HOME RANGE SIZE, HABITAT ASSOCIATIONS AND REFUGE USE OF THE FLORIDA PINE SNAKE, *Pituophis melanoleucus mugitus*, IN SOUTHWEST GEORGIA, U.S.A.

By

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To my son, for a future where he can discover and appreciate the natural world.

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Knowledge of spatial ecology, habitat, and resource requirements is useful when considering the conservation of a species. Very little is known regarding these aspects of the ecology of the Florida pine snake (*Pituophis melanoleucus mugitus*). In this study, 12 Florida pine snakes were radio-tracked within a managed tract of longleaf pine (*Pinus palustris*) forest in southwest Georgia. Home range estimates were generated using three distinct methods, and variations in home range size between sexes and across seasons were examined. Habitat associations were examined at the landscape and within home range scales using Euclidean distance analyses. Microhabitat structure, refuge use and association were also examined. Overall, minimum convex polygon (MCP) home ranges of Florida pine snakes varied among individuals and were significantly smaller in fall/winter than spring and summer. Specifically, males had larger home ranges in spring than in summer or fall/winter, whereas females did not differ across seasons. Florida pine snakes were significantly associated with mixed pine-hardwood forests at the landscape scale and all other habitats were used relative to their availability. I did not detect significant habitat associations for pine snakes at the home range scale and snakes were not associated with any particular microhabitats. Pine snakes

predominately used pocket gopher burrows as fossorial refuges, though I did not detect an association with any refuges during their above-ground activities.

Florida pine snakes used large areas and selected for mixed pine-hardwood forest. Snakes were highly fossorial; therefore refuges, particularly southeastern pocket gopher burrows, are important resources for Florida pine snakes. It appeared that fragmentation by major roads and intensive agriculture may impede pine snake movements. Effective conservation of Florida pine snakes will require the protection, restoration and management of native habitats. Protecting native upland ecosystems and natural disturbance processes such as fire, will benefit pine snakes and, thereby, provide and maintain necessary resources.

CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

The Southeastern Coastal Plain was originally dominated by the longleaf pine ecosystem. Today, less than 3% of the original longleaf pine forest remains intact (Noss et al. 1995), making it one of the most endangered habitats in the U.S. (Noss and Peters 1995, Ricketts et al. 1999). The longleaf pine ecosystem supports a diverse reptile fauna (Guyer and Bailey 1993). However, many longleaf pine associated reptiles, such as the gopher tortoise (*Gopherus polyphemus*), a keystone species (Eisenberg 1983), and eastern indigo snake (*Drymarchon couperi*) are declining (Auffenberg and Franz 1982, Moler 1992). The Florida pine snake (*Pituophis melanoleucus mugitus*), another inhabitant of the longleaf ecosystem, is also believed to be declining. The decline of this species is likely a result of habitat loss and fragmentation, though road mortality and extensive collection may also be contributing factors (Franz 1992). Despite concerns about population declines, very little is known about the ecology or the status of Florida pine snakes. In order to effectively conserve this species, knowledge of their basic ecology and habitat requirements is needed.

Literature Review

Florida pine snakes occur throughout the Southeastern Coastal Plain. Their distribution includes most of Florida, southern Georgia, the southern tip of South Carolina and extreme southern Alabama (Conant and Collins 1998). Florida pine snakes are generally found in a variety of upland habitats, including sandhills, pine flatwoods, oak scrub, and dry oak forests, all of which have well-drained, sandy soils and moderate to open canopies (Ernst and Ernst 2003, Franz 1992). They are also known to occur in old fields and agricultural borders (Franz 1992).

Florida pine snakes are most active in spring and early fall (Franz 1992). They over-winter below ground and, depending on temperature, may be inactive during extreme summer temperatures (Ernst and Ernst 2003). Pine snakes are diurnal but much of their time is spent underground in the burrows of the southeastern pocket gopher (*Geomys pinetis*; Franz 1992, 2005), although other underground refuges are also used. Florida pine snakes are adept at digging (Franz 1991); they use their spade-like head and large rostral scale to gain access into the tunnels of southeastern pocket gophers. This behavior has also been described for bullsnakes at northern pocket gopher (*Geomys bursarius)* burrows (*P. catenifer sayi*; Carpenter 1982, Hisaw and Gloyd 1926),

Florida pine snakes forage both above and below ground and take a variety of prey including mice (*Peromyscus* spp.), cotton rats (*Sigmodon hispidus*), young cottontail rabbits (*Sylvilagus floridanus*), and ground nesting birds and their eggs (see Ernst and Ernst 2003). They also prey upon pocket gophers (Ernst and Ernst 2003, Neill 1951), in addition to using their burrows for refuge (Franz 2005). When underground, the bullsnake will constrict prey by pinning them to the burrow walls with their coils (Hisaw and Gloyd 1926). Florida pine snakes probably also use this technique to restrain pocket gophers.

Knowledge regarding Florida pine snake reproduction is limited. Ernst and Ernst (2003) reported that *P. melanoleucus* breed in April and May. In the southernmost portion of their range, mating may also occur in winter (Ashton and Ashton 1981). Franz (2005) observed Florida pines snakes mating on 31 May. Male black pine snakes (*P. m. lodingi*) actively seek females over large areas, probably using olfaction to locate them (Reichling 1982), and this is likely true for the Florida pine snake as well. Nesting typically occurs from June through August, when 4-8 large leathery eggs are laid in underground cavities or burrows (Franz 1992). Female northern pine snakes excavate an egg chamber rather than using existing cavities (Burger and Zappalorti 1991). In Florida, pine snake eggs typically hatch in September or October and total body length of hatchlings averages 595 mm (Franz 1992).

Little is known about the spatial ecology of Florida pine snakes. To date, only one published study from north central Florida has documented home range size for the subspecies (Franz 2005; 57 ha average home range size). Large-bodied snakes, such as the pine snake presumably require large tracts of land to meet their basic requirements (Gerald et al. 2006a, 2006b; Dodd and Barichivich 2007, Hyslop 2007). For example, prey may be sparse or patchily distributed (Gregory et al. 1987) requiring extensive movements. Also, overwintering sites of may be far removed from summer feeding areas, as has been shown for some crotalids (Reinert and Zappalorti 1988) with movements from winter den sites to foraging sites exceeding 7 km (unpublished data, reported in Brown 1993). Reproductive activities, such as males actively searching for mates or females finding nest sites may determine a snake's use of space as well (Gregory et al. 1987).

Franz (2005) noted that Florida pine snakes used pocket gopher burrows as refuges at a higher frequency than other species, but the degree to which pine snakes are dependent upon this species for food and shelter is unclear. Pocket gophers are considered ecological engineers (Miller et al. 2008, Reichman and Seabloom 2002) and their burrows provide refuge to a variety of species. Gopher burrows serve as the primary habitat for some rare arthropods (see Skelley and Gordon 1995, Skelley and Woodruff 1991). They also provide refuge to many reptiles and amphibians (Funderburg and Lee 1968) including pine snakes. Recent evidence suggests that southeastern pocket gopher populations are declining (Georgia Department of Natural Resources 2008); the impact that these declines may have on pine snakes remains unclear.

The results of this study will increase our knowledge of pine snake ecology as well as contribute to improved decision-making for land acquisition and habitat management for the benefit of pine snakes. This information will ultimately assist managers in developing the most effective conservation practices for Florida pine snakes.

Study Objectives

To effectively implement conservation objectives for the Florida pine snake, a greater understanding of their basic ecology is needed. My objectives were to determine 1) spatial use, 2) habitat association, and 3) refuge use of Florida pine snakes within a managed upland pine forest matrix in southwest Georgia. In Chapter 2, I estimated annual home range size of adult Florida pine snakes. Differences in home range size between sexes and across seasons were also examined. In Chapter 3, I examined habitat association at both the landscape and within home range scale based on Johnson's (1980) natural orders of selection; habitat association at the local scale was examined using habitat structure. Also in Chapter 3, I quantified fossorial refuge use and examined association with specific refuge types, including pocket gopher burrows. In Chapter 4 I summarized the major conclusions of this study and the implications for Florida pine snake conservation.

CHAPTER 2

HOME RANGE SIZE OF FLORIDA PINE SNAKES, *Pituophis melanoleucus mugitus*, IN SOUTHWEST GEORGIA

Introduction

The main threat to biodiversity is habitat loss, fragmentation and degradation (Wilcove et al. 1998). Gibbons et al. (2000) recently pointed out that reptiles, as a group have been largely ignored in conservation, yet they are also likely to be highly affected by habitat loss. The longleaf pine (*Pinus palustris*) ecosystem in southeastern United States harbors the highest reptile diversity in North America (Guyer and Bailey 1993); several reptile species such as the gopher tortoise (*Gopherus polyphemus*) which is a keystone species (Eisenberg 1983), and the eastern indigo snake (*Drymarchon couperi*), both of which are characteristic of the longleaf pine ecosystem, are declining due to habitat loss (Auffenberg and Franz 1982, Moler 1992). The status of other longleaf pine associated species such as the Florida pine snake (*Pituophis melanoleucus mugitus*) is unknown.

The Florida pine snake is a large, albeit secretive, snake that is native to the Southeastern Coastal Plain region of North America (Franz 1992). They have a continuous distribution that includes much of Florida (excluding the Everglades) and southern Georgia, as well as the extreme southern regions of South Carolina and Alabama (Conant and Collins 1998). Florida pine snakes occur in a variety of upland habitats within the Southeastern Coastal Plain (Franz 1992), with the primary historic habitat type being the longleaf pine ecosystem. However, the once-dominant longleaf pine forest and associated habitats have been significantly altered (Frost 1993) and it is estimated that >97% of the original longleaf pine ecosystem has been converted to agriculture, pine plantations, and urban areas (Noss et al. 1995). The few tracts of longleaf pine that remain are highly fragmented (Noss et al. 1995). It is unclear what this loss of upland habitats means for Florida pine snakes and this uncertainty is compounded by our lack of knowledge regarding their natural history.

Franz (1992) suggested that populations of Florida pine snakes are declining due to habitat loss. Despite this concern, the Florida pine snake is only afforded the lowest conservation status, by the International Union for the Conservation of Nature, which lists the parent species, *P. melanoleucus*, as a Red List category of “Least Concern” (Hammerson 2007). Legal protection is lacking; the federal government does not recognize pine snakes as protected. State protection status is also minimal with Alabama, Florida and South Carolina listing Florida pine snakes as least or special concern; whereas Georgia does not provide protection. More information is needed on the status and ecology of the species to determine if it warrants increased legal protection or a higher conservation status.

Aspects of the spatial ecology of the Florida pine snake, including home range size, are particularly important for conservation and management of the species. Home range data can provide insight into habitat use, intraspecific interactions (e.g., reproduction, territoriality) (Gregory et al. 1987) and seasonal variations in spatial use (Macartney et al. 1988). Differences in sex-specific spatial use can also be established. Home range is defined as the area an animal traverses for its normal daily activities (Burt 1943). The concept has been further refined to include temporal considerations (e.g., annual or seasonal home ranges; Gregory et al. 1987).

Several methods have been devised for quantifying home range size. They include, among others, minimum convex polygons (MCP) (Hayne 1949, Mohr 1947), kernels (Powell 2000, Seaman and Powell 1996, Worton 1989), and more recently, local convex hulls (i.e. *k*-nnch or LoCoH; Getz and Wilmers 2004, Getz et al. 2007). The latter two methods incorporate utilization distribution, which is the probability model of home range that considers the relative amount of time an animal spends in any place (Seaman and Powell 1996). Utilization distribution methods can identify areas of habitat that are particularly important to an animal.

The minimum convex polygon method (MCP) is one of the simplest and most commonly used methods for estimating home range size. An MCP is the smallest possible polygon drawn around all of an animal's locations (Hayne 1949). Although this method has historic relevance, it has several short-comings. Minimum convex polygons have no statistical basis (points and their relationship to each other within the polygon have no bearing on the home range estimate), they can incorporate large areas not actually used by the animal, and there is an assumption of even use of the area within the polygon (Powell 2000). Despite these limitations, the MCP method is useful in providing an estimate of the overall extent of an animal's home range.

The kernel density estimator (KDE) is one of the most widely used methods for determining home range size and utilization distribution (Powell 2000, Worton 1989). This method produces probability contours, or kernels, around individual points, based on the intensity of use, which collectively produces a theoretical home range. Fixed KDE is considered the most accurate of the kernel methods (Seaman and Powell 1996). Size of individual kernels is based on a smoothing parameter (*h*). The optimum value of *h* is typically determined using objective statistical methods (Powell 2000, Worton 1995), such as least-squares cross-validation (*lscv*; Seaman and Powell 1996; Worton 1989, 1995). However, *lscv* is sensitive to autocorrelation (i.e. overlapping points due to high site fidelity), which can greatly "under-smooth" kernel shape and thereby underestimate home range size (Seaman and Powell 1996, Silverman 1986, Worton 1989). Other methods for determining *h*, such as bias cross-validation (*bcv*), are more liberal, but this method may "over-smooth" kernals when locations are autocorrelated, thereby overestimating home range size (Worton 1995). Row and Blouin-

Demers (2006) suggested using an *h* value that yields a home range estimate similar to that of MCP for species with high site fidelity, such as many reptiles. However, a more objective method for selecting *h*, such as using the mean of *lscv* and *bcv*, may be more appropriate (Blouin-Demers 2006).

Local convex hull (LoCoH) is a relatively new method for estimating home range size and utilization distribution (Getz and Wilmers 2004). It is most useful in areas with diverse topography or in fragmented habitat (i.e. landscapes with hard boundaries) (Getz et al. 2007). Like KDE, LoCoH is a non-parametric, objective method that produces kernels, in the form of isopleths, around animal locations (Getz and Wilmers 2004, Getz et al. 2007). LoCoH home ranges are created based on a chosen value *k* (the number of nearest neighboring locations), and its value is unique for each home range estimation. Selection of the *k* value is accomplished by running the model with a series of increasing *k*-values and examining the resulting home range size estimates. The optimal *k* is the value obtained when home range size reaches an asymptote in relation to *k*. Isopleths are generated around the points based on *k* and the resultant adjoining of isopleths determines the home range size estimate and delineation of core areas. However, the LoCoH method can over-estimate home range size when there are outlying points (as can occur with MCPs), and LoCoH can also exclude areas adjacent to portions of the home range with high concentrations of locations (areas that would seem likely to be used by the animal); these exclusions are attributed to the geometry and autocorrelation of the locations (A. Lyons, University of California, Berkley, CA, pers. comm.). Despite these issues, LoCoH can provide a more conservative estimate of home range size than MCP, in that it excludes large areas not used by the animal, and it recognizes hard boundaries. Additionally, LoCoH provides the benefit of identifying areas of intense use (i.e. core areas), which could include high quality habitat or key resources within the habitat.

In this study, I addressed a need for additional information on the spatial ecology of Florida pine snakes. I estimated home range size of Florida pine snakes in southwest Georgia, using the three methods outlined above. My goal was to provide home range size estimates that could be compared to other published studies for this species and other large terrestrial snakes (Reinert 1992, Rodríguez-Robles 2003, Hyslop 2007, Wund et al. 2007), as well as to provide the first estimates of core area size in Florida pine snakes. Using MCP estimates, I tested for seasonal variation in home range size as well as differences in home range size between males and females. An improved understanding of pine snake spatial ecology will provide resource managers with additional knowledge that will aid in the conservation and management of this species and its habitat.

Methods

Study Site

This study was conducted at the Joseph W. Jones Ecological Research Center at Ichauway in Baker County in southwest Georgia (Figure 2-1). Ichauway is a privately owned tract of land that is managed for maintenance of the longleaf pine ecosystem and traditional quail (northern bobwhite; *Colinus virginianus*) hunting. Approximately 60% of the 11,740 ha property is fire-maintained second-growth longleaf pine forest (approximately 80 yrs old) with native ground cover including wiregrass (*Aristida stricta*) and native legumes (Goebel et al. 2001). Other pines (e.g., slash pine, *P. elliottii*, loblolly, *P. taeda*, and short-leaf pine, *P. echinata*) and hardwoods (typically oaks, *Quercus* spp.) are also present within the landscape. Additional upland habitat types include longleaf pine restoration plots, slash pine and loblolly pine plantations, small agricultural fields (including wildlife food plots), old field areas and small urban centers. There are numerous small isolated wetlands ranging from dense cypress (*Taxodium* spp.) /gum (*Nyssa sylvatica*) swamps to open, grassy marshes with varying hydroperiods. The Flint River forms the southeastern border of Ichauway and Ichawaynochaway Creek bisects the property and flows into the Flint River at the southern edge of the property. Numerous dirt roads exist on site; Ichauway is also bisected by two paved highways and several small, paved rural county roads. Adjacent land uses include center-pivot irrigation agriculture, a hunting preserve and a small plantation.

Management objectives at Ichauway include longleaf pine restoration, quail and white-tailed deer (*Odocoileus virginianus*) management, and conservation of the endangered red-cockaded woodpecker (*Picoides borealis*). Prescribed fire is used extensively to facilitate management goals. Hardwoods have been removed on approximately 2000 ha of the property to allow reintroduction of fire and to restore longleaf pine and native ground cover.

Data Collection

Twelve Florida pine snakes (8 male and 4 female) were captured either by hand or in snake trap arrays (Rudolph et al. 1999, Burgdorf et al. 2005) from September 2006 through May 2007. The following measurements were taken on all snakes: snout-to-vent length (SVL), tail length (both measured to the nearest 1 mm), and mass (measured to the nearest 1 g); sex was determined by cloacal probing. Each snake was implanted with a passive integrated transponder (PIT) tag (Biomark, Inc., Boise, ID) for individual identification. Snakes were implanted with radio transmitters (Model SI-2 and SI-2T, 9g; Holohil Systems, Ltd., Carp, Ontario, Canada), by wildlife veterinarians using the method developed by Reinert and Cundall (1982). Transmitter weight did not exceed 5% of the snake's body mass. Three snakes were implanted in fall 2006 and the remaining nine were implanted in spring 2007. I released all snakes at the site of capture within 3-5 days after surgery. Transmitters were removed at the completion of the study.

I radio-tracked snakes using a R1000 radio telemetry receiver (Communication Specialists Inc., Orange, CA) with a 3-element folding Yagi antenna (Wildlife Materials International, Inc., Murphysboro, IL). Snakes were tracked for at least one calendar year between September 2006 and June 2008. During spring, summer, and fall (22 March to 20 November) I tracked snakes every 3-4 days, whereas in winter (21 November to 21 March) snakes were tracked once a week. I tracked snakes on an alternating schedule (mornings and afternoons) to reduce time effects. Snakes were located via homing (Mech 1983) and UTM coordinates (NAD 1983, Zone 16N) of locations were collected using a GeoExplorer 3 global positioning system (GPS; Trimble Navigation, Ltd, Sunnyvale, CA), which was accurate to within approximately 2 m.

Home Range Size

I used three methods to calculate home range size: minimum convex polygon (MCP; Mohr 1947, Hayne 1949), kernel area (KDE; Powell 2000, Seaman and Powell1996, Worton 1989, Worton 1995) and fixed local convex hull (LoCoH; Getz and Wilmers 2004, Getz et al. 2007). I used 100% MCP to capture the entire area used by each snake, including all outlying points (Figure 2-2). To examine areas of concentrated use, I used 95% kernel density estimates (Figure 2-3) with 50% core areas (Samuel et al. 1985), as well as 100% and 50% isopleths for fixed local convex hulls (LoCoH). I used Hawth's Tools extension (Beyer 2004) in ArcMap 9.1 (ESRI, Redlands, CA) to produce MCPs and KDEs. I calculated 100% and 50% isopleths for fixed local convex hulls (LoCoH) (Figure 2-4) using the LoCoH extension (University of California, Berkley). To determine the optimum LoCoH estimates for each individual, I ran several iterations of the model for each individual, using increasing values of *k*. I then selected the *k*, value where home range size reached an asymptote (i.e. where home range no longer increased); the value of *k* was unique for each home range estimated.

Data Analyses

I used linear regression analysis to determine if mean annual home range size varied with snake body size (SVL). Sex and seasonal comparisons were made using MCP data (Table 2-2); seasons were defined as spring (21 March to 20 June), summer (21 June to 20 September) and fall/winter (21 September to 20 March). Fall and winter data were combined because of very low snake activity levels over this period. I compared MCP home range size by season and sex using a two-way analysis of variance (two-way ANOVA). A Tukey-Kramer test was used post-analysis to identify differences between sexes among seasons. Data were natural-log transformed to ameliorate problems associated with non-normality and high variance. The significance level was set at $\alpha = 0.05$. Statistical analyses were performed using SAS ver. 9.1 and SAS Enterprise Guide 4.1 (SAS Institute, Inc., Cary, NC). One male snake (PM-2B6F) was found dead (cause of death undetermined) at the start of the summer season and was not included in the summer data analysis.

Results

Home Range Size

I tracked 12 Florida pine snakes for 209 to 581 days, with an average of 83 locations per snake (Table 2-1). MCP home range size varied among individuals ($\bar{x}_{Tot}$ = 59.2 ± 29.3 ha; range = 18.6 – 156.8; Table 2-1). Mean MCP home range size of males did not differ significantly from that of females ($\bar{x}_{Male}$ = 70.1 ± 40.5 ha, range = 25.7 – 156.8; $\bar{x}_{Female}$ = 37.5 ± 29.3 ha, range = 18.6 – 80.7; $t_{0.05, 9.91} = -1.30$, $P = 0.223$).

Kernel density estimates (95% KDE) yielded the smallest home range size of the three methods used and showed the least variation among individuals and between sexes ($\bar{x}_{Male}$ = 27.1 ± 4.3 ha, range = 20.0 – 36.1; $\bar{x}_{Female}$ = 27.0 ± 1.0 ha , range = 20.1 – 41.7; $\bar{x}_{Tot}$ = 27.0 ± 4.1 ha;

range = 20.0 – 41.7). There were from one to six separate 50% KDE core areas within individual pine snake home ranges; 50% KDEs were similar in total size for males and females ($\bar{x}_{Male}$ = 4.0 ± 0.7 ha, range= 2.7 – 5.4; $\bar{x}_{Female}$ = 4.6 ± 2.1 ha, range = 3.1 – 7.7).

Fixed LoCoH estimates (100% isopleths) were larger than 95% KDEs but were slightly smaller than MCP home ranges ($\bar{x}_{Male}$ = 61.2 ± 34.2 ha, range = 21.5 – 135.9; $\bar{x}_{Female}$ = 29.3 ± 15.9 ha, range = 18.7 – 52.4; $\bar{x}_{Tot}$ = 50.6 ha ± 24.5 ha; range = 19.0 – 135.9). LoCoH core areas (50% isopleths) ranged from one to three per snake and were similar in size between the sexes ($\bar{x}_{Male}$ = 2.7 ± 1.4 ha, range = 0.2 – 5.7; $\bar{x}_{Female}$ = 2.3 ± 1.8 ha, range = 0.5 – 4.3; $\bar{x}_{Tot}$ = 2.6 ± 1.1 ha; range = 0.20 –5.7). LoCoH estimates were similar to those derived with MCP, but excluded areas around the periphery of the home ranges that were apparently not used by the snakes. Areas adjacent to high use sites within the home range were sometimes clipped out by the LoCoH model as a result of autocorrelation and geometry of the points (A. Lyons, University of California, Berkley, CA, pers. comm.), which may have underestimated home range size by removing areas that were likely used by the snake.

Seasonal Patterns in Home Range Size

There was no relationship between snake body size (SVL) and MCP home range size (R^2 = 0.0673; Figure 2-5). However, two-way ANOVA revealed that home range size varied by sex and season ($F_{0.05, 5, 27}$ = 7.16; P < 0.001). A Tukey-Kramer test confirmed that there was no significant difference between mean annual home range size of males and females ($F_{0.05, 1, 27}$ = 0.15; P = 0.6990), but home range size differed significantly among seasons ($F_{0.05, 2, 27}$ = 10.32; P = 0.005; Figure 2-6) and between males and females by season ($F_{0.05, 2, 27}$ = 3.34; P = 0.05; Figure 2-7). Seasonal home range size was significantly different in spring and fall/winter (P <0.001) and summer and fall/winter (P <0.05); however, spring and summer home range sizes did not differ significantly (*P* = 0.12). Although the Tukey-Kramer post-analysis found no significant difference in home range size between sexes within seasons (M_{Sp} vs. F_{Sp}, *P* = 0.44; M_{Su} vs. F_{Su}, *P* = 0.87; $M_{F/W}$ vs. $F_{F/W}$, *P* = 0.70), nor between seasons for females (F_{Sp} vs. F_{Su}, *P* = 1.00; F_{Sp} vs. $F_{F/W}$, *P* = 0.74; and F_{Su} vs. $F_{F/W}$, *P* = 0.72), male home range size differed significantly between spring and summer (M_{Sp} vs. M_{Su}, *P* = 0.02), and spring and fall/winter (M_{Sp} vs. $M_{F/W}$, *P* <0.0001; Figure. 2-6). There was no difference between summer and fall/winter home range size in males (M_{Su} vs. $M_{F/W}$, *P* = 0.24). The only differences in home range size between sexes across seasons was between males in spring and females in fall/winter (M_{Sp} vs. $F_{F/W}$, *P* = 0.02; Figure 2-7).

Discussion

Each of the three home range estimators used in this study provided potentially useful information about pine snake spatial ecology. The MCP estimated the maximum area used by an individual within a year (annual home range size), whereas LoCoH and KDE provided information on core areas (e.g., superior habitat or key resources like food and refuge) within the overall home range. Use of the mean of *lscv* and *bcv*, to derive a smoothing factor, *h*, for KDEs yielded a home range size comparable to the MCP as suggested by Row and Blouin-Demers (2006). Although small portions of the LoCoH isopleths were clipped out, in most cases the core areas identified with both utilization distribution methods overlapped. The issues of autocorrelation could have been reduced by subsampling, however this may have led to loss of information (Desolla et al. 1999). I recommend using both MCP and either LoCoH or KDE to determine spatial requirements of pine snakes and other species that use discreet areas for prolonged periods of time (e.g., fossorial refugia, hibernacula).

The overall MCP home range size of Florida pine snakes in this study was 59.2 ha, which is comparable to that obtained for the species in north-central Florida (57.0 ha, MCP; Franz

2005). Although, the mean home range size of males was similar in the two studies, female home range size was more than twice as large in my study as in the Florida study (37.5 ha as compared to 13.5 ha, respectively). The difference in female home range size may be a reflection of the small sample sizes in both this and the Florida study (n = 3; Franz 2005) coupled with high variability among individuals, but differences in resource availability may also have been a factor. Although MCP data were not presented, home range estimates (using 95% KDEs) for northern pine snakes (*P .m. melanoleucus*) were much larger than Florida pine snakes in this study (59.9 ha and 27. 0 ha, respectively; Gerald et al. 2006b). Moreover, in the northern pine snake study *lscv* was used to determine *h*, which typically underestimates home range size, suggesting that if they used the same methods as were applied to my data, the reported home range size for northern pine snakes would have been even larger. This disparity may be related to differences in habitat quality between the two study sites. Whereas this study was conducted in relatively unimpacted habitat, the northern pine snake study was in an area highly fragmented by agriculture and other land uses.

My estimates of Florida pine snake home range size were substantially larger than estimates for the western counterparts, *P. c. catenifer* (n=4, $\bar{x}_{\text{Male}}$ = 2.29 ha; Rodríguez-Robles 2003) and *P. c. deserticola* ($\bar{x}_{\text{Male}}$ = 1.2 ha; $\bar{x}_{\text{Female}}$ = 2.1 ha; Parker and Brown 1980). It is unclear why western *Pituophis* exhibit smaller home ranges than members of the eastern species. Perhaps these differences are due to contrasts in resource availability, competition, or environmental factors. More research investigating the factors driving differences in spatial use between western and eastern *Pituophis* is needed.

I found no difference in mean annual home range size between male and female Florida pine snakes. Home range size did, however, vary seasonally with spring and summer home ranges being significantly larger than fall/winter ranges (Figure 2-6). The small fall/winter home ranges most likely reflected decreased activity due to decreasing temperature and photoperiod; snakes were less frequently observed above ground and movements were concentrated around hibernacula such as pocket gopher burrows in fall/winter (see Chapter 3). The large home ranges in spring and summer were likely related to movements associated with reproduction (Gregory et al. 1987). Pine snakes breed in spring (Ernst and Ernst 2003, Franz 2005), which, for males, may involve extensive movements outside the non-breeding home range. Indeed, three males in this study moved more than 2 km straight line distance in spring (G. Miller, pers. obs.), and I observed three mating events from early to mid-June, which coincided with the longest individual movements of males (G. Miller, pers. obs.). Female Florida pine snakes nest in summer (late June/July) (Lee 1967, Franz 1992, Franz 2005, Ernst and Ernst 2003). Although I did not observe nesting, in mid-July two females (PM-3F3F and PM-3F1E) moved to locations outside of their initial home ranges, and these movements may have been associated with nesting. Specifically, one of the females (PM-3F3F) appeared gravid in mid-July and she moved approximately 250 m to an area outside her initial home range. She later returned to her initial home range and no longer appeared to be gravid.

It is unclear what factors in addition to reproduction might influence home range size of Florida pine snakes. Snake body size was not correlated with home range size in this study. However, I focused only on adult snakes (>910 mm SVL, Franz 1992) with little variation in body size. It may be that juvenile Florida pine snakes use smaller home ranges than adults, although further research is needed to determine this. Intraspecific competition could also influence home range size in pine snakes. Home range overlap occurred on only a few occasions in this study, and only involved males and females during breeding season. In late winter/early spring, however, a non-study male was found basking within 30 m of male PM-1879 (G. Miller, pers. obs.). A more detailed study is needed to determine whether pine snakes exhibit intraspecific competition.

The home range size of Florida pine snakes in this study was similar to the one other study conducted for this subspecies (Franz 2005). However, both studies had relatively small sample sizes. High variability in home range size among the snakes in each study suggests that larger sample sizes were warranted. Additionally, factors that influence home range size need to be further studied, such as competition, intraspecific interactions, and resource availability. Both this study and that of Franz (2005) were conducted within protected areas that are actively managed for maintenance of native forest types. These studies provide useful data in this setting, but additional studies are warranted to determine the extent of variability in home range size among different populations of pine snakes and across a range of habitats with varying degrees of disturbance. In particular, studies are needed in areas that are more representative of existing landscape conditions (e.g., disturbed or fragmented habitats).

Based on these data, we can begin to develop conservation management strategies addressing the spatial needs of Florida pine snakes. Although the minimum viable population size for Florida pine snakes is not known, my estimates of MCP home range size can be used as a basis for determining the approximate spatial requirements of a population. A population of 50 adults (a number that has been proposed as the minimum effective population size for most vertebrates; Franklin 1980) with non-overlapping home ranges would need nearly 3000 ha of habitat. This estimate should be interpreted with caution, because Florida pine snakes in different regions or different habitats might require more or less habitat than pine snakes at Ichauway. Ichauway is managed with frequent prescribed burns to maintain an open canopy forest with diverse native ground cover, which may represent high quality habitat for pine snakes. Populations in disturbed or fragmented habitat may require significantly more habitat. In addition, Florida pine snakes may shift their home ranges within the landscape over time, thus requiring even more habitat. Nonetheless, basic ecological studies such as this may be the first steps in developing an effective management strategy for Florida pine snakes.

Table 2-1. Home range data for radio-tracked Florida pine snakes (*Pituophis melanoleucus mugitus*) using minimum convex polygons (MCP), local convex hulls (LoCoH), and kernel density estimates (KDE) at Ichauway, Baker County, Georgia.

						MCP	LoCoH		Kernel	
Snake ID	Sex	Location/ Snake	Monitoring Period	Snout-Vent length (mm)	Mass (g)	100% (ha)	100% isopleth (ha)	50% isopleth (ha)	95% Contour (ha)	50% Contour (ha)
PM-3060	M	79	5/14/07 - 5/16/08	1442.5	1147.0	25.7	21.5	3.2	24.4	4.8
PM-1879	M	83	5/14/07 - 6/17/08	1117.0	753.0	29.1	27.5	1.2	24.1	3.8
PM-2B6F	M	49	10/18/06 - 5/14/07	1364.5	907.0	30.7	28.1	0.2	21.2	2.7
PM-4E45	M	69	6/12/07 - 5/26/08	1366.0	1156.0	38.1	39.5	2.4	20.0	3.5
PM-4F5D	M	80	6/12/08 - 6/20/08	1351.0	1048.0	30.6	28.1	0.7	25.0	3.1
PM-6571	M	124	9/20/06 - 4/22/08	1376.0	1117.0	95.3	75.3	5.7	33.9	5.4
PM-025A	M	83	5/14/07 - 6/17/08	1367.5	843.0	154.2	135.9	3.4	36.1	5.1
PM-4666	M	83	5/14/07 -6/6/08	1371.5	1066.0	156.8	133.7	5.3	31.7	3.4
PM-3F3F	F	117	10/18/06 - 4/29/08	1337.5	727.0	18.6	19.0	0.9	21.5	3.8
PM-3F1E	F	71	5/14/07 - 4/11/08	1332.5	1048.0	19.9	18.7	3.3	20.1	3.9
PM-5F5E	F	82	5/14/07 - 6/13/08	968.0	365.0	30.9	27.1	0.5	24.7	3.1
PM-612B	F	79	5/14/07 - 5/18/08	1319.0	1204.0	80.7	52.4	4.3	41.7	7.7
Male Mean	-	-	-	1344.5	1004.6	70.1	61.2	2.7	27.1	4.0
(SE)	-	-	-	*(33.9)*	*(53.5)*	*(40.5)*	*(34.2)*	*(1.4)*	*(4.3)*	*(0.7)*
Female Mean	-	-	-	1239.3	836.0	37.5	29.3	2.3	27.0	4.6
(SE)	-	-	-	*(90.5)*	*(185.8)*	*(29.3)*	*(15.9)*	*(1.8)*	*(1.0)*	*(2.1)*
Total Mean	-	-	-	1309.4	948.4	59.2	50.6	2.6	27.0	4.2
(SE)	-	-	-	*(38.2)*	*(70.2)*	*(29.3)*	*(24.5)*	*(1.1)*	*(4.1)*	*(0.8)*

Table 2-2. Seasonal minimum convex polygon (MCP) home range size of Florida pine snakes (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia.

			100% MCP (ha)		
Snake ID	Sex	# of Locations (Sp, Su, F/W)	Spring	Summer	Fall/Winter
PM-3060	M	(27, 21, 31)	23.1	4.8	2.3
PM-1879	M	(30, 22, 31)	23.8	12.7	8.5
PM-4E45	M	(23, 18, 28)	35.6	5.7	5.1
PM-4F5D	M	(26, 23, 31)	30.2	18.0	0.2
PM-6571	M	(32, 23, 69)	84.9	11.3	3.9
PM-025A	M	(30, 23, 30)	153.1	11.1	8.8
PM-4666	M	(29, 23, 31)	153.6	7.3	1.7
PM-2B6F	M	(14, --, 35)	22.0	--	2.7
PM-3F3F	F	(32, 22, 63)	9.5	7.6	5.8
PM-3F1E	F	(17, 23, 31)	9.4	15.9	3.5
PM-5F5E	F	(30, 24, 28)	26.8	12.8	2.7
PM-612B	F	(25, 25, 29)	37.6	65.0	34.4
Male Mean	-	-	65.8	10.1	4.2
(SE)	-	-	*(20.4)*	*(1.7)*	*(1.1)*
Female Mean	-	-	20.8	25.3	11.6
(SE)	-	-	*(6.9)*	*(13.3)*	*(7.6)*
Total Mean	-	-	50.8	15.7	6.6
(SE)	-	-	*(14.9)*	*(5.1)*	*(2.6)*

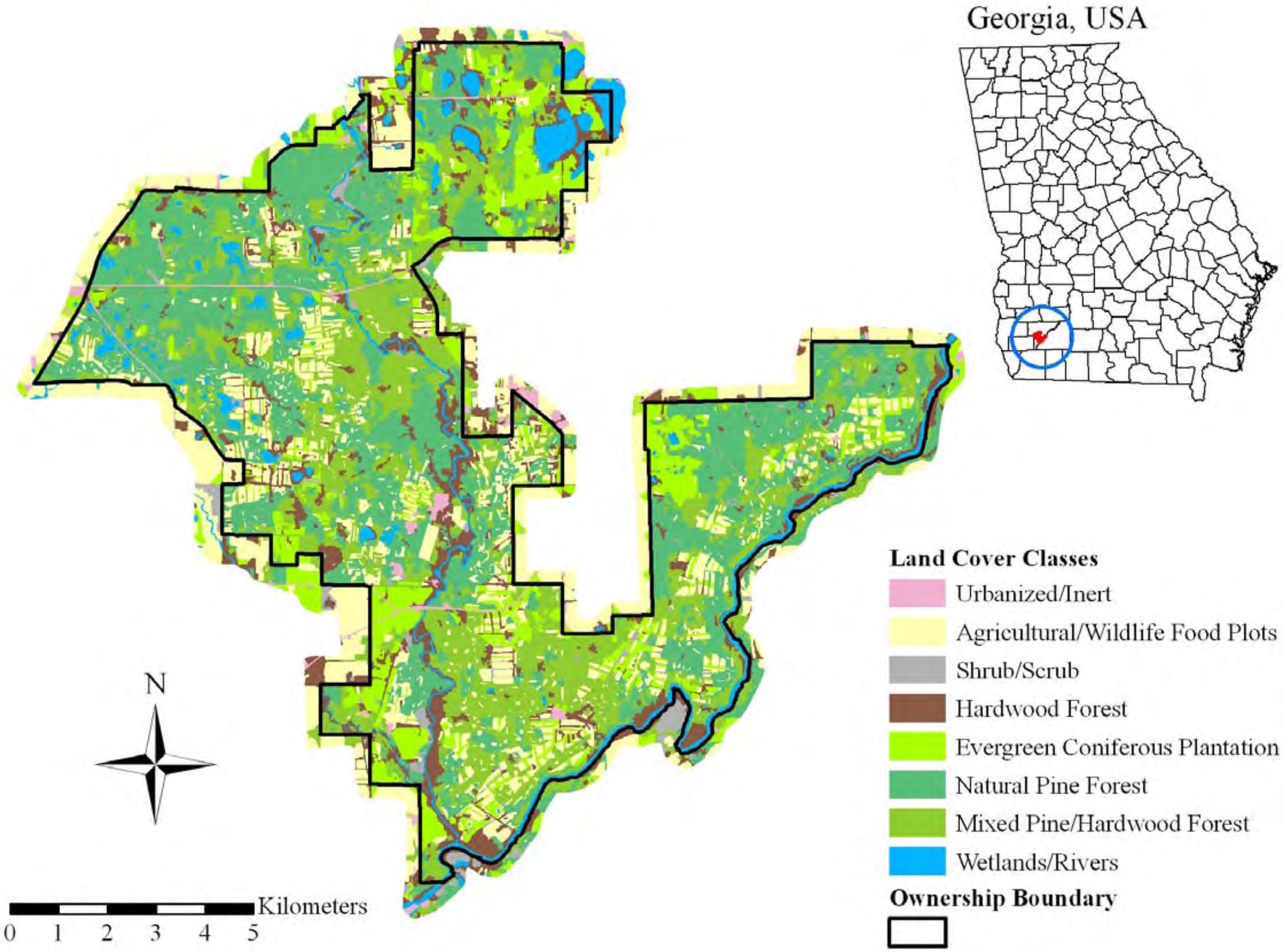

Figure 2-1. Map of Ichauway showing land cover classes, Baker County, Georgia.

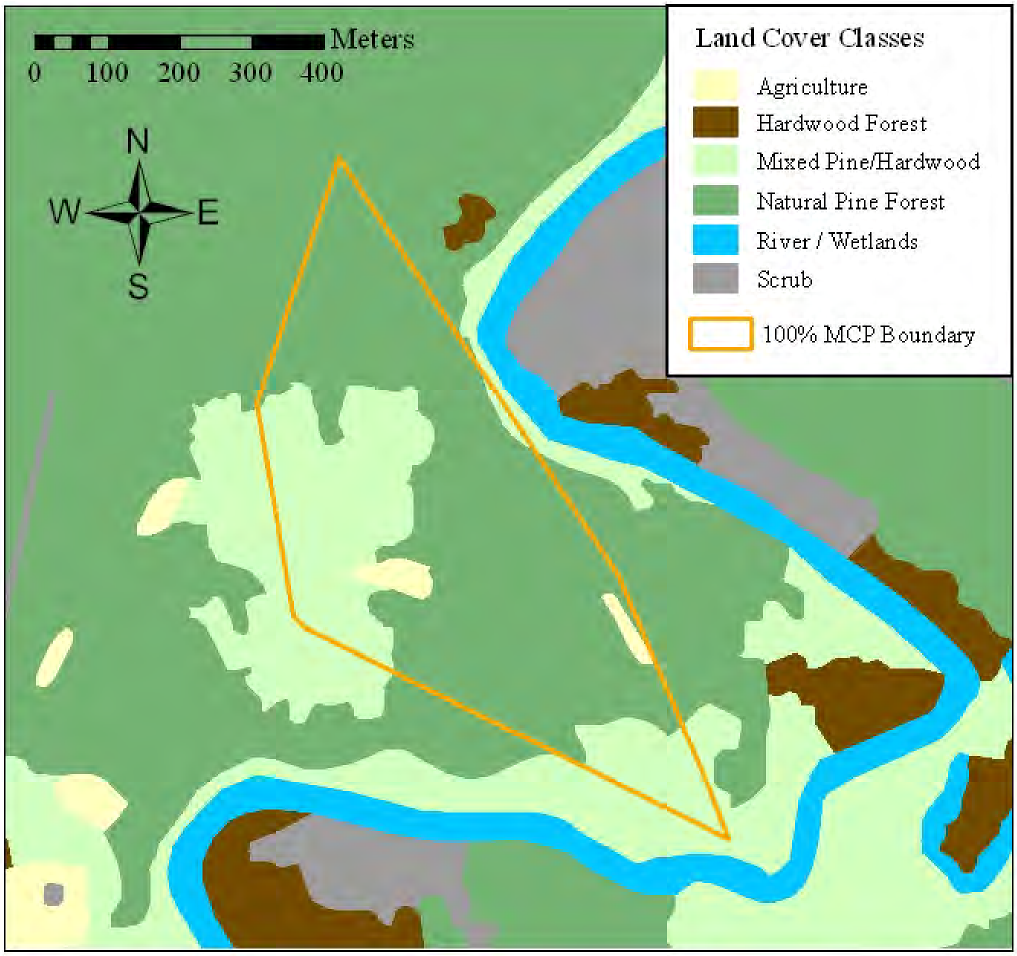

Figure 2-2. Minimum convex polygon (MCP) home range diagram for Florida pine snake (*Pituophis melanoleucus mugitus*) PM-3060 at Ichauway, Baker County, Georgia.

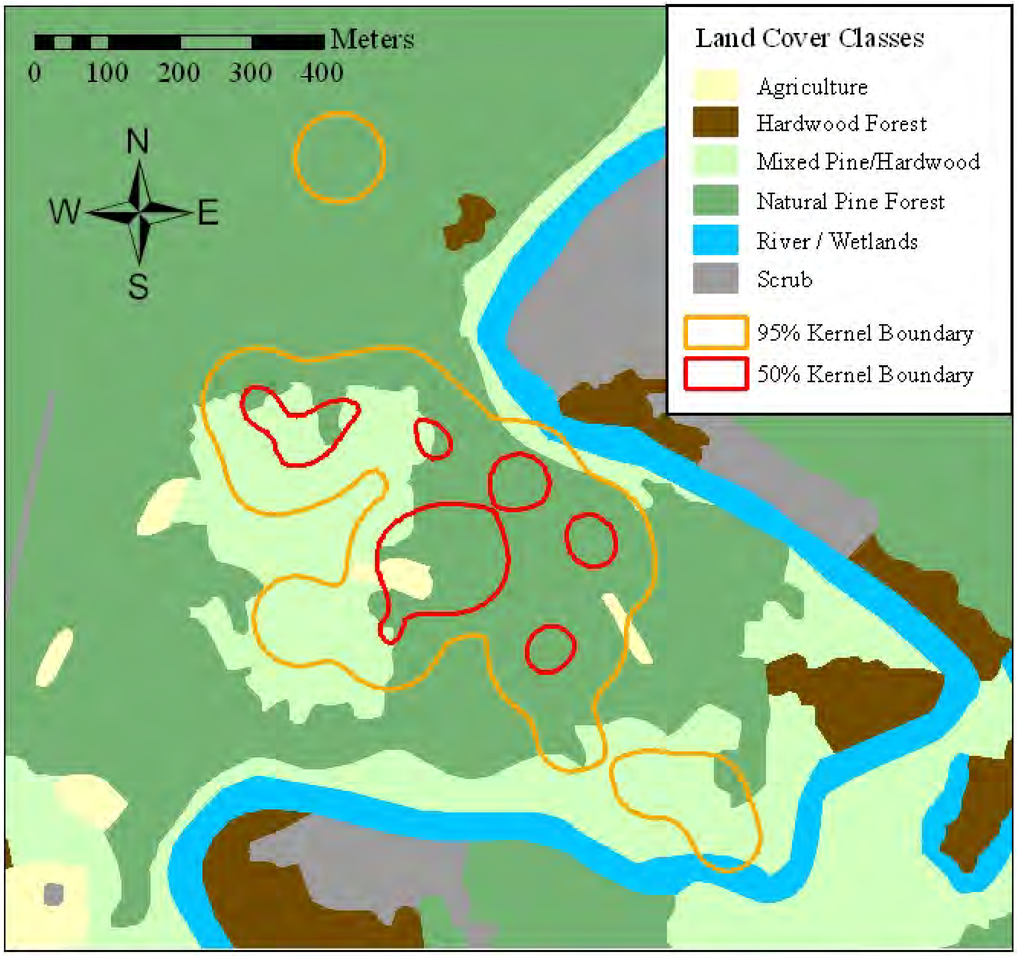

Figure 2-3. Kernel density (KDE) home range diagram for Florida pine snake (*Pituophis melanoleucus mugitus*) PM-3060 at Ichauway, Baker County, Georgia.

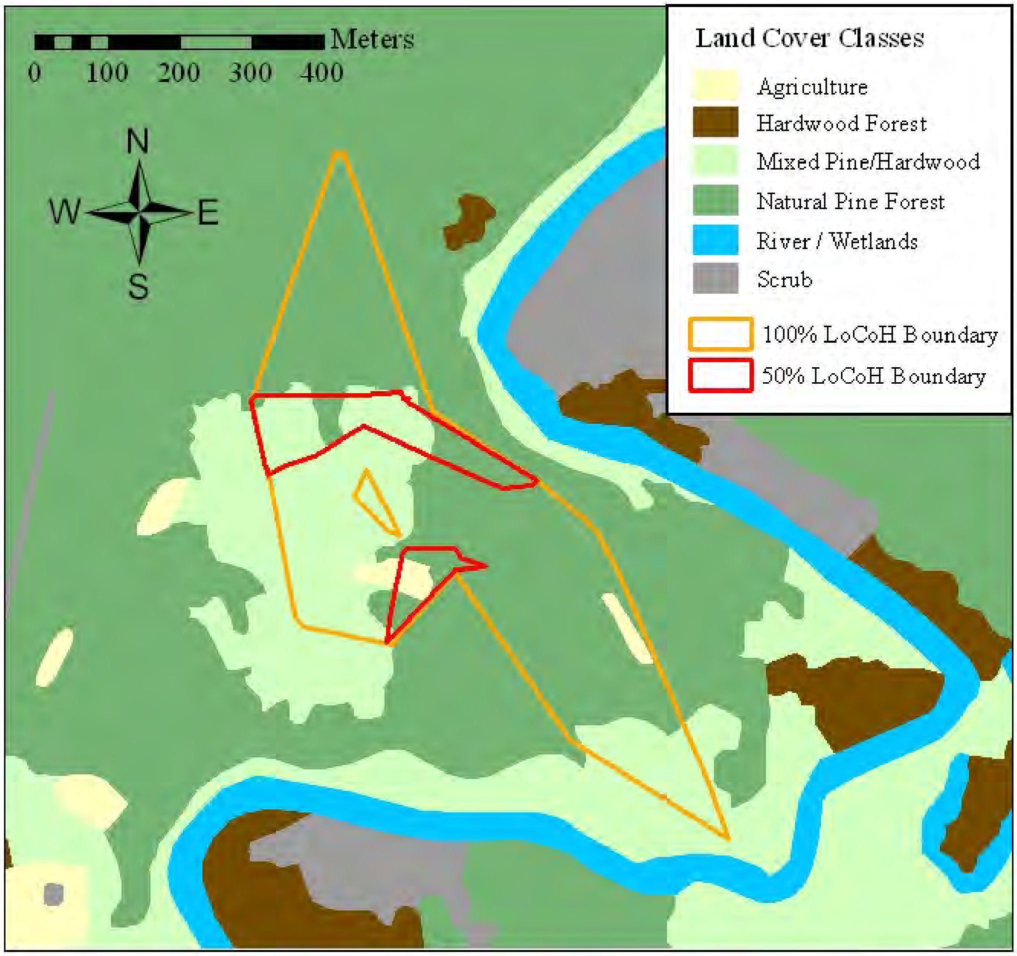

Figure 2-4. Local convex hull (LoCoH) home range diagram for Florida pine snake (*Pituophis melanoleucus mugitus*) PM-3060 at Ichauway, Baker County, Georgia.

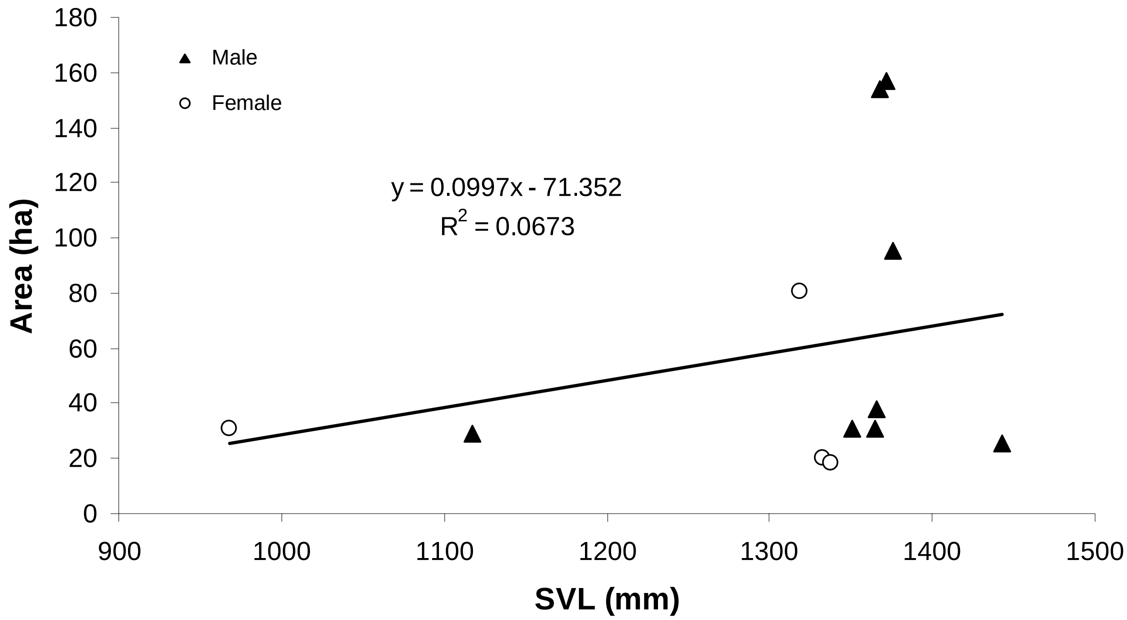

Figure 2-5. Relationship between body size (snout-to-vent length; SVL) and annual minimum convex polygon (MCP) home range size for 12 adult Florida pine snakes (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia.

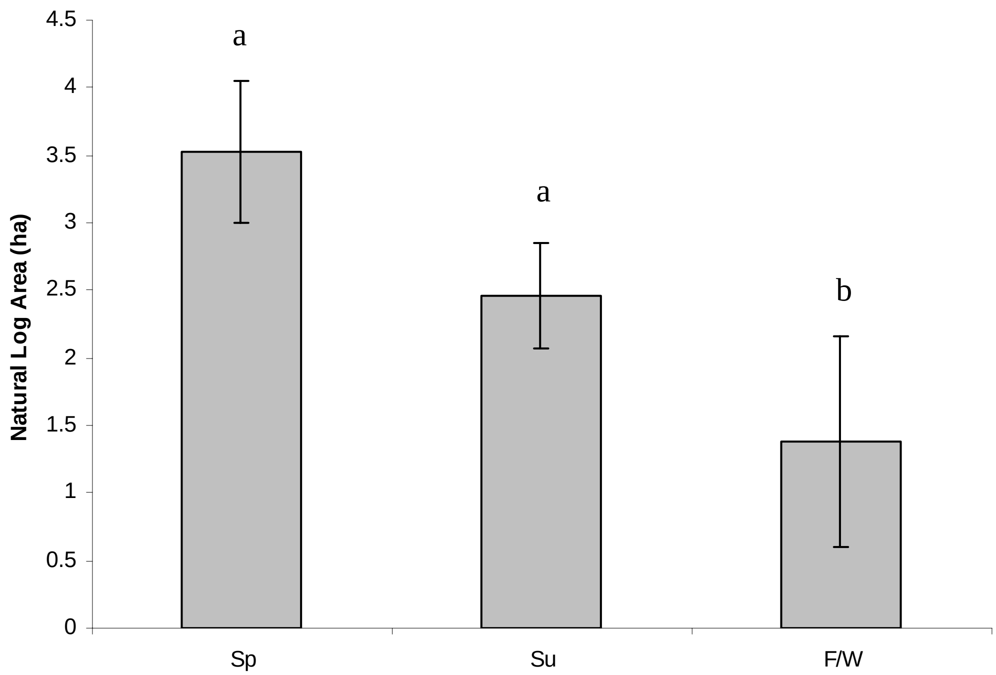

Figure 2-6. Mean minimum convex polygon (MCP) home range size by season for 12 (8 males and 4 females) adult Florida pine snakes (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia. Sp= spring (21 March – 20 June), Su= summer (21 June – 20 September) and F/W= fall and winter (21 September – 20 March). Common letters indicate non-significant seasonal differences.

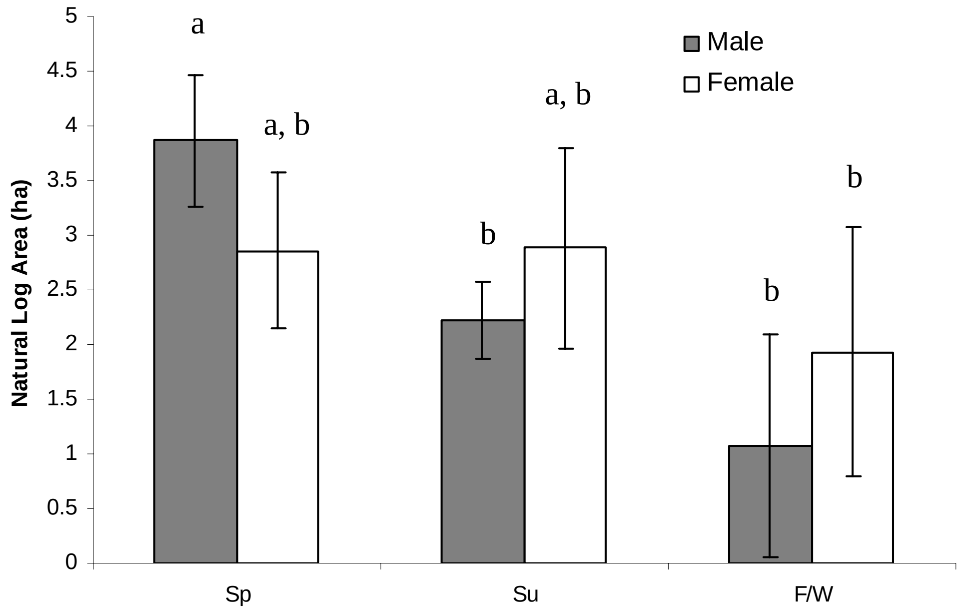

Figure 2-7. A comparison of seasonal minimum convex polygon (MCP) home range size of male (n = 8) and female (n = 4) Florida pine snakes (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia. Sp= spring (March 21 – June 20), Su= summer (21 June – 20 September) and F/W= fall and winter (21 September – 20 March). Common letters indicate non-significant seasonal differences.

CHAPTER 3
HABITAT ASSOCIATIONS AND REFUGE USE IN FLORIDA PINE SNAKES, *Pituophis melanoleucus mugitus*, IN SOUTWEST GEORGIA

Introduction

Pine snakes (*Pituophis melanoleucus*) are large, fossorial snakes that occur in the eastern U.S., from southern New Jersey to Florida and as far west as southern Alabama (Conant and Collins 1998). Of the three recognized subspecies, all are associated with upland habitats with well-drained sandy soils. The Florida subspecies (*P. m. mugitus*) occurs throughout the Southeastern Coastal Plain (Franz 1992), the region that supports the highest reptile diversity in North America (Guyer and Bailey 1993). There are concerns that, like other snake species in the region (Krysko and Smith 2005, Moler 1992, Tuberville et al. 2000), the Florida pine snake may be declining (Franz 1992). Several potential causes of declines in snake populations have been suggested (Franz 1992), but habitat loss may be the most important. Unfortunately, little information is available regarding the habitat requirements of Florida pine snakes; therefore, direct impacts of habitat loss on this species are not clearly understood.

Historically, the Southeastern Coastal Plain was dominated by the fire-maintained longleaf pine ecosystem (Frost 1993). Currently, < 3% of the original longleaf pine habitat remains intact (Noss et al. 1995), and remaining longleaf pine forests are threatened due to the suppression of fire and subsequent hardwood encroachment (Frost 1993). Many forest lands have been converted to even-aged stands of off-site pines including slash pine and loblolly pine. Furthermore, remaining forest patches are highly fragmented and isolated by other land uses (e.g., agriculture, commercial development and roads). The extent to which these impacts to the longleaf pine ecosystem have affected Florida pine snakes has not been quantified, although Franz (1992) suggested that habitat loss was one of the main factors in recent population declines.

In north-central Florida, pine snakes were found to be associated with high pine/sandhill habitat as well as oak woodlands and oldfield sites (Franz 1992, 2005). Habitat requirements of the closely related northern pine snake (*P. m. melanoleucus*) and Louisiana pine snake (*P. ruthveni*) are fairly well known (Burger and Zappalorti 1986, 1988, 1989, 1991; Burger et. al 1988; Ealy et al. 2004; Zappalorti and Burger 1985; Duran 1998; Himes et al. 2006, Rudolph et al. 2007). Both species use upland pine/oak forests and are highly fossorial. Recent research on the Louisiana pine snake suggests that they use pocket gopher (*Geomys* spp.) burrows as refuge (Rudolph et al. 2007) much like Franz (2005) found for Florida pine snakes. However, in New Jersey, the northern pine snake occurs outside of the range of pocket gophers, and snakes in this region use other available refuges or excavate their own refugia (Burger et al. 1988). In southwest Georgia, Florida pine snakes occur within the range of the southeastern pocket gopher (*G. pinetis*), but the degree to which pine snakes are associated with pocket gophers, and details about habitat selection, are unknown.

Animals may select habitat differently depending upon the scale examined (Johnson 1980, Moore and Gillingham 2006, Naugle et al. 1999). Johnson (1980) defined a hierarchical system of habitat selection that includes three different scales. First order selection occurs at the broadest scale, within the geographic range of a species; second order selection determines home range of an individual or group (i.e. within a specific landscape); and third order selection is finer scale selection for specific habitats within an animal's home range. The terms preference, selection, use, and association often are used synonymously in habitat literature (Garshelis, 2000). Preference implies that an animal uses a particular habitat irrespective of its availability or accessibility, which is difficult to measure. Therefore, in this study, the more general terms of habitat use, selection and association are used.

Various methods have been developed to determine habitat use. One of the most common methods is compositional analysis (Aebischer et al. 1993), whereby the proportion of different habitats available is compared to the proportion of habitats used by the animal. Euclidean distance analysis (Conner and Plowman 2001, Conner et al. 2003), a more recent method, determines habitat use based on a comparison of the mean distance from animal locations to different habitats to that of random locations to the same habitats. This method is less strict than compositional analysis and provides a greater array of information regarding habitat availability for each animal location (Conner et al. 2003).

Florida pine snakes in north-central Florida were highly fossorial and spent 81% of the time below ground, most frequently in southeastern pocket gopher burrows (Franz 2005). Pocket gophers (*Geomys* spp.) have been referred to as ecological engineers (Miller et al. 2008, Reichman and Seabloom 2002) and the burrows of southeastern pocket gophers host several species of rare arthropods (e.g., Skelley and Gordon 1995, Skelley and Woodruff 1991). Pocket gopher burrows provide relatively stable environmental conditions, as compared to the surface (Kennerly 1964) and offer suitable refuge for both invertebrates and vertebrates. Several authors have suggested that there may be a strong association between Florida pine snakes and southeastern pocket gophers (Allen and Neill 1952, Franz 1992, 2005, Funderburg and Lee 1968). However, other than the detailed telemetry study by Franz (2005), the extent to which Florida pine snakes depend specifically on pocket gopher burrows has not been investigated. Florida pine snakes also prey upon southeastern pocket gophers (Allen and Neill 1952), although again, the degree to which Florida pine snakes may depend on pocket gophers as a food resource is unknown. A recent report suggested southeastern pocket gophers were declining (Georgia Department of Natural Resources 2008), which may negatively affect pine snake populations.

Data are needed to determine the degree to which pine snakes are associated with longleaf pine forests versus other habitat types and the extent to which they use southeastern pocket gopher burrows versus other fossorial refuge sites.

In this study I examined habitat associations and refuge use in the Florida pine snake on a tract of land with a wide array of upland habitats. I used radio telemetry to track individual snakes for approximately one year. By closely monitoring these individuals, I was also able to describe aspects of pine snake life history, i.e., seasonal activity patterns. The specific objectives of this study were to 1) determine if Florida pine snakes are associated with specific habitats at either a landscape or home range scale; 2) examine microhabitat use and activity patterns, and 3) describe and quantify use of fossorial refuges by Florida pine snakes.

Methods

Study Site

I conducted this study at Ichauway, the research site of the Joseph W. Jones Ecological Research Center in southwest Georgia (See Chapter 2, Figure 2-1). The 11,740 ha property is located in Baker County, approximately 16 km southwest of Newton, Georgia, USA. Ichauway, along with a few private quail (northern bobwhite, *Colinus virginianus*) hunting plantations, harbors one of the few remaining contiguous tracts of native longleaf pine forest in the region (Noss and Peters 1995). The major overstory component of uplands at Ichauway is second-growth longleaf pine (approximately 80 yrs old) with a rich diversity of native ground cover including wiregrass (*Aristida stricta*) and legumes. Other pines (e.g., slash pine, *P. elliottii*, loblolly, *P. taeda*, and short-leaf pine, *P. echinata*) and hardwoods (typically oaks, *Quercus* spp.) are also present. Other land covers include longleaf pine restoration plots, pine plantations, small agricultural fields, wildlife food plots, oldfield areas and small urban centers. Upland management objectives include longleaf pine restoration and conservation, quail and white-tailed deer (*Odocoileus virginianus*) management, and conservation of the endangered red-cockaded woodpecker (*Picoides borealis*). Management objectives are carried out with prescribed fire (typically on a 2- year rotation) and mechanical removal of hardwoods.

Other habitats at Ichauway include numerous small isolated wetlands ranging from cypress (*Taxodium* spp.) /gum (*Nyssa sylvatica*) swamps, to cypress savannas, to open, grassy marshes; two riparian systems, the Flint River and the Ichawaynochaway Creek also are present on the property. Ichauway has numerous dirt roads that serve both as travel routes and fire breaks. The property is transected by two paved highways (Highway 200 and Highway 91) and several rural county roads. Ichauway is surrounded by intensive center-pivot irrigation agricultural land, a small hunting preserve, and a small wildlife management area.

Data Collection

The 12 snakes used in this study were captured either by hand or in snake trap arrays (Rudolph et al. 1999, Burgdorf et al. 2005). Snakes were measured and weighed and sex was determined by cloacal probing. Measurements included snout-vent-length (SVL) and tail length (TL). Snakes were surgically implanted with radio transmitters; three snakes were implanted in spring 2006 and nine additional snakes were implanted in spring 2007. Transmitters [model SI-2 (5) and SI-2T (7), Holohil Systems Ltd., Carp, ON, Canada] weighed 9g and did not exceed 5% of a snake's body mass. Surgeries were performed by a wildlife veterinarian using methods developed by Reinert and Cundall (1982). Snakes were chosen for implantation based on body size, thus they were not randomly distributed across the study site.

After implantation, snakes were released at the site of capture and tracked using a R1000 telemetry receiver (Communication Specialists Inc., Orange, CA) with 3-element folding Yagi antenna (Wildlife Materials International Inc., Murphysboro, IL). Snakes were tracked every 3-4 days for one calendar year, except during winter (21 November to 21 March) when the tracking interval was decreased to once every seven days due to minimal movements by snakes. Tracking time (morning or afternoon) was alternated daily to reduce time effects. Snake locations were acquired by homing (Mech 1983) and UTM coordinates (NAD 1983, Zone 16N) of all locations were recorded with a GeoExplorer 3 global positioning system (GPS; Trimble Navigation Limited, Sunnyvale, CA) which was accurate to within 2 m. Tracking was initiated in September 2006 and concluded in June 2008. A total of 999 unique snake locations were obtained, with an average of 83 locations per individual (range = 49-124).

Habitat Associations

Snake locations, as determined with the GPS, were imported into an existing land cover data layer that had been digitized from 1992 color infrared orthophotography (1:12000 scale). Land cover (habitat) classes used in this analysis included agriculture and wildlife food plots (AG); hardwood forest (HW); mixed pine-hardwoods (MX); natural pine forest (NP); pine regeneration plots and plantations (PP), scrub/shrub or fallow land (SC), aquatic habitats (AQ), and urban areas (UR). Agricultural land was either wildlife food plots (<0.5 ha), small agricultural plots or large center-pivot agricultural fields located adjacent to Ichauway. Hardwood forests contained a mixture of species including southern red oak (*Quercus falcata*), live oak (*Q. virginiana*), laurel oak (*Q. laurifolia*), and water oak (*Q. nigra*). Mixed pine-hardwood habitat had both pine and oaks in the canopy. Natural pine habitat was predominantly mature longleaf pine with native ground cover, but also included areas of naturally occurring loblolly, shortleaf or slash pine. Pine plantations were typically newly planted longleaf pine restoration plots, but also included mature, even-aged stands of planted longleaf pine or slash pine with varying degrees of ground cover. Scrub/shrub included hardwood thickets or old fields in varying degrees of succession. Urban areas included developed sites (rural farms, barns or other buildings). Aquatic habitats included all isolated wetlands and waterways. All habitats (with the exception of agriculture, urban and permanent aquatic habitats) are managed with fire on a 1-2 year rotation.

Euclidean distance analysis (Conner and Plowman 2001) was used to determine whether Florida pine snakes exhibited habitat associations at either the landscape scale (Johnson's 2^{nd} order) or home range scale (Johnson's 3^{rd} order)(Johnson 1980). The analysis, as explained in detail in Conner and Plowman (2001) and Conner et al. (2003), is simply a pairwise comparison of the mean distances between animal locations and particular habitat types, and the mean distances between random locations and habitat types.

For within home range analysis (Johnson's 3^{rd} order), the mean distance from snake locations (n = 999) was compared to 1000 random locations within each animal's MCP home range (see Chapter 2). To test for associations at the landscape scale (Johnson's 2^{nd} order), 12,000 random points within the individual home ranges were compared to those of 10,000 random locations within the "study area" (Figure 3-1). The study area encompassed two disjunct areas, based on the locations of the radio-telemetered snakes; the random locations were equally divided between the two areas. The first area was located north of Highway 200 and the other was just north of and to the south of Highway 91 (Figure 3-2). Random points were generated using Hawth's tools. Distances to habitat classes were calculated using the NEAR function in ArcMap 9.1 (ESRI, Redlands, CA).

A multivariate analysis of variance (MANOVA) was used to determine if the snakes exhibited habitat associations at either the landscape (site wide) or home range scale. If a significant effect was detected with MANOVA, pairwise t-tests were used to identify habitats with a significant association. The significance level was set at $\alpha = 0.05$ and statistical analyses were performed in SAS 9.1 (SAS Institute Inc., Cary, NC).

Microhabitat Use and Activity Patterns

At each location, data on the snake's position (above or below ground) and activity (basking, moving, or feeding) were collected. Microhabitat data taken at each unique snake location included canopy cover, which was the mean of four readings taken around a $1m^2$ quadrat centered over the snake's location using a spherical densitometer. Percent cover of shrubs, grasses, herbs, bare ground, and coarse woody debris also was estimated within the $1m^2$ quadrat centered over the snake, using the following cover class categories: < 1%, 1-5%, 6-15%, 16-25%, 26-50%, 51-75%, 76-100%. The same data were collected at an equal number of randomly selected $1\text{-}m^2$ plots; each of these plots was placed at a random azimuth and distance (5-30 m) from the snake's location. The average percent cover of each cover class for both snake locations and random locations were used in the analysis. A Chi-square test was used to determine whether snakes used microhabitats relative to their availability.

Refuge Use

I attempted to identify the refuge type at each location where a snake was below ground. Refuges included southeastern pocket gopher burrows (as determined by the presence of mounds), gopher tortoise burrows, mouse burrows (*Peromyscus* spp.), nine-banded armadillo (*Dasypus novemcinctus*) burrows, and stump holes (which included stumps, burned out stump holes and tree tip-ups). Snakes were considered to be using a particular refuge type if a structure (e.g., pocket gopher mound) was found within a 2 m radius of the snake's location. If no refuge structure was visible within 2 m of the snake, the refuge type was categorized as "unknown". If multiple refuge types were visible within a 2 m radius of a snake's location, the structure nearest to the location was considered occupied. For gopher tortoise burrows, if the signal was strongest from the burrow opening, I concluded that the snake was in the tortoise burrow. A Fisher's exact test was used to determine if males and females used refuges at different frequencies.

To further document the importance of fossorial refuges to pine snakes, when snakes were observed above ground, I recorded the presence or absence of three refuge types (pocket gopher mound, gopher tortoise burrow, and stumphole) within a 5 m radius of the snake. I recorded the same information for a second location that was at a random distance (from 5 – 30 m) and azimuth (1˚ to 360˚) from the snake's location. Random distances and azimuths were selected using a random number generator (www.random.org). A Fisher's exact test was used to compare the presence and absence for refuges within the 5 m radius of snake versus random locations. A simple t-test was used to compare mean distances from snake locations versus random locations to the three refuge types.

Results

Habitat Associations and Microhabitat Use

Florida pine snakes did not associate with any habitats at the home range scale (Johnson's 3rd order, $F_{0.05, 8, 4}$= 1.92; P= 0.276), i.e., Florida pine snakes used habitat within their home ranges relative to what was available. However, Florida pine snakes did exhibit habitat association at the landscape-scale (Johnson's 2nd order, $F_{0.05, 8, 4}$= 15.85; P= 0.009). A paired t-test comparing mean distances of random locations within-home range and across the landscape revealed that Florida pine snakes were most often associated with mixed pine-hardwood habitat (MX) ($F_{0.05, 1, 11}$= 7.01, P= 0.023), whereas all other habitats examined were used relative to their availability. An analysis of mean distance ratios indicated that within home range locations were significantly closer to MX habitat than would be expected across the landscape ($F_{0.05, 1, 11}$= 7.01, P= 0.023) (Figure 3-3). No habitats were avoided by pine snakes. The order of association as shown in a ranking matrix (Table 3-1), suggested that pine snakes selected for MX, followed by planted pine (PP), scrub/shrub (SC), wildlife food plots/agriculture (AG), urban areas (UR), hardwoods (HW), natural pine (NP), and wetlands (AQ). At the microhabitat scale, Florida pine snakes used sites relative to what was available ($\chi^2 = 2.16$, df = 6, $P > 0.90$; Figure 3-4).

Activity Patterns

Activity patterns (as determined by frequency of above ground observations) of Florida pine snakes varied throughout the year. Snakes were observed above ground most often from March through July (Figure 3-5). They were also somewhat active in September and October. Breeding behavior was observed in late May and June. On 22 May 2008, I observed an unmarked male following within 1 m of a study female. On 12 June 2007, two male pine snakes, one of which was a study animal, were found attempting to copulate with an unmarked female. I observed a study female mating with a much smaller unmarked male on 19 June 2007, and on 25 June 2007, the same female was located within 1 m of a study male within a pocket gopher burrow.

I observed Florida pine snakes feeding on two occasions during the study. A male snake was seen consuming a cotton rat (*Sigmodon hispidus*) in mid-July 2007; a second male was seen taking a juvenile cottontail rabbit (*Sylvilagus floridanus*) in early May 2008. I also x-rayed a female snake with a large prey item that was later identified based on dentition and body measurements as a southeastern pocket gopher (D. Reed, Florida Museum of Natural History, University of Florida, pers. comm.). Lastly, in June 2008, a male pine snake that was held in the lab for transmitter removal at the end of the study regurgitated eight northern bobwhite eggs.

Pine snakes were largely inactive during the winter (i.e. they were above ground at only 20% of observations), and made just a few short movements (Chapter 2). Basking was observed infrequently in winter (18% of observations) and typically involved the same two individuals, a male and the smallest female (64% of observations for both). Snakes became more active in March (above ground in 33% of observations) as average daily temperature increased (Georgia

Automated Environmental Monitoring Network; www.griffin.uga.edu/aemn). Two individuals (male PM-6571 and female PM-3F3F), were radio-tracked for two consecutive fall seasons and, though they did not use the same refuge site each year, they overwintered within 335 m of their previous year's hibernacula.

Refuge Use

Florida pine snakes were highly fossorial in this study. They were located below ground at 76% of all locations and used a variety of below ground refuge sites, including burrows of nine-banded armadillo, mice (*Peromyscus polionotus* and *P. gossypinus*), southeastern pocket gophers, eastern wood rat (*Neotoma floridana*), and gopher tortoises, as well as stump holes. In this study, pine snakes were most frequently observed using pocket gopher burrows (62.5% of observations for both males and females; Figure. 3-3). All other refuges were used at much lower frequencies; these included stump holes (M 5.7%, F 3.9%, total 5%), tortoise burrows (M 3.5%, F 1.6%, total 2.8%), armadillo burrows (M 3.9%, F 4.7%, total 4.2%), mouse burrows (M 2.6%, F 3.9%, total 3%) and various other refuges (M 1.7, F 0.8%, total 1.4%). I was unable to identify the refuge type for 21% of below ground locations (M 20%, F 22.7%) (Figure 3-6). I suspect that in many of these cases the snakes were in either a pocket gopher burrow or other small mammal burrows, because old mounds and burrow entrances were often difficult to locate. There was no difference in the type of refuges used by males and females (P =0.765).

Snakes were not associated with any particular refuge when they were above ground (P_{PG}=0.66, P_{TB}=0.12, P_{SH}=0.12 respectively). Pocket gopher burrows were present with a 5 m radius at 65% of snake locations versus 67% of random locations: tortoise burrows were present at 2% of snake locations as compared to 3% of random locations, and stump holes were present at 16% of snake locations versus 22% of random locations. I also found no significant difference between the mean distance from snake locations versus random locations to the three refuge types: pocket gopher burrows (*P*=0.09), tortoise burrows (*P*=0.93), or stump holes (*P*=0.68).

Discussion

Johnson (1980) suggested that animals may select habitat differently at different scales. In my study, Florida pine snakes exhibited landscape scale habitat association, while at the home range scale, they did not associate with any habitat type. Furthermore, Florida pine snakes selected microhabitats relative to what was available. At the landscape scale, Florida pine snakes were positively associated with mixed pine-hardwood habitat at the landscape scale, while all other habitat types, including natural pine, were used relative to their availability. Much of the MX habitat at Ichauway was subjected to hardwood removal prior to this study. The impact of this removal on habitat selection in pine snakes is not known, however, in some areas, the MX habitat now more strongly resembles natural pine habitat. Ichauway land cover data are currently being updated and, once this is completed, a re-analysis of the data may be warranted

It is unclear what factors drive landscape scale habitat association in Florida pine snakes. One possibility is prey availability. If prey composition of MX differed from other habitat types, it might explain the use of a particular habitat. My observations suggest Florida pine snakes take an array of prey as has been previously reported in the literature (see Ernst and Ernst 2003). However, the small mammal composition is similar among the different upland forest types at Ichauway and prey population densities vary depending on environmental factors rather than overstory composition (L.M. Conner and J.C. Rutledge, pers. comm.). Of the habitats considered, AG is the only habitat that has greater abundance in prey; yet pine snakes were not associated with this habitat. On occasion, I noticed that pine snakes in this study used the edges of agricultural areas. However, the species may not use AG because it lacks suitable refugia and vegetative cover.

I suspect that refuge availability plays an important role in habitat selection in pine snakes. In this study, pine snakes were underground for 73% of all observations. They used pocket gopher burrows in at least 62.5% of below ground observations (Figure 3-6). Likewise, Franz (2005) reported that pine snakes were below ground for 81.1% locations and also exhibited an apparent preference for pocket gopher burrows. Pocket gophers also present a food resource to pine snakes (Ernst and Ernst 2003). A recent report by the Georgia Department of Natural Resources (2008) concluded that Ichauway harbors the largest concentration of southeastern pocket gophers in the state, hence, pocket gophers and their burrows are likely not a limiting resource for pine snakes at Ichauway. Unfortunately, pocket gopher density in the different upland habitats considered in this study is not known (i.e. mixed pine-hardwood habitat exhibiting the highest pocket gopher densities). Mounds provide evidence of pocket gopher activity; however, there is no clear way to relate mound activity to burrow or pocket gopher abundance. Northern pine snakes populations in New Jersey do not coexist with pocket gophers, but instead rely on the presence of other available refuges or create their own (at least for nesting purposes; Zappalorti et al. 1983). Surveys for Florida pine snakes in areas where southeastern pocket gophers have declined are badly needed.

When above ground, pine snakes in this study were not closer to pocket gopher mounds than would be expected by chance, despite their apparent preference for these burrows as refuge sites. Pine snakes are large and mobile and may simply move through the landscape without regard for distance to a particular refuge type. However, it is also possible that an association was masked by the lack of independence between snake and random locations in this study (i.e. the 5-30 m radius for selection of random points may have been inadequate). This may have been remedied by using an alternate sampling technique for selecting random locations, such as selecting sites randomly across the landscape, rather than based on proximity to snake locations. The high population densities of pocket gophers at Ichauway also may mean that these refuge types are not limited. Repeating this study in areas where pocket gophers are less abundant may be more conclusive.

One major difference between this study and Franz (2005) was the use of other refuge types. In this study, Florida pine snakes only infrequently used stump holes, gopher tortoise burrows, armadillo burrows and mouse burrows. Whereas in Florida, Franz (2005) reported higher rate of use of tortoise burrows and stump holes (e.g., pine snakes in this study used tortoise burrows 5% as compared to 31% in Florida). This difference may have been related to differences in tortoise and pocket gopher densities between the two sites.

Also of interest in this study, was that radio-telemetered pine snakes never left Ichauway. Although the home ranges of several snakes bordered off-site agricultural fields, these snakes were never detected entering this habitat. Snakes were also not observed crossing either of the two major highways that bisect the property despite five individuals having home ranges abutting them. They would, however, infrequently cross dirt roads. One male did cross a small, paved county road on several occasions (spring movements), but this is likely due to his home range being bordered by both a major highway and a large agricultural field, which minimized his ability to find mates and other resources. This tendency to stay within high quality habitat suggests that Florida pine snakes may be sensitive to highly disturbed and open areas.

In this study, Florida pine snakes were most closely tied to mixed pine-hardwood forests, therefore managing for a hardwood component in upland pine forest systems may be beneficial to Florida pine snakes. The presence of a naturally occurring fire regime is likely important to ensure maintenance of this habitat. Relatively undisturbed, actively managed sites like Ichauway in southwest Georgia and the Katharine Ordway-Swisher Memorial Preserve in Florida, are of great importance for pine snake conservation. More research on the species is needed to understand pine snake habits in lower quality habitats, specifically where habitat is highly fragmented. Pine snakes also require ample refuge resources, specifically southeastern pocket gopher burrows. It is critical to determine how the loss of pocket gophers might affect pine snake populations. Habitat loss and fragmentation is likely to continue in the region and the continued decline of pocket gophers for food and refuge may be paramount. Efforts are needed to conserve this species through the aquisition and proper management of upland habitats which ensure the presence of the resources necessary for Florida pine snake persistence.

Table 3-1. Ranking matrix of Florida pine snake (*Pituophis melanoleucus mugitus*) habitat use at the landscape scale on Ichauway, Baker County, Georgia. Values are t-statistics (*P*-values) associated with the pairwise comparison of the mean distance ratio of random locations within home range to the mean distance ratio of random locations across the landscape.

	Agriculture	Hardwood	Mixed	Natural Pine	Pine Plantation	Scrub/Shrub	Urbanized	Aquatic
Agriculture		-0.50 (0.630)	2.08 (0.062)	-0.57 (0.579)	0.55 (0.591)	0.98 (0.347)	-0.04 (0.971)	-1.16 (0.271)
Hardwood	0.50 (0.630)		1.82 (0.096)	-0.38 (0.711)	0.92 (0.379)	1.06 (0.314)	0.37 (0.716)	-1.04 (0.323)
Mixed	-2.08 (0.062)	-1.82 (0.096)		-1.81 (0.097)	-0.40 (0.698)	-1.04 (0.322)	-1.58 (0.142)	-3.40 (0.006)
Natural Pine	0.57 (0.579)	0.38 (0.711)	1.81 (0.097)		0.81 (0.433)	0.91 (0.380)	0.59 (0.570)	-0.56 (0.585)
Pine Plantation	-0.55 (0.591)	-0.92 (0.379)	0.40 (0.698)	-0.81 (0.433)		-0.15 (0.882)	-0.72 (0.487)	-1.22 (0.247)
Shrub/Scrub	-0.98 (0.347)	-1.06 (0.314)	1.04 (0.322)	-0.91 (0.380)	0.15 (0.882)		-0.51 (0.622)	-1.91 (0.082)
Urbanized	0.04 (0.971)	-0.37 (0.716)	1.58 (0.142)	-0.59 (0.570)	0.72 (0.487)	0.51 (0.622)		-1.15 (0.275)
Aquatic	1.16 (0.271)	1.04 (0.323)	3.40 (0.006)	0.56 (0.585)	1.22 (0.247)	1.91 (0.082)	1.15 (0.275)	

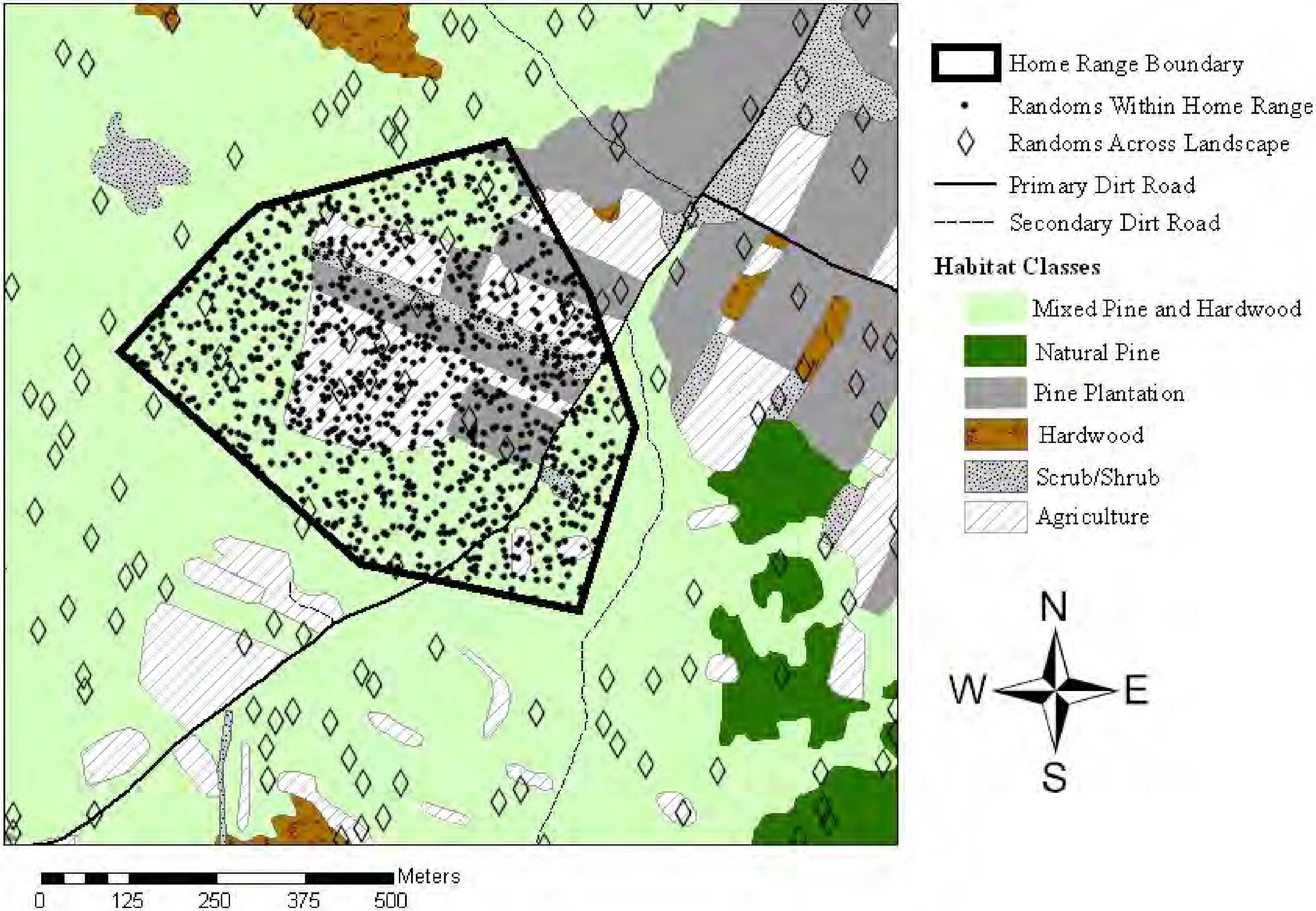

Figure 3-1. Landscape scale habitat selection for a Florida pine snake (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia. A mean of the distances to the nearest edge of each habitat type for random locations within the home range (n = 1,000 per snake home range) are compared to the mean distances of random locations (n = 10,000) across the study site.

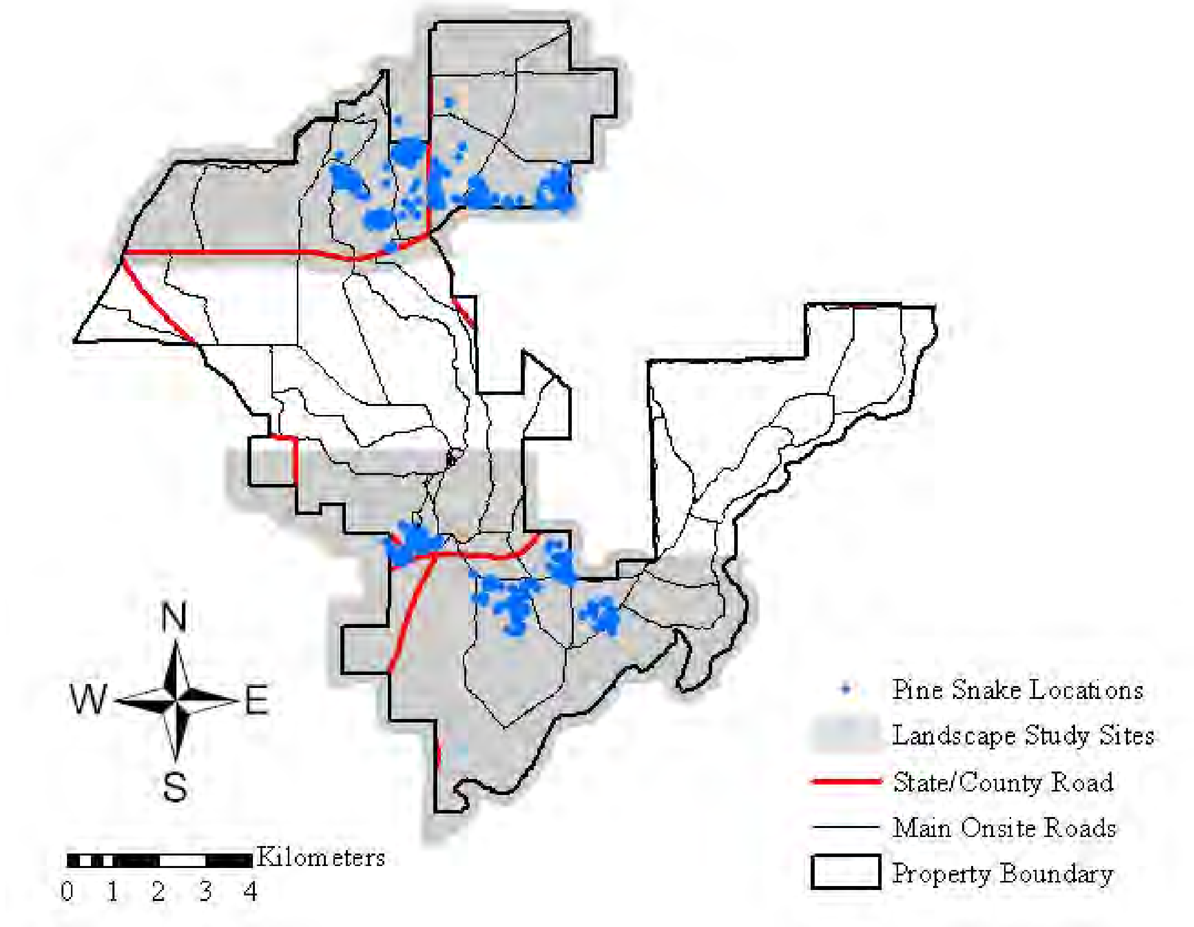

Figure 3-2. Landscape study sites selected for landscape random point generation based on locations of Florida pine snakes (*Pituophis melanoleucus mugitus*) on the Ichauway property, Baker County, Georgia. The Gray fill indicates areas used in landscape analysis of habitat association while areas in white were ignored.

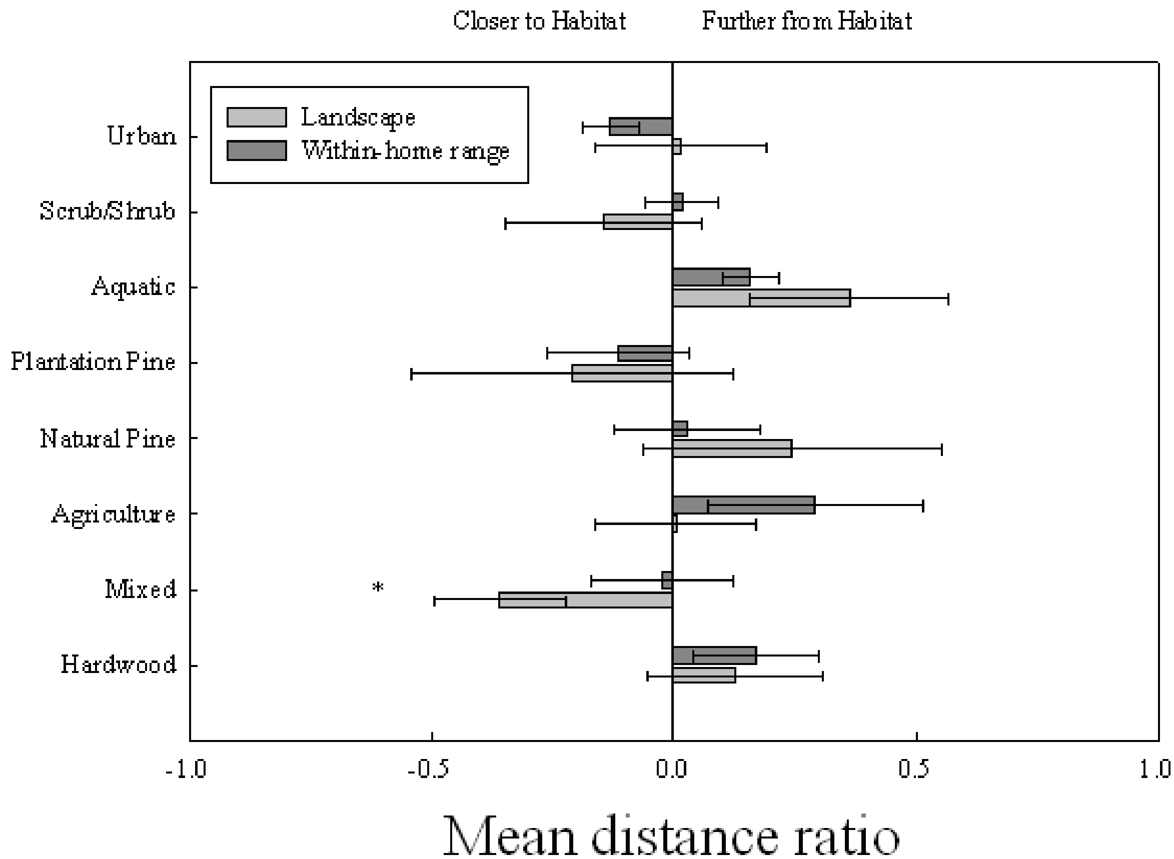

Figure 3-3. Mean distance ratios (±1 SE) for landscape and within home range scale habitat use across eight distinct habitat types for Florida pine snake (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia. Mean distance ratios that are negative signify snakes being closer to habitat and positive signify snakes were further from habitat. The asterisk denotes statistically significant association for mixed pine-hardwood habitat at the landscape scale.

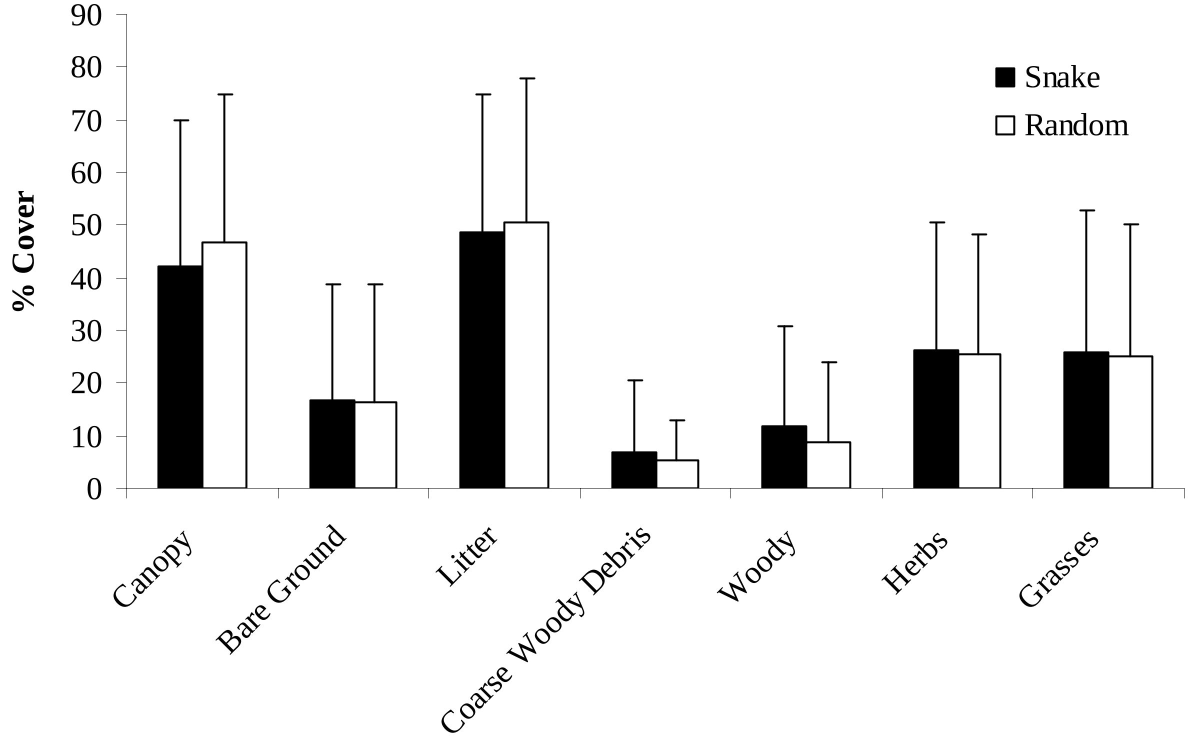

Figure 3-4. Microhabitat use by 12 radio-instrumented Florida pine snakes (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia.

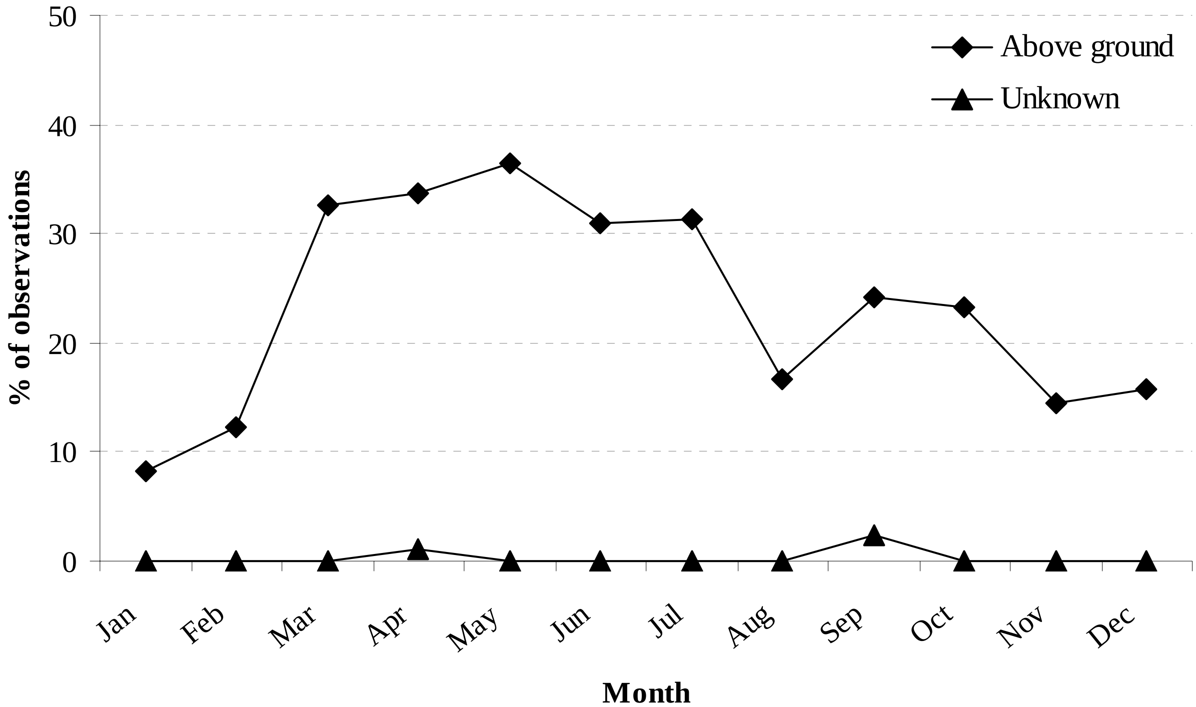

Figure 3-5. Activity patterns of Florida pine snakes (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia.

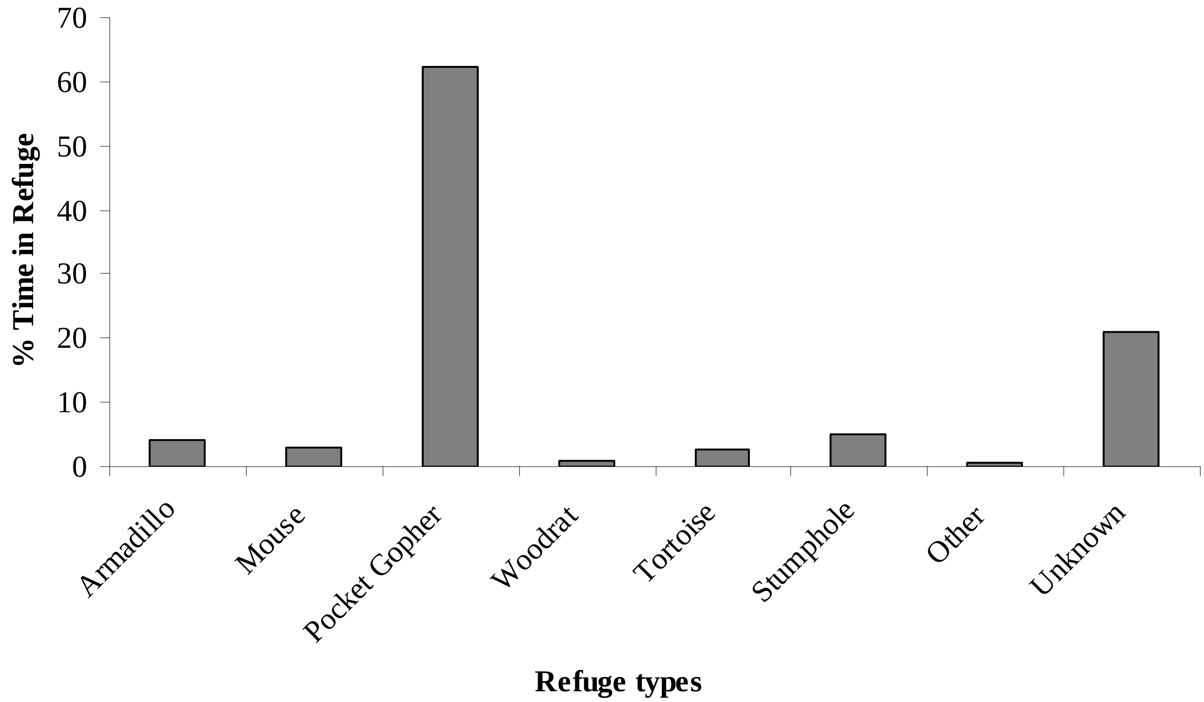

Figure 3-6. Refuge use by 12 radio-instrumented Florida pine snakes (*Pituophis melanoleucus mugitus*) at Ichauway, Baker County, Georgia. Refuge types included burrows of nine-banded armadillo (*Dasypus novemcinctus*), mouse (*Peromyscus* spp.), southeastern pocket gopher (*Geomys pinetis*), wood rat (*Neotoma floridana*), and gopher tortoise (*Gopherus polyphemus*), as well as stumpholes.

CHAPTER 4
CONCLUSIONS AND MANAGEMENT IMPLICATIONS

This study addressed questions regarding resource requirements of the Florida pine snake (*Pituophis melanoleucus mugitus*). The natural history of the Florida pine snakes is poorly known relative to that of its northern counterpart, *P. m. melanoleucus*, (Burger and Zappalorti 1986, 1988, 1989, 1991; Burger et al. 1988; Zappalorti and Burger 1985), yet there is concern about possible declines in Florida pine snake populations (Franz 1992). To evaluate the status of Florida pine snakes, specific data on habitat associations and area requirements were needed. Therefore, in this study, I estimated home range size and habitat use across multiple spatial scales. Florida pine snakes are thought to be closely associated with southeastern pocket gophers, both for food and refuge; therefore, I also examined refuge use. The impetus of this research was to evaluate aspects of the ecology of Florida pine snakes that are needed for development of management and conservation strategies for this species.

The results of the home range portion of this study suggest that Florida pine snakes use moderate to large areas within second growth longleaf pine forest/hardwood matrices. The average overall home range size was 59.2 ha (based on MCP data) and varied greatly among individuals (n= 12; range 18.6 – 156.8 ha). Although factors driving home range size of Florida pine snakes are not clear, as one of the largest snake species in North America (Ernst and Ernst 2003), they undoubtedly require large areas for procuring resources such as food, mates and refuge sites (e.g., Gregory 1984). Given that pine snakes in this study were highly fossorial (76% of all locations), refuges for hibernation and daily cover may serve as a determinant of home range size and habitat use. Snakes in this study spent a large majority of their time underground within pocket gopher burrows (62.5% of fossorial locations). Therefore, presence of this species may strongly influence pine snake populations. More research is needed on pine snake habits in areas with limited pocket gopher populations.

In some snake species, home range size is influenced by sex or body size (see Macartney et al. 1988), though this is not generally the case (Gregory et al 1987). Although such an influence was not detected in this study, small sample size may have masked a difference. It would be useful to follow more individuals of different size classes (including hatchlings and juveniles) and a greater number of female pine snakes to determine if a difference truly exists. It is possible that different size classes require different resources throughout the landscape. Home range size differed among seasons in this study. Reproduction likely has a strong influence on home range size in pine snakes in spring and summer. Males had significantly larger home range areas in spring than in summer and fall/winter. In this study, several males traveled up to 2 km, from their core home ranges during breeding season, presumably in search of mates.

This study suggests that in a forested upland landscape, management for a mixed pine-hardwood matrix would benefit Florida pine snakes. Maintenance of a mixed pine-hardwood community in southeastern forests requires use of prescribed fire or other means of preventing succession toward a hardwood dominated forest (Noss and Peters 1995). Fire also promotes growth of ground cover vegetation (Goebel et al. 2001), which may offer effective cover from predators and thermal extremes. Burning also establishes an open canopy, providing substantial basking habitat for snakes. Prescribed burning may benefit southeastern pocket gophers by providing preferred forage and creating stump holes for refugia (Means 2005). Though stump holes were not often used by pine snakes, their presence may be beneficial to other species, including prey. By managing habitat, resources required by pine snakes would be encouraged and perpetuated. Management for rare upland species such as the red-cockaded woodpecker (*Picoides borealis*) would likely ensure that pine snake conservation needs are met as well.

Portions of the mixed pine-hardwood habitat at Ichauway have been subjected to recent hardwood removal to allow reintroduction of prescribed fire. However, I was unable to determine what influence this management activity may have on pine snake habitat selection. The hardwood removal areas that were used by pine snakes were structurally similar to natural pine habitat, exhibiting dense ground vegetation with moderate to open canopies as well as the presence of ample refugia.

Florida pine snakes used pocket gopher burrows more than any other available refuge resource. According to a recent population survey of gophers in Georgia (Georgia Department of Natural Resources 2008), it was determined that Ichauway had the largest remaining population of southeastern pocket gophers in Georgia, but elsewhere in the state their numbers have declined dramatically. Pocket gophers may be an important keystone species providing refuge (and food) for a variety of species including pine snakes (J. Ozier, Georgia Department of Natural Resources, pers. comm.). Action should be taken to conserve populations of pocket gophers, which in effect would benefit pine snakes, and other upland species that use their burrows.

Despite their use of moderately disturbed areas, such as hardwood removal sites and small agricultural plots, Florida pine snake home ranges were remarkably restricted to Ichauway. Snakes rarely approached highly disturbed, offsite areas such as the center pivot irrigation fields, or developed areas. Florida pine snakes may avoid these areas because of the absence of refuges or because they lack suitable cover. Moreover, Florida pine snakes were never detected crossing the two major paved highways, even though several of the snakes had home ranges that abutted them. Large agricultural fields and high use paved roads may effectively limit movements of Florida pine snakes, thereby decreasing genetic exchange among populations. Use of smaller agricultural fields with hedgerows may help to facilitate movement of snakes between habitat patches, thereby decreasing isolation of populations in these landscapes. Roads have been determined to fragment habitat for wildlife (Smith and Dodd 2003, Dodd et al. 2004), allow dispersal of exotic species (Seabrook and Dettmann 1996, Stiles and Jones 1998), and cause direct, and sometimes substantial, mortality (Ashley and Robinson 1996, Rudolph et al. 1999, Shine et al. 2004, Smith and Dodd 2003). Use of ecopassages (Dodd et al. 2004) may facilitate movements of pine snakes across large highways, although research is needed to determine the effectiveness of such structures for large snakes. It is unclear how restrictive roads and other land developments are to pine snake movements, suggesting that implications of such structures should be considered for conservation purposes.

A number of southeastern snake species are thought to be in decline (Krysko and Smith 2005, Rudolph and Burgdorf 1997, Tuberville et al. 2000). Habitat loss and fragmentation are implicated to be a main cause of these declines (Dodd 1987, Gibbons et al. 2000). To stem the decline of Florida pine snakes, remaining tracts of native forest should be protected (e.g., placed in conservation easements or acquired by state and federal agencies). On existing protected areas, land owners and managers should incorporate scientifically proven management practices, such as prescribed burning. Allowing a component of hardwoods to occur within upland pine forests should be encouraged. Where possible, fragmentation of quality habitats should be minimized. Efforts should be made to protect refuge resources; this would include fostering southeastern pocket gopher populations as well as leaving stumpholes and other fossorial cavities. Wise management on both public and private lands will be needed if we are to perpetuate the long-term survival of Florida pine snakes and the rest of our unique wildlife heritage.

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BIOGRAPHICAL SKETCH

Gabriel “Gabe” Miller was born and raised in southeast Minnesota. During his childhood he showed great interest in nature and enjoyed many trips to his uncle’s farm situated above the hills and bluffs of the Mississippi River valley. After graduating in 1995 from Lincoln High School in Lake City Minnesota, he attended Central Lakes College in Brainerd, Minnesota where he earned an A.A.S. degree in natural resource technology in 1998. He earned his B.S. in wildlife management in 2003, at the University of Wisconsin-Stevens Point. His interest in reptile conservation started when working with the Minnesota Department of Natural Resources on wood turtle (*Glyptemys insculpta*) conservation. He took his interest to the University of Florida in Gainesville where he conducted his thesis research on Florida pine snakes. He earned his M.S. in wildlife ecology and conservation in 2008. Gabe is currently married and is the proud father of a young son.