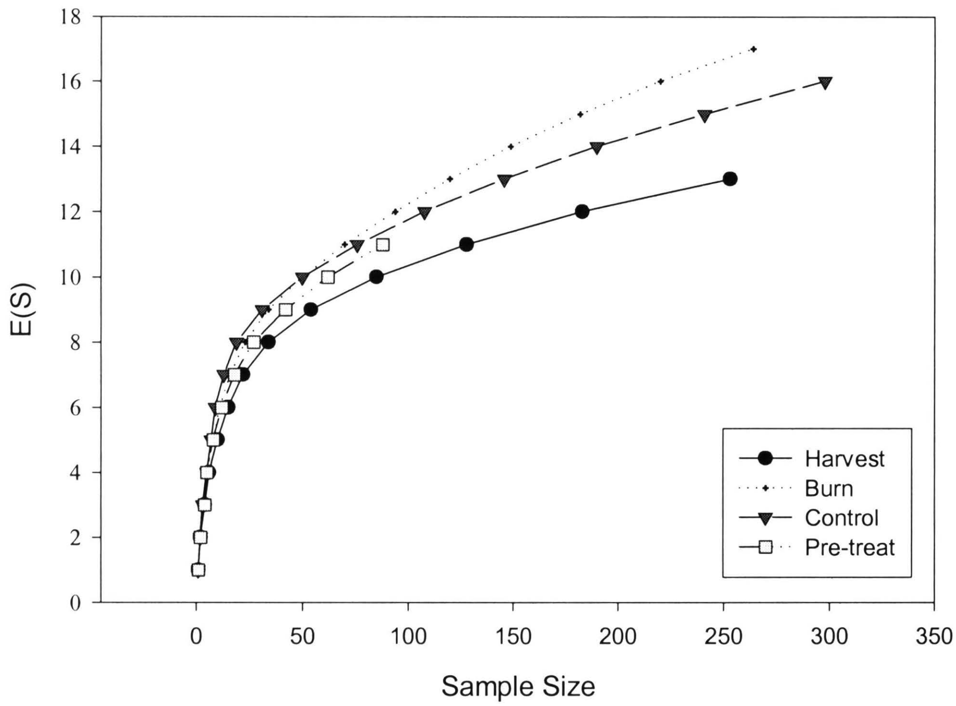

Figure 5. Rarefaction curves for each treatment, undisturbed plots and pre-treatment study. The vertical axis shows the estimated number of species in the sample. The horizontal axis shows the sample sizes.

Treatments were compared for evenness using one of the most commonly used evenness indices, Pielou's J' ($E1$), and the modified Hill's ratio ($E5$) because of its desirable qualities as a good all-round index that is tolerant to numerically dominant species (Ludwig and Reynolds 1988). Figure 6 suggests that the undisturbed plots were the most even, the harvested plots the least even and the burned plots were intermediate.

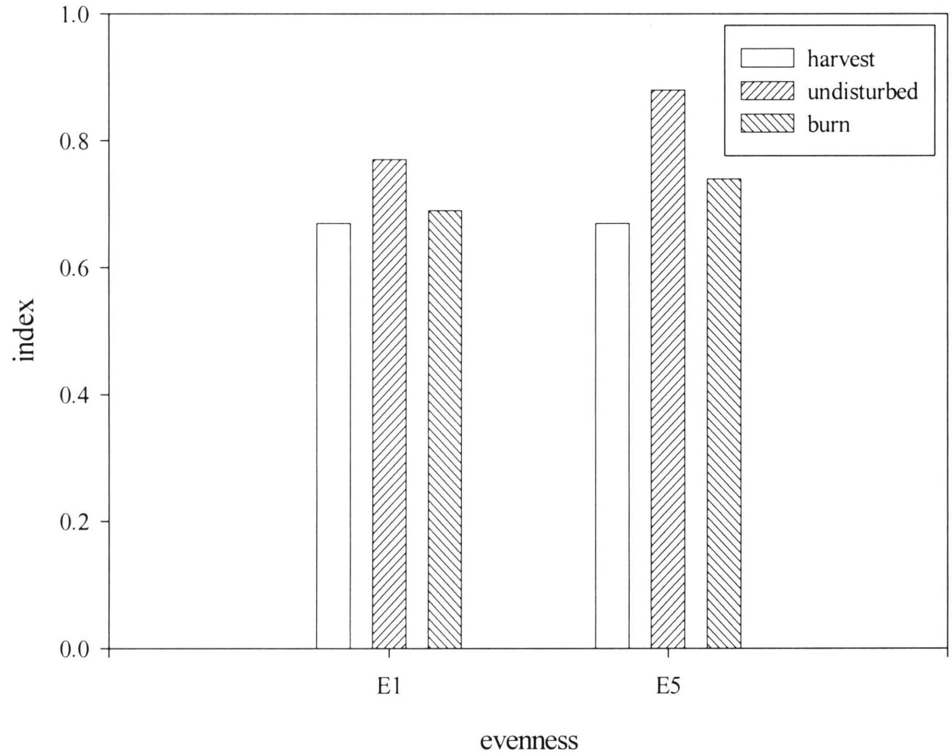

Figure 6. Species evenness in the harvest, burned and undisturbed plots calculated using using *J'* (*E*1) and Hill's modified ratio (*E*5)

The Shannon-Wiener diversity index indicated that harvested plots tend toward greater numerical dominance of a few species when compared with the burned plots and undisturbed plots. The undisturbed plots tended to be more diverse and even (Figure 7).

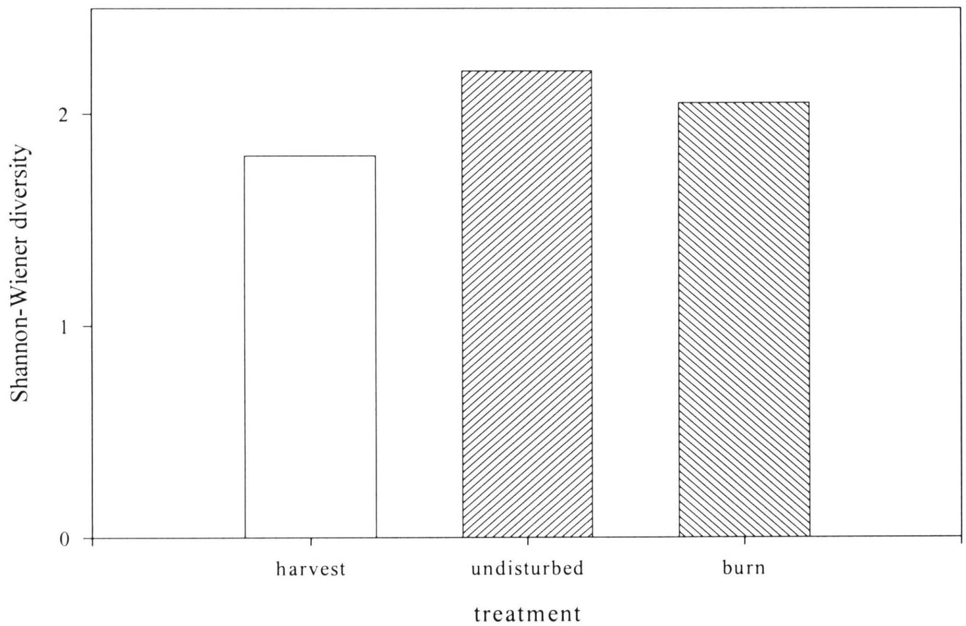

Figure 7. Comparison of Shannon-Wiener diversity between treatments and undisturbed plots.

Vegetation characteristics of the treatment plots and undisturbed plots were compared. The percent canopy cover and bare ground were compared for each sampling unit and the test revealed that there was a highly significant negative correlation between the two variables (r = -0.73, p = 0.002). A significant positive relationship was found between percent canopy cover and percent litter (r = 0.81, p = 0.009). In addition to the preceding relationships, a significant positive correlation was also found between percent litter and litter depth (r = 0.67, p = 0.043). Correlations between canopy cover and percent litter are expected because of higher litter accumulation directly below trees, and it follows that increased canopy cover reduces the amount of bare ground via litterfall.

Several species showed significant correlations with the vegetational and structural variables chosen for the study (Table 5). Bufo terrestris was significantly correlated with percent bare ground and negatively correlated with canopy and percent litter. Cemophora coccinea was significantly positively correlated with percent litter. Cnemidophorus sexlineatus was significantly negatively correlated with canopy, and significantly positively correlated with percent bare ground. Only the highly significant correlations remain significant when the tests are Bonferoni corrected.

Table 5. Spearman's rank correlation values relations among species, vegetation and structural variables. Significant and highly significant correlations are marked with one or two astrices respectively. Correlations that were within the 10% level are also reported in this table, the remaining correlations were not reported (n/a).

Species	Percent Canopy	*p*-value	Percent Bare Ground	*p*-value	Percent Litter	*p*-value	Litter-depth	*p-value*
B. terrestris	-0.44**	0.000	0.51**	0.000	-0.5*	0.000	n/a	n/a
C. coccinea	n/a	n/a	n/a	n/a	0.21*	0.045	n/a	n/a
C. constrictor	-0.47**	0.000	0.38**	0.000	n/a	n/a	n/a	n/a
C. sexlineatus	0.18	0.088	n/a	n/a	n/a	n/a	n/a	n/a
E. planirostris	0.21*	0.044	n/a	n/a	n/a	n/a	n/a	n/a
E.inexpectatus	n/a	n/a	n/a	n/a	0.19	0.071	n/a	n/a
G.carolinensis	-0.23*	0.027	0.23*	0.029	-0.29**	0.006	-0.48**	0.000
N. reynoldsii	n/a	n/a	0.2	0.059	n/a	n/a	-0.197	0.062
S. holbrookii	n/a	n/a	n/a	n/a	0.193	0.069	n/a	n/a
S. lateralis	n/a	n/a	-0.22*	0.035	n/a	n/a	n/a	n/a
S. woodi	n/a	n/a	0.23	0.027	-0.21*	0.046	n/a	n/a

DISCUSSION

The results of my study suggests that the undisturbed plots were the most diverse of the three types of plots, and that the burn plots were more diverse than the harvested plots. The treatments also appeared to influenced the composition of the communities found within them. Harvested plots were dominated by several very common generalist species that are associated with open canopy cover. In addition to the species associations with open canopy cover, the burned and undisturbed plots contained species associated with denser canopy cover.

Different management regimes can influence both the overall diversity and herpetofaunal community composition of Florida sand-pine scrub. Species richness was greatest in the burn plots and least in the harvest plots, although these differences were small. This pattern however, may suggest that timber harvesting does not exactly mimic the effects of prescribed burning and that timber harvesting may have a slight negative effect, at least in the short term, on sand pine scrub vertebrate species richness and composition. Hill's diversity numbers indicate that species were reduced and that the undisturbed plots had a higher effective number of species than the burn plots which, in turn, were more diverse than the harvested plots. Although the differences between the treatments were small when comparing species number, incorporating species abundance made the differences between the treatments greater. Collectively, these indices suggest that although there are a relatively large number of herpetofaunal species in the harvest plots, many of them may be rare and a few species may be numerically dominant in the species assemblage found there. Thus, during the course of my study the harvest plots had low diversity overall. The burn plots appear to be more diverse than the harvest plots in terms of species number, a pattern that was consistent also when the species abundances were factored into the analysis (Figure 2). Species abundance had very little influence on the estimated number of species present in the undisturbed plots which suggests that species' abundances were evenly distributed among most species found there.

Further investigation of species richness using Hurlbert's method of rarefaction (Ludwig and Reynolds 1988), supported the notion that the herpetofaunal community may be affected detrimentally by harvesting. The rarefaction curve for the harvest treatment suggested that when the sample size was increased above 60 the likelihood of sampling a new species decreased and remained lower than the likelihood of sampling a new species in the burn treatment and undisturbed plots. At a sample size of only 40 individuals it appeared that the rarefaction curve for the harvested plots was flatter than the other curves and approaching an asymptote. At a sample size of 250 there appeared to be a difference in the estimated species richness ($E(S)$) of about 30 percent (4 species) between the burn and harvest treatments. The harvest plots were also distinguishable from the undisturbed plots although the difference was not as obvious as the difference between the harvest and the burn plots (17%). In addition to the apparent differences in species richness, the curve appears to be approaching an asymptote at a lower value of $E(S)$ in the harvest relative to the burn plots. The slope of the curve for the burn plots was steeper in the same region and it was more difficult to predict where it may have reached a plateau. The curve for the burn plots would likely plateau at a higher $E(S)$ than the curve for the harvest. That the slope of the curve is declining toward zero also suggests that the study was relatively successful in sampling most of the species that could be sampled in that treatment; even with a doubling of the sample size the species richness was not likely to change appreciably.

Comparisons of evenness among treatments plots and the undisturbed plots using both Pielou's J' and the modified Hill's ratio (Ludwig and Reynolds 1988) revealed the same trends as those indicated by the richness indices. The harvest treatment was the least even of the two treatments and the undisturbed plots were the most even, which is again indicative of high abundances of few species and also suggests dissimilarities in abundance among those species that are in the harvest. The burn treatment was more even than the harvest, but the presence of more species, including several of which were not very common such as *Ophisaurus ventralis*, *Micrurus fulvius*, *Eleutherodactylus planirostris*, and *Heterodon simus,* contributed to the lower evenness of this treatment relative to the undisturbed plots. Shannon-Wiener diversity index H' indicated that the harvest plots also were the least diverse.

Harvesting practices may reduce the biodiversity of the harvested area. The lack of vegetational complexity in clear cut habitats may explain some of the reduced species diversity at these sites. The harvested sites had very little litter and canopy cover but what litter there was occurred in relatively deep piles. The burned plot, on the other hand, had sparse to moderate canopy and litter cover, interspersed within the open patches. The mosaic left by the fire provided both shady habitat patches, patches with greater exposure to sun and lower daily temperature overall and thus, provided a greater variety of habitat for herpetofauna to utilize. *Bufo terrestris*, *Cnemidophorus sexlineatus* and *Gastrophryne carolinensis* abundances were all positively correlated with percent bare ground and negatively correlated with percent canopy cover. *Sceloporus woodi* showed the same trend although the negative correlation with percent canopy was not significant. These correlations indicate that the four above mentioned species prefer more open habitat, such as that which is found in the harvested sites. Although significance was not tested, there appeared to be a greater proportion of *B. terrestris*, *C. sexlineatus*, *G. carolinensis* and *S. woodi* found in the harvested plots relative to the burn and undisturbed plots. Three of these species (*S. woodi* being the exception) are generalists species and their habitat ranges include but are not limited to, flatwoods, prairie, sand-hill and scrub (Conant and Collins 1991). *Bufo terrestris*, *C. sexlineatus*, *G. carolinensis* are well adapted to the open landscape were traits such as speed, camouflage and toxic skin allow these species to cope with greater predation pressure from birds of prey and other fast moving predators that are common in such areas.

Other species associations were also revealed by the tests. *Cemophora coccinea* showed a significant positive correlation with percent litter, consistent with its fossorial habits. *Eleutherodactylus planirostris* showed a significant positive correlation with percent canopy, which matches its preference for forested habitat (Conant and Collins 1991). *Eumeces inexpectatus* and *Sceloporus holbrookii* both showed tendencies to prefer areas with high amounts of litter ($p = 0.071$ and $p = 0.069$). *Scincella lateralis* showed a significant negative correlated with percent bare ground ($p = 0.035$). Generally this species is found in the litter layer. *Tantilla relicta* was correlated with percent canopy, showed a significant negative correlation with bare ground, and was also positively correlated with litter-depth. All these species appear to show a preference for habitat characteristics that are typical of forested areas such as the undisturbed plots and the burn plots, and were found in lower proportions in the harvest treatment. Low levels of exposure to sun may prevent exposure to elevated temperatures and lessen dessication which may be an important factor for these species.

The data suggest that the treatments used in this experiment result in varying or different herpetofaunal assemblages. The analyses indicate that the harvest treatment revealed in a lower species diversity than either the burn or undisturbed treatment although the test of species richness was not significant. In addition to lower species diversity in the harvest treatment, the evidence suggests that the herpetofaunal assemblages found in the harvest treatment are distinct from the assemblages found in the other treatments. The burn and undisturbed treatments were more similar to each other with respect to the diversity indices than either of those was to the harvest treatment. In fact the different diversity analyses gave a conflicting results when comparing the burn treatment and undisturbed plots with the harvest treatment. Hill's N1, N2, Shannon-Wiener *H'* index, Pielou's *J'* and the modified Hill's ratio all indicated that the undisturbed treatment were more diverse than the burn treatment. In contrast, Hill's N0 and the rarefaction technique indicated that the burn treatment was more diverse than the undisturbed plots. The harvest treatment had slightly fewer species than the other treatments, and this difference was even more evident when species richness was weighted by abundances, although these relationships were not statistically significant. The low species richness indicates that there were several dominant species in the harvested treatment and many rare species. Numerical dominance by a few species may be explained by the reduction of structure (especially canopy cover), in these plots as a result of the harvesting technique; immediately after the harvest there was little or no vegetation that exceeded 20 centimeters in height, and there were no vegetated or shaded patches. The lack of canopy may preclude some species that use the trees and shrubs as a resource. The indirect effects of canopy cover however, may be more important in this case. The shade provided by canopy cover reduces the overall temperature of an area and litter fall from the canopy cover provides additional habitat structure. Evidence from this investigation suggests that the species that occur commonly in the harvested areas prefer the open clear areas. For example, *Cnemidophorus sexlineatus* uses its speed as its primary defense against predation, and it may be hindered by complex and thick vegetational structure. Additionally, it has been shown that *C. sexlineatus* as well as *S.woodi* use a greater proportion of open habitat (Mushinsky 1985, Anderson and Tiebout 1993), and Campbell and Christman (1982a) found these species to be "xeric adapted." Conversely, *E. inexpectatus* was found to prefer fallen trees (Mushinsky 1992), logs and woody litter (Anderson and Tiebout 1993), and is not "xeric adapted" (Campbell and Christman 1982a).

The burn treatment was similar to the undisturbed treatment in species composition and diversity. The prescribed burn opened up the understory and the canopy particularly where the fire was intense enough to reach into the tree crowns (CW-1). Fire was not as destructive as the roller-chopping treatment however, and recovery of vegetation occurred more quickly. After even quite intense burns, re-sprouting from still living roots can occur almost immediately. Recovery of habitat structure may occur more rapidly post-burn than post-harvest because the leaf litter and other vegetation release nutrients into the soil after a prescribed burn providing re-sprouts and seedlings with a nutrient "boost" directly after the burn. In contrast, in harvested sites much of the above ground biomass is removed from the site, and what remains will supply nutrients to returning vegetation much more slowly, through decay. Furthermore, many scrub plants have fire adapted seeds that germinate readily after a burn but may not do so after harvesting.

The differences that were observed between the harvested, prescribed burn and control plots although not significant, suggest that the typical silvicultural practices used in Florida sand-pine scrub may have a detrimental affect on species diversity and alter species composition within the scrub. My study suggests that in the short term at least, herpetofaunal diversity may be jeopardized by the silvicultural practices currently utilized. Finding an apparent detrimental affect of silvicultural practices on herpetofaunal scrub communities contrasts with the findings of Greenberg *et al.* (1994a). They found no significant differences in richness, diversity or evenness in their study of high-intensity wildfire and silviculture on scrub. The results found by Greenberg *et al.* however, should be interpreted with caution because they lacked true undisturbed plots and they did not have any pre-treatment data from their study sites. Both Greenberg *et al.* (1994a) and this study found that community composition changed as a result of harvesting indicating that, while the diversity may or may not be influenced by the treatment, the community was altered by the treatment.

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