Habitat Preferences of the Eastern Fence Lizard, *Sceloporus undulatus*, in Southwestern Virginia

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ABSTRACT

Habitat preferences of the eastern fence lizard, *Sceloporus undulatus*, were investigated in southwestern Virginia. Habitat features were measured at 158 lizard-centered plots and at paired random plots. Landscape-level variables, southerly aspect and mixed forest type, distinguished lizard-centered from random sites. Hatchlings were associated with relatively high temperature at perch height (23 °C), relatively high amounts (per 1- m^2) of coarse woody debris (15%) and bare ground (15%), and relatively low amount of litter (34%). Adults and juveniles were associated with a relatively high number of rocks (22 per 0.01 hectare) and amount of coarse woody debris (9% per 1- m^2). Habitat preferences were modeled with a Geographic Information System (GIS) using landscape-level variables and with logistic regression and Akaike's Information Criterion using site-level variables. The best-fitting site-level model for adults/juveniles included % CWD. The best-fitting model for hatchlings included % CWD and number of rocks, and the second best-fitting model also included % litter. Landscape (both classes) and site-level models (adult/juveniles only) were tested at 15 GIS-predicted "suitable" study areas and at 15 GIS-predicted "unsuitable" areas. Site-level models for hatchlings were tested with independent data collected at two study areas. Sixteen lizards were found at "suitable" areas and one at an "unsuitable" area; the GIS-based model was a good predictor of lizard presence at the landscape level. The best-fitting site-level models for adults/juveniles and hatchlings were poor predictors of lizard presence while the second best-fitting hatchling model was a good predictor of hatchling presence.

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BACKGROUND AND OBJECTIVES

The main objectives of this research were to develop and test predictive habitat models for the eastern fence lizard (*Sceloporus undulatus*) in southwestern Virginia. Procedures used to develop and test landscape- and site-level habitat models for this species can also be used to predict suitable habitat for other species with similar distribution patterns and/or habitat preferences. Below, I provide a brief background for the ideas and processes relevant to my thesis work. Then, I define the specific objectives of my research and describe the organization of this thesis. Finally, I provide a brief review of the natural history of my study species, *Sceloporus undulatus*.

Background

The distribution of a species is determined, in part, by habitat preference. Habitat preference of individuals is based on characteristics that include physical structure, prey availability, nest sites, refuges from inclement weather, predators, etc. (Bellows et al. 2001, Smith and Ballinger 2001). Habitat preferences are adaptive, such that fitness is higher in preferred habitats (Jaenike and Holt 1991). Habitat assessment leads to an understanding of the life requisites of a species, and thus its ecology. Determination and modeling of ‘preferred’ habitat characteristics provide tools for locating and managing target species or populations. For my thesis work, I used two techniques, a Geographic Information System (GIS) and Logistic Regression with Akaike’s Information Criterion (AIC), to form integrated models of preferred habitat variables for *Sceloporus undulatus* in southwestern Virginia.

GIS-based modeling uses landscape-scale computer-based mapping techniques for a host of demographic and land-use planning applications, and more recently with species habitat modeling. A GIS can show fine-scale habitat features, like a single tree, on up to coarse-scale habitat types across a continent. GIS-based models can delineate suitable habitat versus non-suitable habitat for a particular species across a landscape based on researcher-assigned attributes of that landscape, such as soil type or forest type. Several governmental agencies and non-governmental organizations have developed attribute layers for landscapes across the country, including such variables as land cover class, elevation, population size, and socioeconomic levels.

Akaike's Information Criterion (AIC) is a method for choosing a logistic regression model that "best" fits the reference data used to build a set of candidate models (Burnham and Anderson 1998). When using AIC with logistic regression, candidate models are ranked, with the lowest AIC values and highest Akaike weight indicating the best, most parsimonious model. Logistic regression can be used to model site-level features, thereby assisting researchers in understanding the biological structure of an ecological system (Gibson et al. 2004, Johnson and Collinge 2004, Hashimoto et al. 2005, Alexander et al. 2006).

The eastern fence lizard, *Sceloporus undulatus,* was selected to test landscape- and site-level habitat preference models because its distribution in southwestern Virginia is patchy at multiple spatial scales. Modeling and testing processes developed for this species would also be appropriate for other species in Virginia with scattered local populations, such as the northern coal skink (*Eumeces a. anthracinus*), canebrake rattlesnake (*Crotalus horridus atricaudatus*), and broadhead skink (*Eumeces laticeps*) (Virginia Department of Game and Inland Fisheries 2007). Developing accurate models for such species provides managers with tools for locating individuals or populations and for locating suitable habitat for species relocation or restoration. GIS-based mapping techniques used in conjunction with logistic regression models provide a modern approach to habitat suitability assessment and are broadly applicable to species with heterogeneous distributions (Olson et al. 2004).

Thesis Objectives and Organization

My objectives in studying the eastern fence lizard (*Sceloporus undulatus*) were 1) to define the landscape- and site-level habitat preferences for each sex and age class, 2) to develop a GIS-based model composed of landscape-level habitat variables that differentiated lizard-centered sites from random sites, 3) to generate logistic regression models composed of site-level habitat variables that differentiated lizard-centered sites from random sites, and evaluate these models using AIC, and 4) to test model accuracy through field surveys at locations determined by the GIS to be 'suitable' or 'unsuitable' for fence lizards.

In Chapter 1, I determined the landscape- and site-level habitat variables that differentiated lizard-centered sites from random sites for adult females, adult males, juveniles, and hatchlings. In Chapter 2, I developed a landscape-level habitat model for the species and logistic regression site-level models for those sex/age classes that showed site-level habitat preferences distinct from other classes. I then tested the accuracy of the landscape-level model and 'best' site-level models, as ranked by AIC, with field surveys across six southwestern Virginia counties.

A Brief Natural History of *Sceloporus undulatus*, the Eastern Fence Lizard

Sceloporus undulatus, a phrynosomatine lizard, is widely distributed in the United States, ranging from southern New Jersey to Florida and west to Colorado and western Texas. This species occurs in woodlands, grasslands, and canyonlands across its range (Ferguson et al. 1980), with color and pattern variation that suggests adaptation to local conditions (Leache and Reeder 2002).

These lizards are diurnal and spend most daylight hours basking, such that home ranges usually are centered on one or more basking sites (Blair 1960). Fallen trees and large rocks are used for basking sites (Haenel et al. 2003). Nights are spent under bark, logs, rocks, or in rock crevices (Mitchell 1994, Warner 2001). Fence lizard home ranges vary from 700 m^2 to 8900 m^2 (mean = 3361 m^2) for males and from 1.5 m^2 to 700 m^2 (mean = 147 m^2) for females (Haenel et al. 2003).

Nest sites are often outside the boundaries of normal home ranges (Blair 1960). Gravid females migrate into open areas shortly before oviposition (M. J. Angilletta, Indiana State University, personal communication). Because the female abandons the nest after oviposition, the survival of embryos depends on the environmental conditions within the nest (Warner 2001).

Fence lizards are sit-and-wait predators, eating invertebrates such as beetles, grasshoppers, ants, moths, spiders, millipedes, and snails (Mitchell 1994). Predators of the fence lizard in Virginia include black rat snakes (*Elaphe obsoleta*), copperheads (*Agkistrodon contortrix*), predatory birds, and domestic cats and dogs (Mitchell and Beck 1991, Mitchell 1994).

In Virginia, fence lizards have an 86 mm maximum snout-vent length (SVL) (Mitchell 1994). Adult lizards vary from brown to gray in color and have dark undulating bars across the dorsum. Adult males have a hyacinth-bluish color on the throat and along the sides of the belly.

Individuals are generally found in edge habitats of mixed deciduous forest, pine woods, and areas impacted by humans, such as barns, rock piles, and abandoned homes (Mitchell 1994, Warner 2001). These habitats typically receive high levels of solar radiation (Ferguson et al. 1980). The eastern fence lizard is found throughout southwestern Virginia, although its pattern of distribution across this region is patchy (i.e. disjunct populations) (Mitchell 1994, Mitchell and Reay 1999). Here, the species is characteristic of open areas within forested habitats, and individuals are often plentiful where present. Their activity period is from March through October, and females are gravid in May with oviposition occurring in late May or June. Hatching typically occurs between late July and early September, with clutch sizes ranging from 5 to 16 eggs (Warner and Andrews 2003). Growth of hatchlings is rapid and some individuals reproduce the summer following hatching.

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CHAPTER 1

Habitat Preferences of the Eastern Fence Lizard, *Sceloporus undulatus,* in Southwestern Virginia

ABSTRACT

Conservation and management of a species depends on an understanding of its habitat preferences. Species with patchy distributions on landscape or site-level scales, or both, may be difficult to manage because of strict habitat requirements and/or population/habitat fragmentation. Habitat use by the patchily-distributed eastern fence lizard, *Sceloporus undulatus*, was investigated in southwestern Virginia. From May to October 2003, I weighed, measured, and sexed 158 *S. undulatus* at study areas in Bland, Craig, and Montgomery counties. Lizards were classified as hatchlings, adult males, adult females, or juveniles. Searches were conducted along 50 m transects perpendicular to trails or around clearings. Habitat features were measured within five 1-m^2 lizard-centered quadrats, nested in a 0.01 hectare circular plot. For each lizard-centered plot and set of quadrats, a random plot and quadrats were located at a random direction 50 m from the center of the lizard-centered plot. Landscape-level habitat variables (aspect, elevation, forest type) did not distinguish classes, but aspect (southerly) and forest type (mixed) distinguished lizard-centered from random sites. Hatchling habitat preferences differed from those of adults and juveniles, which did not differ from one another. Hatchlings were associated with relatively high temperature at perch height (23 °C), relatively high amounts (per 1- m^2) of coarse woody debris (15%) and bare ground (15%), and relatively low amount of litter (34%). Adults and juveniles were associated with a relatively high number of rocks (22 per 0.01 hectare) and amount of coarse woody debris (9% per 1- m^2).

INTRODUCTION

Knowledge of a species' distribution is essential for its management or conservation (Guisan and Zimmermann 2000). Habitat preference assessment, whether at a coarse, landscape scale or fine, organism-centered scale, can lead to an understanding of a species' habitat requirements and thus its distribution. Wildlife managers use habitat preference information for locating, relocating, or conserving species (Gibson et al. 2004). Habitat preferences can be vary by sex or age class within a species and within different spatial scales (Mackey and Lindenmayer 2001, Fisher et al. 2003), complicating management and conservation processes.

The physical association between the local distribution of a species and a particular habitat type is usually obvious. For lizards, distributions are associated with factors such as thermal requirements, food availability, presence of conspecifics, refugia from predators, and nesting sites (Huey 1991, Downes 2001). What may not be so obvious are the essential habitat features used by individuals when they establish their home ranges (i.e. habitat preferences).

One way to assess the essential features of selected habitat is to contrast features of sites where individuals occur with features of sites that are randomly chosen. Randomly-chosen sites provide a null model for habitat selection, that is, features that do not differ between the random sites and individual-centered sites are unlikely to be relevant for habitat selection. On the other hand, features of individual-centered sites that differ from random sites are likely to be features that are, or are related to, the actual basis for selection. More precisely, local distribution is a function of the combined habitat choices of different groups within a population. For example, adult males and females could differ in their habitat preferences, or adults could have different habitat preferences than juveniles. Contrasting individual-centered sites and random sites necessitates the study of an area substantially larger than the observed home ranges of individuals in the study population (Litvaitis 1996).

My objective was to define the characteristics of habitats preferred by sex and age classes of the eastern fence lizard, *Sceloporus undulatus*, in southwesternVirginia. To meet my objective, I determined the values of landscape- and site-level habitat variables associated with adult females, adult males, juveniles, and hatchlings at three study areas. The general premise of this work was that features of sites occupied by lizards reflect habitat preference only if these features differ from features of sites that were not occupied by lizards.

MATERIALS AND METHODS

Study Organism

Sceloporus undulatus, a phrynosomatine lizard, is widely distributed in the U. S., ranging from southern New Jersey to Florida and west to Colorado and western Texas. This species occurs in woodlands, grasslands, and canyonlands across its range (Ferguson et al. 1980), with color and pattern variations that suggest adaptation to local conditions (Leache and Reeder 2002). It is found throughout southwestern Virginia, although its local distribution is patchy (Mitchell 1994, Mitchell and Reay 1999). Typical habitats in Virginia are the edges of mixed deciduous forest, pine woods, and areas impacted by humans, such as barns, rock piles, and abandoned homes (Mitchell 1994, Warner 2001).

Habitat preferences may reflect the thermal requirements of this species. Mean body temperatures average about 35°C at a wide range of latitudes and altitudes and in a variety of habitats (Adolph 1990, Andrews 1998). Home ranges usually are centered on one or more basking sites that include downed trees and large rocks (Blair 1960, Haenel et al. 2003*a*). In mountainous areas, for example, occupied sites typically have southerly exposures, presumably because these habitats receive the high levels of solar radiation required for thermoregulation and for incubation of eggs.

An individual's habitat preferences may also reflect its sex or age (Adolph 1990, Smith and Ballinger 2001). Adults are generally syntopic. Adult males seek habitat that is inclusive of the home ranges of several females (Haenel et al. 2003*b*). Adult females briefly leave their home ranges and migrate to open areas shortly before oviposition and return to the forest immediately afterwards (Blair 1960, Angilletta 2000, M. J. Angilletta, Indiana State University, personal communication). Thus, eggs are exposed to higher temperatures than found in the forest Hatchlings tend to remain in these open areas for several months after hatching (Warner and Andrews 2002*a*). When leaf-fall occurs in autumn, juveniles move into more forested areas.

Study Areas

Study areas were located in Bland, Craig, and Montgomery counties in southwestern Virginia (Figure 1.1) (Appendix A). These counties lie in the ridge and valley physiographic province, characterized by long linear ridges, composed primarily of sandstone and shale, separated by narrow valleys. Elevation ranges from 300 m valleys to 1372 m peaks (Virginia Ground Water Protection Steering Committee 2003). Forested regions are dominated by chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), Virginia pine (*Pinus virginiana*), red maple (*Acer rubrum*), and yellow poplar (*Liriodendron tulipifera*).

Three study areas were chosen based on the presence of fence lizards. The AT study area was a 500 m section of the Appalachian Trail (AT) located near Trout Creek in Craig County at an elevation of 418 m to 573 m (Figure 1.2). This location included diverse aspects, slopes, and habitat types and showed evidence of having been logged and burned approximately 10-15 years ago. The Wake Forest study area was on private property in the Wake Forest section of northwest Montgomery County (Figure 1.3). This area extends from an abandoned sawmill clearing (at 754 m elevation) to a homesite dump (at 624 m elevation) connected by an overgrown dirt road roughly 780 m long. The sawmill clearing and the homesite dump (composed of stacked lumber, woodpiles, and lawn clippings) are surrounded by mixed forest. The Little Creek study area, also located on private property, was in the Long Spur community of the Little Creek section of southeastern Bland County (Figure 1.4). This area encompassed a 345 m long dirt driveway leading to a log cabin and an ATV trail extending from the cabin 1310 m up the mountain. Elevation of this study area ranged from 502 m to 1025 m.

Survey and Capture of Lizards

At the AT study area, lizard surveys (for hatchlings only) were conducted from 16 September to 30 September 2003 along 50-m transects perpendicular to the AT. Transects were alternated at 25-m intervals along the trail such that transects on the same side of the trail were separated by 50 m (Figure 1.5). Such separation reduced the probability of capturing the same lizards on adjacent transects. At the Wake Forest study area, surveys (for hatchlings only) were conducted from 29 August to 15 October 2003. As at the AT study area, alternating 50-m transects were surveyed along the dirt trail leading from the homesite dump to the sawmill clearing and around the 128-m and 169-m forest opening perimeters around the dump and clearing, respectively. At the Little Creek study area, lizard surveys (for all age classes) were conducted from 14 May to 16 October 2003. Alternating transects were located perpendicular to the dirt driveway and connecting ATV trail and were surveyed in the same manner as for the AT and Wake Forest study areas. In addition to the standard protocol transect survey at the Little Creek study area, two additional 500-m transect lines were surveyed parallel to and approximately 100 m from the ATV trail, one on each side. These lines extended from 50 m below the cabin to 450 m above the cabin and were surveyed to determine if any lizards could be located deeper into the forest, away from human-disturbed areas. At each study area, transects were surveyed twice over the course of the study period, with the exception of the two additional 500-m transect lines at Little Creek which were surveyed only once on 13 June. On the second round of surveys, the side to which each perpendicular transect was initially surveyed was switched. Overall, 2100 m were surveyed at the AT study area (1050 m surveyed twice), 4400 m at Wake Forest (2200 m surveyed twice), and 7700 m at Little Creek (3350 m surveyed twice and two 500-m transects surveyed once).

I surveyed for lizards by walking slowly and visually scanning both sides of the transect lines for lizards on the ground and on downed trees, rocks, and tree trunks. Surveys were conducted between 0930 hours and 1940 hours on sunny days. Lizards were captured by hand or nylon noose attached to a fishing pole. Each was weighed, measured, and sexed (based on presence of an enlarged postanal scale in males), and uniquely marked with a permanent, felt-tipped marker on the dorsum. Captured lizards were classified as juveniles if they were in their second activity season (between 38 and 57 mm SVL) or hatchlings if they were the young of the year (less than 38 mm SVL). Lizards were classified as adults if they were in their second year or, in some instances, if they were yearlings that had reached adult size their first year (greater than 57 mm SVL). Lizards were processed as quickly as possible on site and returned to the exact location of their capture. Habitat measurements were made once per lizard, except that one or more of six adult lizards captured at Little Creek after 20 August could have been recaptures. Adults were observed shedding at that time, and these lizards could have lost their marks rather than being individuals new to the survey.

Habitat Measurements

For each captured lizard, a 5-m^2 lizard-centered quadrat and an associated random quadrat were established. By pairing a random quadrat with each lizard-centered quadrat, measurements were made at the same time, with the same weather conditions and habitat resources (Compton et al. 2002). Each lizard-centered and random quadrat consisted of five 1-m x 1-m sub-quadrats, where the center sub-quadrat was bounded on each side by another 1-m^2 sub-quadrat. These random and lizard-centered ‘crosses’ had a north-south, east-west orientation. A 0.01 ha (5.64m radius) circular plot, centered over each lizard-centered and random quadrat, was also demarcated.

For each lizard-centered quadrat, a random quadrat was located in a random direction, 50 m distant. Because the average home range radii of adult males and females are 32.7 m and 6.8 m, respectively (Haenel et al. 2003*a*, Haenel et al. 2003*b*), a random quadrat located 50 m from a lizard-centered quadrat generally would be outside of the home range of a captured lizard. A SAS System-generated list of random azimuths determined the direction of the random quadrat. If the azimuth on the list placed the random quadrat into a water source, over a cliff, or other locations that were impossible to sample, then the next listed azimuth was chosen. For each lizard-centered and random quadrat, I recorded aspect, slope, elevation, forest type, perch type (lizard-centered sites only), canopy cover species, number of rocks and downed trees, basal area, percentages of canopy cover, bare ground, grass, fern, forb, shrub, rock, coarse woody debris (CWD), and litter cover, and temperature at perch height (Table 1.1) (Appendix B). At random sites, temperature at perch height was measured at the center of the site at the same height above the ground as the perch was at the lizard-centered site. Temperature at perch height was used only in comparisons of lizard-centered sites and random sites.

Hypotheses and Statistical Tests

I tested two null hypotheses: 1) habitat characteristics do not differ between lizard-occupied sites and random sites, and 2) habitat preferences do not differ among adult males, adult females, juveniles, and hatchlings.

I tested the first hypothesis using Wilcoxon Signed-Rank and Chi-square (for aspect and forest type) tests, which compared habitat measurements between random and lizard-centered sites. The non-parametric Wilcoxon Signed-Rank test was used because habitat variables had non-normal distributions. Lizard-centered versus random site comparisons were made for all lizard classes combined from the Little Creek surveys, where all age classes were studied. The Wilcoxon Signed-Rank test was also used to make similar comparisons with hatchling data from surveys at all three study areas. I used Spearman's Rho correlation analyses to assess correlation among habitat variables.

The second hypothesis was tested with the Wilcoxon Rank Sum, Kruskal-Wallis, and Chi-square tests, to determine if habitat preferences differed among sex/age classes. Only data from Little Creek were used in these analyses, as this was the only study area where lizards from all age classes were captured.

I used additional Wilcoxon Rank Sum analyses to assess seasonal differences in habitat preferences for each sex/age class by comparing early captures (May – July) with late captures (August – October) at Little Creek.

For hatchling captures, where more than one hatchling was sighted at the same time and within 0.5 m of another hatchling, only the data from the first hatchling captured was included for analysis. Excluding non-independent captures reduced the total sample size from 158 to 142 by 16 hatchlings (2 from the AT site, 14 from the Little Creek site).

All data were analyzed using the SAS System 8.2 (2001) and JMP 4 (2001). An alpha level of $P < 0.05$ was used to determine statistical significance.

RESULTS

Landscape-level Habitat Variables

Of the landscape-level habitat variables, aspect and forest type distinguished lizard-centered from random sites (Table 1.2). Comparisons among study areas showed that only elevation differed between areas (Table 1.3). None of the landscape-level variables distinguished between adult/juvenile and hatchling classes (Table 1.4). Over 88% of lizard-centered sites had an aspect with a primarily southern component (east-southeast to west-southwest), while 73% of random sites had such aspects. Ninety-nine percent of lizard-centered sites were located in mixed forest habitat, whereas 92% of random sites were in mixed forest habitat. Neither overstory nor understory tree species differentiated lizard-centered sites from random sites

(Appendix C). At lizard-centered and random sites, the dominant trees providing overstory cover were largely oaks, with chestnut oak (*Quercus prinus*) and scarlet oak (*Quercus coccinea*) the most common. Shortleaf pine (*Pinus echinata*) and black locust (*Robinia pseudoacacia*) were also common at only lizard-centered sites, whereas sourwood (*Oxydendrum aculate*) occurred more commonly at random sites than at lizard-centered sites. The understory tree species at lizard-centered sites was primarily Virginia pine (*Pinus virginiana*). The understory tree species at random were mostly Virginia pine and red maple (*Acer rubrum*).

Elevation did not differentiate lizard-centered sites from random sites. Fewer than 4% of lizard captures were at elevations below 490 m or above 850 m, though transects were searched from 418 m to 1025 m in elevation (Table 1.5). Fifty-five percent of lizards were found between 700 m and 800 m in elevation. Percent survey effort was highest (32%) between 600 m and 700 m, where over 4000 m of transect were surveyed.

Site-Level Habitat Variables: Comparisons of Hatchling Data

For hatchlings, habitat characteristics differed between lizard-centered sites and random sites at all three study areas (Table 1.6). Of the 14 site-level measurements, four variables at the AT study area, seven at the Wake Forest study area, and four at the Little Creek study area differed between lizard-centered sites and random sites. No one variable differentiated lizard-centered sites from random sites at all three study areas, although temperature at perch height, number of rocks, % CWD, % bare ground, and % litter differentiated lizard-centered sites from random sites at two study areas. At two of the three study areas, temperature at perch height, number of rocks, % bare ground, and % CWD were greater at lizard-centered sites than at random sites, and percent litter was much lower at lizard-centered sites than at random sites.

Habitat characteristics of hatchling-centered sites differed among all three study areas only for the number of rocks and number of downed trees (Table 1.7). The AT and Wake Forest study areas were more different from each other than either was from the Little Creek area. I always found hatchlings on or very near areas of bare soil having little or no canopy cover. At the AT study area, hatchlings were found only in open areas surrounding the bare soil of the AT, and at Wake Forest, they were found only within the forest openings at the old sawmill and homesite dump. At Little Creek, hatchlings were found on both erect and downed fence posts directly adjacent to a wide bare-soil driveway and on downed trees located between an ATV trail of dirt and rock and a grassy, backyard clearing.

Site-level Habitat Variables: Little Creek Data

Habitat characteristics for adults and juveniles differed seasonally for only two of fourteen variables measured (Appendix D). Temperature at perch height and basal area were higher in the 'late' season. For all classes combined, 4 of 14 habitat variables differed between lizard-centered and random sites (Table 1.8). Temperature at perch height, number of rocks, % bare ground, and % CWD were greater at lizard-centered sites than at random sites. Of 76 lizards captured at the Little Creek study area, 57% were found perching on downed trees, 21% on the ground, 8% on trees, 8% on fence posts, and 3% on rocks. No correlations were significant ($\rho > 0.7$) between the fourteen site-level habitat variables measured, though the strongest correlation was between % bare ground and % litter ($\rho = -0.686$) (Appendix E).

Habitat preferences differed among all lizard classes - adult females, adult males, juveniles, and hatchlings - for 6 of 13 variables (Table 1.9). Hatchling habitat preferences differed from all other classes for these six variables (Appendix F). In general, hatchling and adult/juvenile lizards selected different microhabitats. Hatchlings were associated with much lower % litter and basal area than adults and juveniles, and much greater % bare ground and % grass. Adults and juveniles were found in and adjacent to large and small forest openings, near dirt trails through the forest, and in the forest bordering these open areas. In comparisons of lizard-centered and random sites for adults and juveniles combined, number of rocks and %CWD differentiated adult/juvenile-centered sites from random sites (Table 1.10). Number of rocks and % CWD were both higher at adult/juvenile-centered sites than at random sites.

Lizards were not found where understory and/or shrub cover were dense. A thick understory is unlikely the cause of any difficulties I might have had sighting lizards in dense vegetation. When approached, lizards generally remained motionless. On closer approach (≤3 m), lizards ran up, down, or across their perch object, which they did quite noisily. No lizards were seen or heard in areas of closed-canopy forest.

DISCUSSION

Landscape-level Habitat Preferences

Landscape-level variables (with the exception of elevation) differentiated lizard-centered sites from random sites, but did not differentiate adult/juvenile from hatchling habitat preferences. All classes of eastern fence lizards were associated with southerly aspects, mixed forest type, and elevations between 500 m and 800 m. Interpretation of these landscape-level associations is, to some extent, confounded by initial study area selection and variable correlations. Therefore, I will address these broader issues within the context of the landscape-level variables that I measured.

Aspect differentiated lizard-centered sites from random sites. Southwestern Virginia is in the “ridge and valley” physiographic region and is characterized by long linear ridges separated by linear valleys (Bailey 1999). All three study areas were located on the generally southeastern face of a major ridge system of the Appalachian Mountains: Brush Mountain in Montgomery County, North Mountain in Craig County, and Big Walker Mountain in Bland County. To what extent then, is the association of fence lizards with southerly aspects due to initial study area selection and to what extent is it due to an actual preference for this aspect? Only one lizard was located on a north-facing aspect. This particular lizard was found at the AT study area on a downed tree situated just over the crest (on the north side) of a ridge. Thirty-seven percent of random sites at the AT study area were located on the northern face of that ridge. None of the random-site data collections, nor the alternating transect arm surveys that took me to the north side of the ridge (approximately 250 m), resulted in lizard sightings. Over all three study areas, more than 12% of random sites had northerly aspects. Despite the time spent surveying transects for lizards and taking habitat measurements on northerly aspects, all but one of 158 lizards were captured at locations with southerly aspects, supporting fence lizard ‘preference’ for southerly aspects.

A second issue concerning the landscape-level variable aspect is its level of association with forest type (Thomas and Anderson 1993, Rubino and McCarthy 2003). Chestnut oak and Virginia pine were the most numerous overstory and understory tree species, respectively, on both lizard-centered and random sites at all three study areas (Appendix C). Chestnut oak is a dry-upland species, occurring primarily on southern aspects when growing on upper elevations of mountain ridges (Whitaker 1956, Eyre 1980, Golden 1981). A common associate species for the chestnut oak in the Appalachian Mountains is the Virginia pine. Virginia pine is a pioneer species that occurs on drier ridges and mountainous slopes (Whitaker 1956, Eyre 1980). These two species form a major portion of the 'mixed' forest type in which fence lizards were almost always found over the course of my study. At the AT study area, all of the random sites with northerly aspects were of a 'mixed' forest type and were also predominately canopied by chestnut oak and Virginia pine. Therefore, the differences in forest type and overstory tree species between northerly and southerly aspects on the AT study area indicate that aspect and forest type are not confounded in my study.

The association between fence lizards, southerly aspect, and mixed forest type is likely the result of the species' thermal requirements. Microhabitat that affords lizards the best opportunities for regulating body temperatures includes both sun and shade (Adolph 1990). Mixed forest provides lizards with both canopy openings for basking and areas of thicker cover for predator avoidance. Most of the overstory trees at lizard-centered sites at the Wake Forest and the AT study areas were "pioneer" species, those that are the first to populate a forest opening. Random sites were generally populated with species associated with a later successional stage. Very few lizards were found in thicker forests surrounding clearings, roads, and trails (Figures 1.3 – 1.5). Southern aspects provide lizards the longest daily basking times, which are important for maintaining their preferred body temperature, at which locomotion, prey digestion, etc. are most efficient (Angilletta 2001*a*, Hertz 1992, Pinch and Claussen 2003). Moreover, southerly aspects have warmer soils than northerly aspects, which facilitate egg development (Warner and Andrews 2002*b*).

The third issue concerning landscape-level variables is the elevational distribution of the eastern fence lizard. In my study, elevation did not differentiate lizard-centered sites from random sites. Elevation ranged from 418 m to 1,025 m over my three study areas, although lizards were not found above 888 m. I believe the elevational distribution of lizards that I observed was due to forest features and land-use, rather than elevation per se. The highest elevation surveyed was near the top of the ridge at the Little Creek study area, where the canopy was closed and the understory and shrub cover dense. The lowest elevation surveyed at the Little Creek study area was 502 m, below which were a mowed field, a stream, and a paved road. The lowest elevation surveyed, from all three study areas, was at the AT study area. Below this elevation was a dirt road, approximately a meter or so above Trout Creek. Even at the Wake Forest study area, which had neither the highest or lowest elevations surveyed, the forest surrounding the study area was extremely dense. Understory tree/shrub density and land-use, not elevation, appear to be primary features determining ‘suitable’ fence lizard habitat at my study areas.

Moreover, fence lizards are found in almost every county in Virginia, including two barrier islands, though populations in southwestern Virginia are widely scattered (Mitchell and Reay 1999). Fence lizards are found at nearly sea level in Accomack County and in higher elevations in the mountainous counties of Highland, Bland, Smyth, Craig, Wise, Giles, and Scott (Virginia Fish and Wildlife Information Service 2006). Individuals are often seen at Dragon’s Tooth, in Craig County, Virginia, at an elevation of 930 m. In North Carolina, the species has been recorded as high as 1,554 m (Palmer and Braswell 1995). In West Virginia, fence lizards have been found at elevations from 91 m to 975 m (T. K. Pauley, Marshall University, personal communication). Thus, the apparent elevational limits to lizard captures at my study areas correspond more to changes in aspect or forest type than to the actual elevational limits of the species.

Site-level Habitat Preferences

Comparisons among sex/age classes indicated that adults and juveniles had similar habitat preferences, and that their preferences were distinct from those of hatchlings. Adults and juveniles were found at sites with denser canopy cover, more large trees, and more litter than hatchlings. Hatchlings were found at sites having greater slope and higher percentage of bare ground than adults and juveniles. Additionally, hatchling locations had less canopy cover and much less litter cover than adult/juvenile locations. Comparisons between lizard-centered sites and random sites indicated differences and similarities between the habitat preferences of adults/juveniles and hatchlings. Sites centered on adults and juveniles had more rocks and coarse woody debris than random sites. Sites centered on hatchlings had more rocks, more coarse woody debris, and more bare ground than random sites. Fence lizards (all classes combined) were associated with greater temperature at perch height, greater number of rocks, greater % bare ground, greater % CWD, and lower basal area than conditions at random sites.

Perch sites are an important component of fence lizard habitat. Both hatchling and adult/juvenile classes were associated with rocks and coarse woody debris, which act as hiding cover and basking sites (Grover 1996, Zani 2001). Where hatchlings were also strongly associated with bare ground, this habitat feature was used as a perch site by almost 17% of the individuals of this class. Over half of all lizards captured used downed trees as perches. *S. undulatus* uses dead trees, both downed and standing, more frequently than live trees despite the greater availability of live trees (James and Mcloskey 2003).

The distinctive habitat preferences of hatchlings are a sub-set of those preferences for the population as a whole. Generally, hatchlings were found in or near areas without canopy cover and on or adjacent to steeply-cut banks of shale or other loose, bare substrate. The association of hatchlings with bare substrates is, in part, due to female oviposition requirements. Females migrate from forested areas to select exposed sites in which to dig nests, and do so in loose soil (Andrews and Rose 1994, Qualls and Andrews 1999, Angilletta 2001*b*). Hatchling *S. undulatus* remain near nesting areas for several months after hatching (Warner and Andrews *2002a*). Massot et al. (2003) found that western fence lizard (*Sceloporus occidentalis*) hatchlings also remained near their hatching sites for more than one month. Hatchling fence lizards remain near their hatching sites most likely because of the differences in habitat characteristics between hatching sites and the surrounding areas. Hatching sites are more open, offering greater solar penetration (for egg development and thermoregulation by hatchlings), while the surrounding areas may be forested, with varying degrees of canopy cover. Forest thus acts as a natural boundary for hatchling dispersal (Warner and Andrews 2002*b*, Massot et al. 2003).

Implications for Conservation

This study offers two broad implications for studies of habitat preference. First, pairing occupied and random sites allows for use versus availability comparisons, which offer a much clearer picture of the actual habitat features preferred by individuals (Ripple et al. 1997, Eichler and Whiting 2004, Giese and Cuthbert 2005, Row and Blouin-Demers 2006). Analyses of only occupied (presence-only) sites have distinct disadvantages in the interpretation and prediction of habitat preference (Brotons, et al. 2004, Hirzel et al. 2006, Pearce and Boyce 2006). Second, this approach facilitates assessment of habitat preferences of all sex/age classes (Canon and Bryant 1997, Mallet et al. 2000, Reaney and Whiting 2003). Information about differences in habitat preferences among classes can greatly enhance management efforts for a species. For example, finding adult and juvenile eastern fence lizards does not guarantee finding hatchlings, whose habitat preferences are a distinct sub-set of those of the species as a whole. Effective management of species with patchy distributions entails strict attention to class differences in habitat requirements.

Management within the constraints of the landscape- and site-level habitat preferences of the adult/juvenile and hatchling classes of eastern fence lizard would dictate that southerly-facing forest openings be a part of management plans. The infrequent distribution of habitats having 1) a southerly exposure, 2) open areas within or adjacent to mixed forest 2) bare ground, 3) basking sites, and 4) hiding cover can lead to the patchy distribution of species dependent on such areas. Black rat snakes (*Elaphe o. obsoleta*), northern black racers (*Coluber c. constrictor*), five-lined skinks (*Eumeces fasciatus*), and eastern box turtles (*Terrapene carolinensis*) were also found on the three study areas. These are examples of other reptile species that occupy habitats with a southerly aspect and mixed forest type, including basking sites/hiding cover, for at least some portion of the year. Species that depend on habitat that is patchily-distributed on either a site-level or landscape-level scale, or both, will be patchily-distributed at one or both scales themselves. Habitat preference studies for such species, as well as for those species more uniformly distributed across a landscape, should incorporate a pairing of occupied and random sites (use versus availability), and management efforts should focus on maintaining/creating appropriate habitat for all sex/age classes.

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TABLE 1.1. Habitat variables measured and equipment and processes used in taking field measurements. Basal area determinations were based on the Noon (1980) tree size class midpoints modified from James and Shugart (1970). The Braun-Blanquet cover abundance scale, modified from Mueller-Dombois and Ellenburg (1974) and Daubenmire (1959), was used to determine percentage cover class midpoints.

Habitat variables	Measurement taken at:	Equipment/Process
Landscape-level		
Aspect	center of lizard/random site	Compass
Elevation	"	Attribute layer of Digital Ortho Quarter Quads (DOQQ) aerial photography images
Forest type	"	Deciduous, coniferous, mixed
Site-level		
Slope	"	Clinometer
Percent canopy cover	"	Concave spherical densiometer
Canopy cover species	"	Identify
Perch type	"	Rock, log, tree, fence, building, …
Air temperature at perch height	"	Thermometer
Number of rocks > 10 cm diameter	circular plot (5.64 m radius)	Count of rocks of a size useful for basking
Number of downed trees > 10 cm diameter	"	Count of downed trees of a size useful for basking
Basal area	"	Counts within dbh classes
% Bare ground, % Grass, % Rock, % Fern, and % Litter	quadrats (5 sub-quadrats averaged)	Estimate percent cover of each

TABLE 1.1. Continued.

Habitat variables	Measurement taken at:	Equipment/Process
% Forb	"	Estimate percent cover of forbs < 1 m tall
% Shrub	"	Estimate percent cover of shrubs from 1 m -3 m tall
% Coarse woody debris	"	Estimate percent cover of woody debris > 2 cm diameter

TABLE 1.2. Landscape-level habitat variables at lizard-centered and random sites for all lizard classes combined, at all three study areas. P-values are from Wilcoxon Signed-Rank (for elevation only) and Chi-square tests.

Habitat variable	Lizard-centered sites (n=142)	Random sites (n=142)	Test statistic	P-value
Elevation range (m) (Mean ± S. E) (Median)	418-888 666.8 ± 9.3 (708)	467-888 665.1 ± 8.9 (708)	W+ = 225.5	0.739
Aspect	98% ESE to WSW	83% ESE to WSW	χ^2 =21.1	0 .001
Forest type	99% mixed	92% mixed; 6% pasture	χ^2 = 18.4	0.001

TABLE 1.3. Comparison of landscape-level habitat variables for hatchlings at all three study areas. Mean ± S.E. (Median) are reported for elevation. P-values are from Kruskal-Wallis (elevation only) and Chi-square tests. [All pairwise comparisons of elevation among the study areas were significant at $p < 0.0001$, using Wilcoxon Rank Sum tests (AT vs. Wake Forest, U=1498; AT vs. Little Creek, U=852; Little Creek vs. Wake Forest, U= 686).]

Habitat variable	AT (n=38)	Wake Forest (n=28)	Little Creek (n=15)	Test statistic	P-value
Elevation	507.1 ± 3.5 (510)	672.1 ± 8.2 (649)	718.4 ± 16.8 (737)	H= 53.7	< 0.0001
Aspect	97% ESE to WSW	100% ESE to WSW	93% ESE to WSW	$\chi^2 = 4.9$	0.294
Forest type	100% mixed	96% mixed	100% mixed	$\chi^2 = 2.1$	0.342

TABLE 1.4. Comparison of landscape-level habitat variables for adult/juvenile and hatchling classes at the Little Creek study area. P-values are from Wilcoxon Rank Sum (for elevation only) and Chi-square tests.

Habitat variable	Adults/Juveniles (n=61)	Hatchlings (n=15)	Test statistic	P-value
Elevation range (m) (mean ± S.E.) (median)	688-888 (753.6 ± 5.2) (746)	502-763 (718.4 ± 16.8) (737)	U = 442	0.077
Aspect	88% ESE to WSW	93% ESE to WSW	$\chi^2 = 0.947$	0.623
Forest type	100% mixed	100% mixed	$\chi^2 = 0.00$	1.000

TABLE 1.5. Capture rate and percent survey effort for lizards caught (n=158) over the elevational distribution at the AT, Wake Forest, and Little Creek study areas. Capture rate equals # lizard captures per 100 m surveyed. Percentage survey effort equals the proportion of transect meters surveyed at all three study areas over each 100 m of elevation to the total number of transect meters surveyed over the course of this study.

Elevation (m)	401-500	501-600	601-700	701-800	801-900	901-1000	1001-1100
# Lizard captures	13	29	21	87	8	0	0
Capture rate	1.2	2.9	0.5	2.6	0.5	0	0
# Transect meters surveyed	1,111	989	4,033	3,289	1,461	1,461	395
% Survey effort	9	8	32	26	11	11	3

TABLE 1.6. Comparisons of site-level habitat variables, for hatchlings only, at the AT, Wake Forest, and Little Creek study areas. Percent coarse woody debris is abbreviated as % CWD. Median (Range) is reported. P-values are from Wilcoxon Signed-Rank tests. Significant P-values are in **bold** typeface. Temperature at perch height is abbreviated as TPH.

	AT (n=38)			Wake Forest (n=28)			Little Creek (n=15)		
Habitat variable	Lizard-centered	Random	W+, P-value	Lizard-centered	Random	W+, P-value	Lizard-centered	Random	W+, P-value
Slope	22 (9-36)	27 (8-38)	212.0, **0.001**	7 (0-17)	9 (1-24)	54.5, 0.220	15 (4-41)	13 (3-39)	-34.5, 0.838
% Canopy cover	69 (19-94)	80 (14-98)	132.5, 0.064	49 (1-100)	99 (1-100)	157.0, **0.000**	67 (51-96)	94 (1-99)	229.5, 0.219
TPH	24 (2-30)	23 (15-29)	-130.5, 0.057	23 (16-32)	20 (13-30)	-202.0, **0.000**	24 (18-30)	21 (17-31)	-691.0, **0.000**
# Rocks	35 (2-100)	21 (0-100)	-146.5, **0.039**	0 (0-55)	0 (0-36)	-17.5, 0.337	20 (0-41)	3 (0-27)	-437.5, **0.013**
# Downed trees	5 (2-11)	4 (0-11)	-140.5, **0.019**	1 (0-5)	2 (0-7)	27.5, 0.411	3 (0-5)	2 (0-8)	-232.5, 0.094
Basal area	15 (1-45)	15 (2-40)	-8.0, 0.913	3 (1-20)	17 (0-39)	143.0, **0.000**	3 (1- 32)	7 (0-53)	337.0, 0.075
% Bare ground	2 (0-67)	3 (0-58)	-14.5, 0.760	8 (0-93)	1 (0-48)	-125.0, **0.001**	17 (2-53)	0 (0-81)	-269.0, **0.041**

TABLE 1.6. Continued.

	AT (n=38)			Wake Forest (n=28)			Little Creek (n=15)		
Habitat variable	Lizard-centered	Random	W+, P-value	Lizard-centered	Random	W+, P-value	Lizard-centered	Random	W+, P-value
% Grass	2 (0-15)	3 (0-10)	-54.5, 0.337	3 (0-90)	0 (0-15)	-100.5, **0.001**	9 (1-72)	1 (0-98)	34.5, 0.719
% Rock	5 (1-43)	3 (0-72)	-73.0, 0.237	1 (0-90)	0 (0-98)	-21.5, 0.363	3 (0-43)	1 (0-98)	-150.0, 0.261
% Fern	0 (0-0)	0 (0-1)	1.5, 0.500	0 (0-0)	0 (0-1)	0.5, 1.000	0 (0-0)	0 (0-1)	5.0, 0.516
% Litter	58 (13-98)	63 (8-98)	74.0, 0.308	5 (0-90)	93 (0-98)	170.0, **0.000**	3 (<1-20)	38 (0-98)	40.0, **0.021**
% Forb	10 (1-63)	20 (1-76)	84.0, 0.228	5 (1-63)	3 (0-98)	-25.0, 0.486	8 (2-53)	4 (2-98)	-253.0, 0.123
% Shrub	1 (0-13)	0 (0-38)	-29.5, 0.589	0 (0-10)	0 (0-8)	6.5, 0.591	0 (0-2)	0 (0-67)	-107.0, 0.106
% CWD	10 (2-38)	5 (1-63)	-165.0, **0.015**	8 (1-98)	2 (0-13)	170.0, **0.000**	8 (0-24)	1 (0-58)	83.0, 0.546

TABLE 1.7. Comparisons of site-level habitat variables at lizard-centered sites for hatchlings at the Little Creek (n=15), AT (n=38), and Wake Forest (n=28) study areas. P-values are from Wilcoxon Rank Sum tests between pairs of study areas. Study areas are abbreviated as LC, AT, and WF. Percentage coarse woody debris is abbreviated as % CWD. Significant P-values are in **bold** typeface.

	LC vs. AT		LC vs. WF		AT vs. WF	
Habitat variables	Test statistic (U)	P-values	Test statistic (U)	P-values	Test statistic (U)	P-values
Slope	378.5	0.600	484.0	**0.001**	444.5	**0.001**
Temp. at perch height	403.5	0.984	353.0	0.567	880.0	0.456
% Canopy cover	430.0	0.629	439.0	**0.006**	699.0	**0.002**
# Rocks	274.0	**0.010**	457.0	**0.001**	505.5	**0.001**
# Downed trees	203.5	**0.001**	407.5	**0.043**	492.5	**0.001**
Basal area	262.0	**0.005**	314.0	0.692	570.0	**0.001**
% Bare ground	558.5	**0.002**	387.0	0.149	1046.0	0.161
% Grass	559.5	**0.002**	393.0	0.110	1064.5	0.100
% Fern	405.0	1.00	330.0	1.00	938.0	1.00
% Forb	350.5	0.284	378.0	0.222	751.0	**0.015**
% Shrub	318.0	0.068	335.5	0.872	772.0	**0.018**
% Rock	373	0.531	426.0	**0.013**	676.5	**0.001**
% CWD	328.5	0.130	306.5	0.556	868.5	0.368
% Litter	138.5	**0.001**	295.5	0.383	535.5	**0.001**

TABLE 1.8. Comparisons of site-level habitat variables at lizard-centered sites and random sites, for all age classes combined, at the Little Creek study area. P-values are from Wilcoxon Signed-Rank tests. Percentage coarse woody debris is abbreviated as % CWD. Mean ± S.E. (Median) is reported. Significant P-values are in **bold** typeface.

Habitat variables	Lizard-centered (n=76)	Random (n=76)	Test statistic (W+)	P-value
Slope	16.0 ± 0.9 (15)	14.2 ± 0.9 (14)	-34.5	0.838
Temp. at perch height	24.7 ± 0.4 (25)	23.8 ± 0.3 (23)	-691.0	**0.001**
% Canopy cover	80.9 ± 1.6 (84)	77.4 ± 3.4 (95)	229.5	0.219
# Rocks	19.2 ± 1.9 (12)	14.6 ± 1.8 (9)	-437.5	**0.013**
# Downed trees	3.5 ± 0.3 (3)	2.6 ± 0.3 (2)	-232.5	0.094
Basal area	14.9 ± 1.5 (13)	19.0 ± 1.7 (17)	337.0	0.075
% Bare ground	11.2 ± 2.0 (2)	2.0 ± .4 (0)	-269.0	**0.041**
% Grass	17.1 ± 2.8 (2)	5.7 ± 0.8 (0)	34.5	0.719
% Fern	0.01 ± 0.0 (0)	0.04 ± 0.0 (0)	5.0	0.516
% Forb	16.5 ± 1.7 (13)	13.3 ± 1.6 (8)	-253.0	0.123
% Shrub	0.5 ± 0.2 (0)	3.0 ± 1.1 (0)	107.0	0.106
% Rock	6.5 ± 1.1 (2)	6.3 ± 1.4 (1)	-150.0	0.261
% CWD	6.9 ± 0.7 (4)	2.8 ± 0.3 (3)	-707	**0.001**
% Litter	48.4 ± 4.5 (58)	51.5 ± 4.5 (50)	83.0	0.546

TABLE 1.9. Comparisons of site-level habitat variables at lizard-centered sites for adult females, adult males, juveniles, and hatchlings at the Little Creek study area. Percentage coarse woody debris is abbreviated as % CWD. Mean ± S.E. (Median) is reported. P-values are from Kruskal-Wallis tests. Significant P-values are in **bold** typeface.

Habitat variables	Adult Females (n=26)	Adult Males (n=16)	Juveniles (n=19)	Hatchlings (n=15)	Test statistic (H)	P-value
Slope	14.9 ± 1.5 (14)	13.9 ± 2.1 (14)	13.2 ± 1.8 (14)	19.0 ± 2.8 (15)	3.29	0.349
% Canopy cover	84.7 ± 3.1 (91)	78.7 ± 6.3 (86)	87.2 ± 2.8 (93)	68.4 ± 3.4 (65)	11.38	**0.010**
# Rocks	27.1 ± 3.8 (21)	11.9 ± 3.1 (10)	27.5 ± 6.7 (17)	21.2 ± 3.6 (21)	7.10	0.069
# Downed trees	4.5 ± 0.5 (4)	3.9 ± 0.9 (3)	4.2 ± 0.9 (4)	2.5 ± 0.4 (3)	5.26	0.154
Basal area	18.5 ± 2.8 (19)	17.8 ± 3.4 (17)	18.1 ± 2.7 (20)	7.0 ± 2.6 (1)	10.78	**0.013**
% Bare ground	4.8 ± 2.3 (1)	12.4 ± 5.4 (0)	6.8 ± 3.7 (1)	24.0 ± 5.1 (15)	18.44	**0.001**
% Grass	2.4 ± 1.3 (0)	11.0 ± 6.4 (1)	9.7 ± 4.2 (0)	19.2 ± 6.7 (8)	16.87	**0.001**
% Fern	0.1 ± 0.0 (0)	0.0 ± 0.0 (0)	0.0 ± 0.0 (0)	0.0 ± 0.0 (0)	3.82	0.282
% Forb	21.6 ± 3.0 (17)	14.7 ± 3.7 (13)	18.5 ± 4.7 (13)	16.2 ± 4.0 (8)	3.22	0.359
% Shrub	1.3 ± 0.7 (0)	0.1 ± 0.1 (0)	0.3 ± 0.2 (0)	0.3 ± 0.1 (0)	3.28	0.351
% Rock	3.8 ± 1.4 (2)	1.5 ± 0.4 (1)	2.6 ± 1.0 (2)	8.1 ± 2.9 (3)	10.55	**0.014**
% CWD	7.7 ± 1.3 (6)	9.1 ± 3.4 (4)	10.5 ± 2.2 (8)	8.9 ± 2.1 (8)	3.47	0.325
% Litter	73.3 ± 6.0 (88)	66.2 ± 10.2 (90)	64.6 ± 8.6 (85)	8.3 ± 3.3 (3)	25.15	**0.001**

TABLE 1.10. Comparisons of site-level habitat variables at lizard-centered sites and random sites, for adults and juveniles combined, at the Little Creek study area. Percentage coarse woody debris is abbreviated as % CWD. Mean ± S. E. (Median) is reported. P-values are from Wilcoxon Signed-Rank tests. Significant P-values are in **bold** typeface.

Habitat variables	Lizard-centered sites (n=61)	Random sites (n=61)	Test statistic (W+)	P-value
Slope	14.1± 1.0 (14)	14.5 ± 0.8 (15)	49.0	0.669
% Canopy cover	83.9± 2.3 (91)	83.9 ± 3.4 (96)	193.5	0.135
# Rocks	22.4± 2.2 (17)	15.4 ± 1.9 (11)	-252.5	**0.044**
# Downed trees	4.2 ± 0.4 (4)	3.6 ± 0.5 (3)	-168.0	0.065
Basal area	18.2 ± 1.7 (19)	21.6 ± 1.9 (20)	179.0	0.179
% Bare ground	7.4 ± 2.1 (1)	2.9 ± 1.0 (0)	-33.5	0.691
% Grass	6.9 ± 2.2 (0)	14.7 ± 3.8 (0)	49.0	0.345
% Fern	0.0 ± 0.0 (0)	0.1 ± 0.0 (0)	3.0	0.656
% Forb	18.9 ± 2.2 (13)	16.7 ± 2.4 (8)	-156.0	0.157
% Shrub	0.7 ± 0.3 (0)	2.5 ± 1.1 (0)	51.0	0.276
% Rock	2.8 ± 0.7 (2)	4.1 ± 1.5 (1)	25.0	0.781
% CWD	9.0 ± 1.2 (5)	3.9 ± 0.8 (3)	-485.0	**0.001**
% Litter	68.7 ± 4.5 (88)	63.2 ± 5.0 (88)	-58.0	0.519

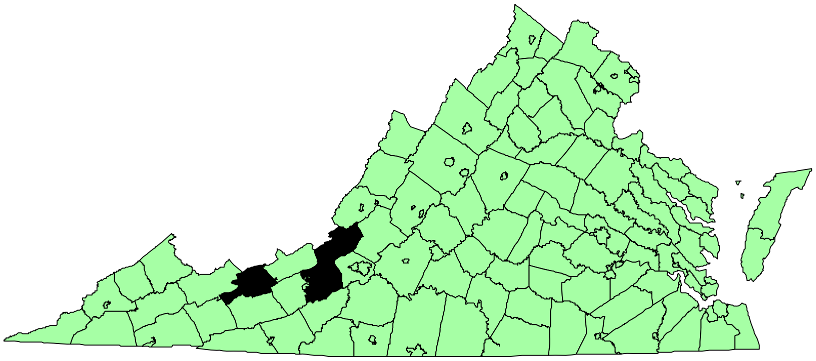

FIGURE 1.1. In Bland, Montgomery, and Craig counties, fence lizards were captured from May to October, 2003. Image derived from TIGER/Line files (U.S. Census Bureau 2000).

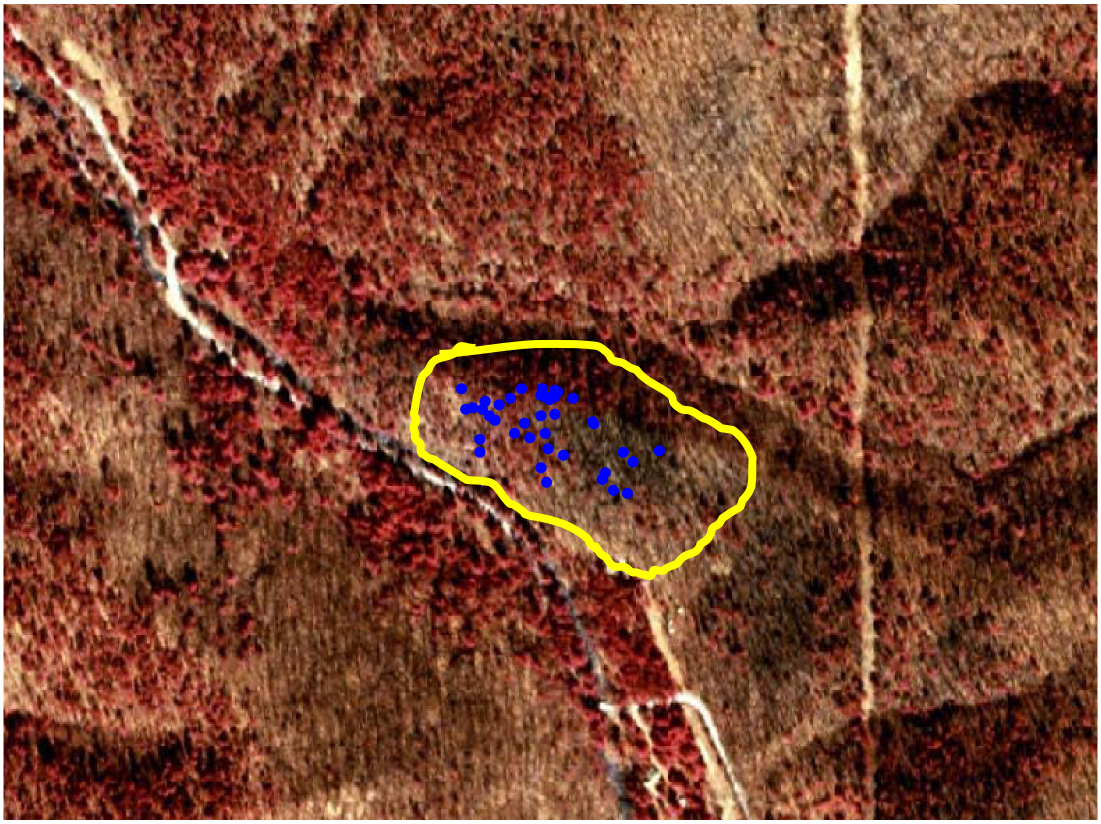

FIGURE 1.2. AT study area showing a blue dot for each hatchling location (Virginia Economic Development Partnership 1999). The yellow line encompasses the area surveyed (approximately 200 m x 400 m). Lizards were found along the Appalachian Trail from the dirt road up to the ridge line.

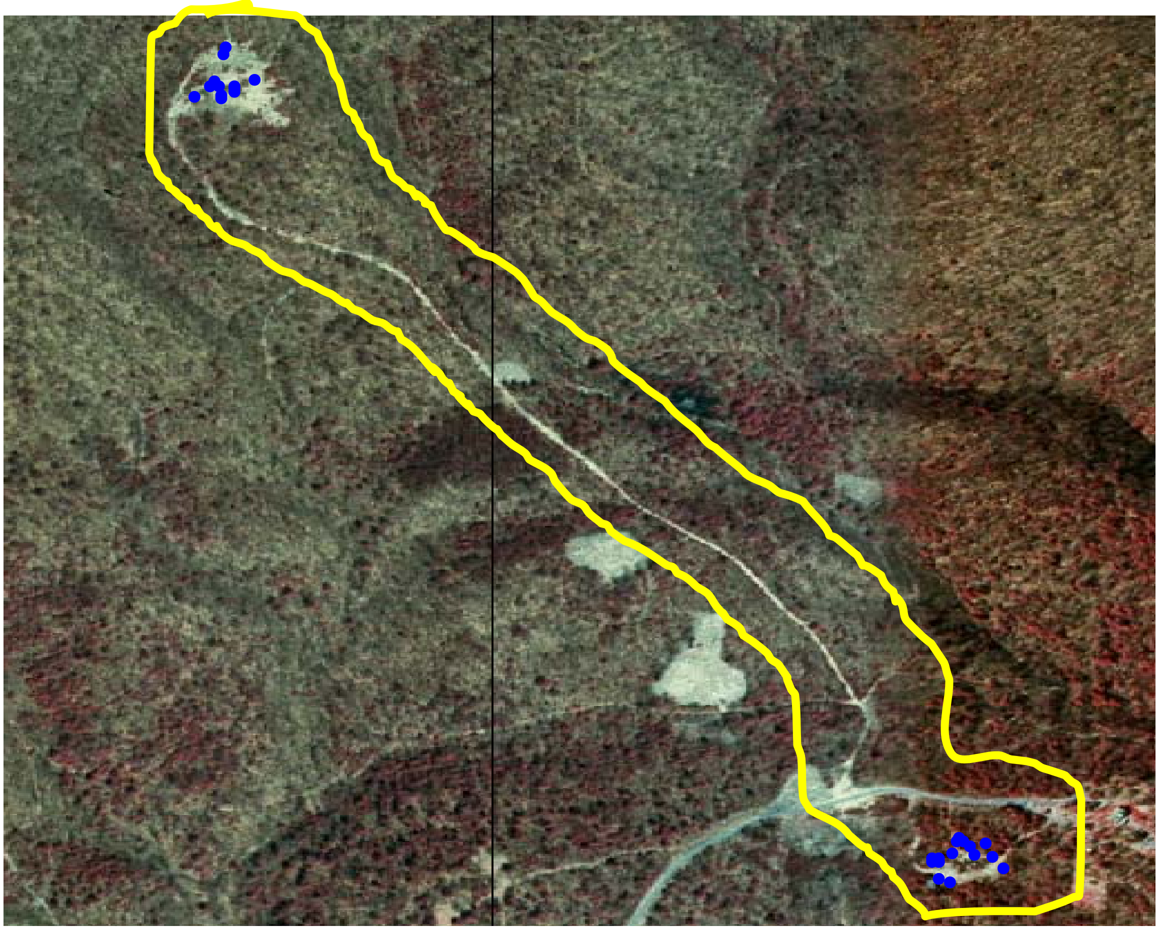

FIGURE 1.3. Wake Forest study area showing a blue dot for each hatchling location (Virginia Economic Development Partnership 1999). The yellow line encompasses the area surveyed (approximately 950 m x 150 m). Areas of dot (lizard) concentration represent the homesite dump in the lower right corner and the old sawmill in the upper left corner.

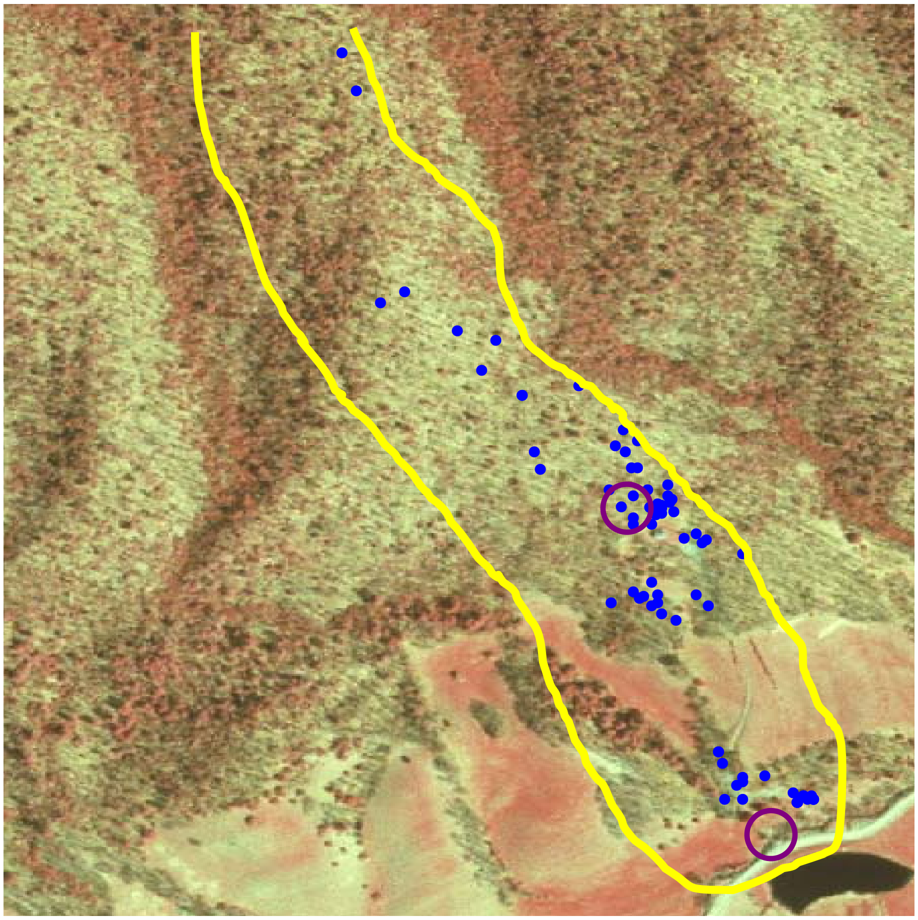

FIGURE 1.4. Little Creek study area showing a blue dot for each lizard located (Virginia Economic Development Partnership 1999). The yellow line encompasses the area surveyed (approximately 1700 m x 300 m). Lizards were found along a shale bank near the road and nearby or adjacent to a dirt trail ascending the mountain. Hatchling locations are circled in purple.

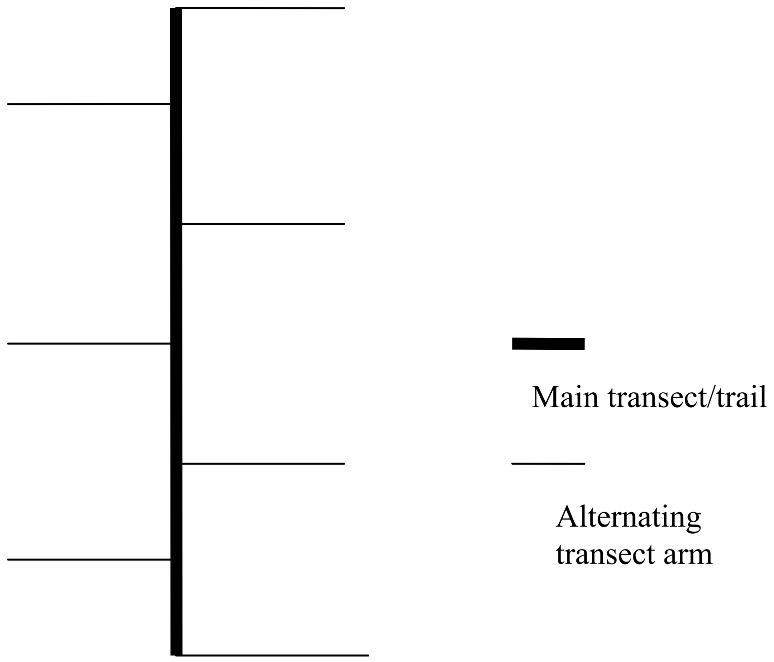

FIGURE 1.5. Schematic illustration of transect layout. Transect arms are 50 m long and are at 25 m intervals, alternating sides along the main transect/trail.

CHAPTER 2

Habitat Model Development and Testing for Eastern Fence Lizards, *Sceloporus undulatus,* in Southwestern Virginia

ABSTRACT

Managers can use models generated from logistic regression and Geographic Information Systems (GIS) in combination to efficiently define habitats and predict the locations of species. I incorporated these modeling techniques to predict the distribution of the eastern fence lizard, *Sceloporus undulatus*, in southwestern Virginia. I developed a GIS-based landscape-level model and site-level logistic regression models from field data collected in summer 2003. The GIS-based model included the variables aspect, elevation, and forest type. The best-fitting logistic regression model, as determined by Akaike's Information Criterion (AIC), for adults and juveniles included % coarse woody debris (CWD), while that for hatchlings included % CWD and number of rocks, and the 2nd best-fitting model included % CWD, number of rocks, and % litter. Surveys were conducted across six counties in southwestern Virginia at 15 GIS-predicted "suitable" study areas and at 15 GIS-predicted "unsuitable" study areas. Sixteen lizards were found at "suitable" study areas and one at "unsuitable" areas. The site-level model for adults/juveniles was tested using this survey data, while models for hatchlings were tested with independent field data collected in 2003 at two study areas. Though the best-fitting models for adults/juveniles and hatchlings were poor predictors of lizard occupancy, the second best-fitting hatchling model was a good predictor of hatchling occupancy over the test areas.

INTRODUCTION

The distribution of a species can be described geographically or as a function of the specific habitats utilized within some geographic area. Understanding the determinants of local distribution is of paramount importance where species management, including preservation, conservation, relocation, and reintroduction are of concern. Species with patchy distributions, at coarse and fine scales, may be difficult to manage because of their strict habitat requirements or habitat and/or population fragmentation or loss. Habitat models developed for such species can be instrumental in management efforts, allowing for efficient and accurate distribution predictions or habitat assessments. Models may be of little use to researchers or managers looking for an accurate and time-efficient means of locating a species or its ‘preferred’ habitat, unless tested on independent data (Gaudette and Stauffer 1988, Fielding and Bell 1997, Manel et al. 1999). Geographic Information System (GIS)-based modeling combined with multivariate statistical analyses (e.g. logistic regression) can be a powerful tool for creating accurate, predictive habitat or species distribution models, but only if models are evaluated with test data (Gibson et al. 2004, Yen et al. 2004, Garcia-Ripolles et al. 2005, Guthery et al. 2005).

Geographic Information Systems provide a means of storing, manipulating, and summarizing features of spatial (geographically-referenced) data. Landscape-level spatial data used in a GIS are composed of a geographic reference and an attribute. Spatial analysis is performed on the referenced data, resulting in the production of detailed, multi-layered maps that can be used to build predictive models. This technology can be tailored to efforts for determining habitat suitability, species distribution, the location and extent of habitat change, and for restoration efforts for threatened and endangered species (Fecske et al. 2002, Lauver et al. 2002, Li et al. 2002, Ray 2002 et al., Salem 2003). An accurate and complete GIS can assess conditions that exist at a particular location or find locations where certain conditions are met (Gibson et al. 2004, Garcia-Ripolles et al. 2005).

GIS-based mapping, a relatively new instrument for wildlife managers, has the versatility and power to make it a useful tool for assessing habitat characteristics (Danks and Klein 2002). Biologists must often base management decisions on scant empirical data. GIS-based models using little reference data can still allow for efficient assessment of the availability of suitable habitat and guide surveys for rare species or those with fragmented distributions (Schadt et al.

2002, Griffin et al. 2003, Yang et al. 2006). For a species with a wide, yet patchy distribution, like the eastern fence lizard, a GIS-based model can be valuable in efforts to locate potential suitable habitat and predict population locations.

Habitat modeling efforts often use logistic regression as a means to generate a set of candidate models. In logistic regression, a likelihood function describes the relationship between a dichotomous response variable (e.g. presence/absence) and a set of explanatory variables (e.g. habitat features). Akaike's Information Criterion (AIC) is an information-theoretic model selection criterion for choosing the model that "best" fits the reference data used to build the candidate models (Burnham and Anderson 1998). When using AIC with logistic regression, candidate models are ranked by AIC values. The lowest AIC value indicates the "best," most parsimonious model. Model selection using AIC makes inferences from the supporting data, but is not intended to describe or define reality (Burnham and Anderson 1998). Logistic regression and AIC can be used to model site-level features, and thus assist biologists in assessing the potential impacts of environmental changes and to develop necessary conservation measures (Smith and Ballinger 2001, Gibson et al. 2004, Johnson and Collinge 2004, Hashimoto et al. 2005, Alexander et al. 2006).

GIS-based mapping techniques used in conjunction with logistic regression provide a modern approach to habitat suitability assessment and are broadly applicable to species with patchy distributions (Olson et al. 2004). By integrating GIS technology with logistic regression modeling, suitable patches of habitat can be predicted and efficiently located once habitat data have been collected at a reference area. GIS-based models are commonly developed on landscape-level habitat features that do not take into account site-level characteristics, while logistic regression can be used to incorporate site-level features into a species-habit model (Garcia-Ripolles et al. 2005, Alexander et al. 2006).

The eastern fence lizard, *Sceloporus undulatus*, can serve as a model for multi-scale habitat modeling because of its patchy distribution. My objectives were (1) to develop a GIS-based model incorporating the landscape-level habitat variables differentiating paired lizard-centered and random sites, (2) to develop site-level logistic regression models using AIC for *S. undulatus* hatchling and adult/juvenile classes, based on analyses of site-level habitat variables differentiating lizard-centered sites from random sites, and (3) to test the landscape- and site-level models with field surveys of areas predicted to be "suitable" and "unsuitable" for fence lizard habitat. These objectives built upon a field study from the summer of 2003 where I (1) determined differential habitat preferences for adult/juvenile and hatchling classes, and (2) determined the landscape- and site-level habitat variables differentiating lizard-centered sites from random sites for hatchling and adult/juvenile lizard classes (Chapter 1).

MATERIALS AND METHODS

Subject and Study Areas

Sceloporus undulatus, the eastern fence lizard, is found throughout southwestern Virginia, although its landscape- and site-level distribution is patchy (Mitchell 1994, Mitchell and Reay 1999, Hager 2001). Fence lizards in southwestern Virginia are associated with southerly aspects, mixed forest type, rocks, bare ground, coarse woody debris, warm perch sites, and low basal area (Chapter 1). Adults and juveniles exhibit similar site-level habitat preferences, while habitat preferences of hatchlings are a subset of those exhibited by the species as a whole (Chapter 1). Hatchlings are found in or near open areas and most often on or adjacent to steeply-cut banks of shale or other loose, bare substrate. They are associated with less litter cover and lower basal area than adults and juveniles, and more bare ground and grass. The association of this species, particularly hatchlings, with bare substrates is likely due to female oviposition requirements and that hatchlings remain near their oviposition sites for several months (Warner and Andrews 2002).

Study areas were located in the ridge and valley physiographic province of southwestern Virginia, characterized by long linear ridges separated by narrow valleys. Ridges are composed primarily of sandstone and shale, with elevations ranging from 300 m valleys to 1372 m peaks (Virginia Ground Water Protection Steering Committee 2003). Forested regions are dominated by chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), Virginia pine (*Pinus virginiana*), red maple (*Acer rubrum*), and yellow poplar (*Liriodendron tulipifera*). The three study areas used for development of habitat models were located in Bland, Craig, and Montgomery counties (Chapter 1). Thirty study areas for habit model testing were located across Bland, Giles, Wythe, Craig, Pulaski, and Montgomery counties (Figure 2.1) (Appendix G). All study areas were located in forested terrain.

Sources of Data

Model Development Data

Data collection was described in Chapter 1. The landscape-level variables – aspect (southerly) and forest type (mixed) – differentiated lizard-centered sites from random sites for all age classes (Chapter 1 – Table 1.2). Ninety-eight percent of lizard-centered sites were southerly facing and 99% were of mixed forest type, while 83% of random sites were southerly facing and 92% were of mixed forest type. The site-level variables – % coarse woody debris (% CWD) and number of rocks – differentiated adult/juvenile-, and hatchling-centered sites from random sites; % bare ground and % litter further differentiated hatchling-centered sites from random sites (Chapter 1 – Tables 1.6, 1.10.; Table 2.1). Lizard-centered sites had higher % CWD and number of rocks than random sites, while hatchling-centered sites were also characterized by more bare ground and less litter than random sites.

Model Testing Data

In summer 2004, I worked with Ken Convery of the Conservation Management Institute, Virginia Polytechnic Institute and State University, to develop a GIS-based landscape-level model using the habitat variables that differentiated lizard-centered from random sites. The model was used to predict fence lizard habitat across six southwestern Virginia counties. Data on the landscape-level variables were stored in the GIS as raster data. U. S. Geological Survey (USGS) topographical maps served as the basis for landcover, topographical, and cultural features used in the GIS. Landscape-level variables were added as data layers (spatially- and attribute-referenced variable categories) into the GIS, forming a landscape-level model for "suitable" fence lizard habitat.

Landscape-level habitat variables (aspect, forest type, elevation) were incorporated as attribute layers into the GIS using ArcMap 8.0 software. The North American Datum (NAD) 1983 coordinate system was used to geographically reference areas of suitable habitat in the GIS. I identified "suitable' habitat as those areas with a mixed forest type (Figure 2.2), a southerly aspect from 90 degrees to 270 degrees (Figure 2.3), and an elevation between 500 m and 799 m (Figure 2.4). The upper and lower limits of the elevation range are artificial constraints resulting from a lack of substantial habitat to survey above 800 m or below 500 m. Elevation did not distinguish lizard-centered from random sites, but was nevertheless included in the GIS because of the nature of disturbance found across the mountainous areas of southwestern Virginia. [Low elevation areas are generally open-canopy valleys of grasslands, with housing and livestock grazing, while ridgelines often have thick, shrubby vegetation. Mid-elevations, where I found fence lizards, generally have experienced some human disturbance; closed canopies are often broken by dirt roads and trails, old logging sites, current forest management activities, and prescribed burns.] Together, the three attribute layers formed an integrated map of landscape-level habitat quality that could not be discerned by inspection of individual layers (Figure 2.5).

From the resulting predictive map, queries were developed to (1) determine suitable habitat areas at least 60 m X 60 m, within the six study counties and (2) determine forested areas of otherwise "unsuitable" habitat for fence lizards. I randomly chose 15 study areas out of 49 areas that the GIS predicted to be suitable fence lizard habitat based on optimum indices (0.7 - 1.0 on a scale from 0.0 - 1.0) for each attribute layer- forest type, aspect, and elevation (Table 2.2, Figure 2.6). Index values for each layer are then combined to arrive at a final index number- Final Index = forest type index X aspect index X elevation index- for an area. I also randomly chose 15 study areas out of the 75 locations that the GIS predicted to be unsuitable habitat, based on final indices values < 0.7.

Field surveys were conducted at each of the 30 study areas, from 24 June to 29 September 2004, to determine if fence lizards were present at model-predicted suitable areas more often than at randomly-located unsuitable areas. At the start of each survey, I chose the UTM coordinates that represented the southwestern corner of the area, such that the entire survey plot would fall within the area (deemed suitable or unsuitable habitat by the GIS. At each of the 30 study areas surveyed, I started in the southwest corner and walked a zig-zag pattern across a 60 m X 60 m plot. I made 11 crossings of each plot, with 5 m between crossings. Total search time was between one hour and one and a half hours, depending on terrain and slope. At study areas where lizards were found, habitat measurements were taken at the location of each lizard captured, following the same protocol as for summer 2003 surveys (Chapter 1). I recorded the age class of each lizard and measured the habitat variables forest type, aspect, elevation, slope, % litter, and % shrub. Habitat measurements were averaged for each study area. At study areas where no lizards were found, the same habitat measurements were made at the four corners of the plot and at the center, and then averaged.

Additional Model Testing Data

In late summer and autumn 2005, I revisited 10 suitable and 10 unsuitable study areas, randomly selected from the original 15 suitable and 15 unsuitable areas surveyed in 2004. At least two study areas were chosen from each county originally surveyed. I recorded number of rocks, % CWD, % bare ground, % litter, % grass, % forb, % shrub, and slope, following summer 2003 protocol (Chapter 1). I did not search for lizards during these surveys. I took the habitat measurements at the four corners and center of each study area, and averaged the measurements.

Data Analyses and Statistical Tests

Model Development

I used Spearman's Rho Correlation Coefficients to detect significant correlations ($\rho \geq 0.70$) among the site-level habitat variables differentiating lizard-centered sites from random sites, for adults/juvenile and hatchling classes (Table 2.1). None of these variables, for either class, were correlated (Appendix H.)

I used logistic regression to fit *a priori* models of uncorrelated site-level variables previously determined to define adult/juvenile and hatchling habitat preferences. I evaluated and ranked each set of models based on AICc, AICc differences (Δ_i), and Akaike weights (ω_i) (Burnham and Anderson 2002). AICc is bias-adjusted for small sample sizes. To better appreciate the explanatory power of the models, I included the null model (i.e. intercept only) with each set of candidate models. Models with the lowest AICc and highest Akaike weight are determined to be the models that best fit the data (Burnham and Anderson 2002).

Model Testing

I used a Fisher's Exact test to determine if the number of suitable study areas where lizards were captured differed from the number of unsuitable study areas where lizards were captured. The Fisher's Exact test is used in the analysis of categorical data where sample sizes are small.

Habitat measurements from the 2004 and 2005 surveys at 10 suitable study areas and 10 unsuitable study areas included three of the same site-level variables – % litter, % shrub, and slope. Paired comparisons of the 2004/2005 habitat measurements, using Wilcoxon Signed-Rank tests, showed no differences between years, at the same locations (Appendix I). Thus, further analyses using habitat measurements incorporated only the 2005 habitat data.

I used Wilcoxon Rank Sum and Chi-square tests to compare the habitat measurements from the 2005 surveys at 10 suitable and 10 unsuitable study areas. Wilcoxon Rank Sum tests were performed on all site-level variables and elevation, while Chi-square tests were performed on forest type and aspect.

I used a Kruskal-Wallis test to determine if % CWD differed among the 6 study areas where adult and juvenile lizards were found. I used Wilcoxon Rank Sum tests 1) to compare % CWD at suitable study areas where adult/juvenile lizards were found to suitable areas where lizards were not found and 2) to compare % CWD at suitable study areas with adult/juvenile lizards to all unsuitable study areas surveyed.

I used a Wilcoxon Rank Sum test to determine if % litter and number of rocks differed between the AT and Wake Forest study areas (at hatchling-centered sites) surveyed in 2003 (Chapter1). I used Wilcoxon Signed-Rank and Chi- square tests to determine if hatchling-centered sites and random sites differed at the AT and Wake Forest study areas, for all habitat variables measured in 2003. Wilcoxon Signed-Rank tests were performed on all site-level variables and elevation, while Chi-square tests were performed on forest type and aspect.

I used independent habitat data to test the best-fitting logistic regression models for each lizard class. To test the best-fitting adult/juvenile model, I used the data from the 2005 suitable and unsuitable study areas. To test the best-fitting and second best-fitting hatchling models, I used the data from the AT and Wake Forest study areas surveyed in 2003. For adult/juvenile and hatchling classes, I determined the probability of occurrence for lizards at each study area. For adults/juveniles, I then used Wilcoxon Rank Sum tests to 1) determine differences in prediction/occurrence probabilities between suitable and unsuitable study areas and 2) between study areas with lizards and unsuitable study areas without lizards. For the adult/juvenile class, I also used the lizard capture data in a confusion matrix to determine measures of classification accuracy – correct classification rate, false positive rate, false negative rate, and Kappa.

All data were analyzed using JMP 6.0.2 (2006). An alpha level of $P < 0.10$ was used to judge statistical significance (Terry 1981, Rotella and Ratti 1992, Bristow and Ockenfels 2004). I chose this level so that habitat variables that might be biologically significant, but not statistically significant at a lower alpha level, could be included in modeling processes.

RESULTS

Model Development and Selection

A priori habitat models were developed using the site-level variables that differentiated lizard-centered sites from random sites (Table 2.1). For adults/juveniles, the best site-level model included only % CWD (Table 2.3). This model had the smallest AICc value (159.65) and largest Akaike weight (0.74). The full model was the next-best fitting model, with only a slightly higher AICc value (161.74), but with a much lower Akaike weight (0.26). The best-fitting model for adults/juveniles fits the data nearly three times as well as the full model. For hatchlings, the best-fitting model (AICc = 34.69, $\omega_i = 0.30$) included number of rocks and % litter (Table 2.3). The next-best fitting model for hatchlings included number of rocks, % litter, and % CWD (AICc = 35.16, $\omega_i = 0.24$). This model had only a slightly higher AICc value and a slightly lower Akaike weight than the "best" model for hatchlings. Thus, the adult/juvenile model and both hatchling models were evaluated with independent field data.

Model Testing

The GIS-based model, incorporating the landscape-level variables, was used to select 15 suitable and 15 unsuitable study areas. During surveys of these 30 areas, I captured lizards on five of 15 suitable study areas and on one of 15 unsuitable study areas (Table 2.4). The probability of capturing lizards at suitable study areas differed from the probability of capturing lizards at unsuitable sites ($P = 0.084$). The suitable and unsuitable areas differed in forest type and aspect, but not elevation (Table 2.5). Half of the site-level variables also differed between suitable and unsuitable study areas. Suitable areas had higher % litter and % CWD, and lower % grass and % forb than unsuitable areas (Table 2.5).

The site-level habitat model for adults/juveniles was tested using habitat data recorded at the 10 suitable and 10 unsuitable study areas surveyed in 2005 (Table 2.6). Fourteen study areas (9 suitable and 4 unsuitable), including all areas with lizards, had prediction probabilities above a cut point of 0.40. The highest prediction probability was from an unsuitable study area where no lizards were found. This particular study area had the highest % CWD, an elevation of 663 m, and mixed forest, but also high percentages of litter (74%) and forb (48%), and a westerly aspect. There was little bare ground (for nest digging) and few rocks (for perching/hiding). Study areas where lizards were found had prediction probabilities ranging from 0.408 to 0.583. Suitable study areas tended to have higher prediction probabilities than unsuitable study areas, while prediction probabilities did not differ between study areas with lizards and unsuitable study areas without lizards (Table 2.7). The confusion matrix and measures of classification accuracy showed a false positive rate of 0.44 and a Kappa rate of 0.27 (Tables 2.8 a and b).

The site-level models for hatchlings were tested using the habitat measurements at lizard-centered and random sites from surveys performed in 2003 (Chapter 1) at the AT and Wake Forest study areas. [Data used in the model-building process (i.e. input variables) for hatchlings were collected at the Little Creek study area.] Data from the AT and Wake Forest study areas were analyzed separately because the best-model variables - number of rocks and % litter - differed between study areas (P's < 0.0001). Comparisons of hatchling-centered and random sites were made to determine which habitat variables indicate hatchling habitat preferences. Aspect, number of rocks, % CWD, and slope differed between hatchling-centered and random sites at the AT study area (Table 2.9). Aspect, forest type, elevation, % litter, % CWD, % bare ground, and % grass differed between hatchling-centered and random sites at the Wake Forest study area (Table 2.10). Hatchling-centered sites at both study areas had significantly more coarse woody debris (13-22%) than random sites (3.5 – 10%). Results of testing the best-fitting habitat model for hatchlings showed that for both study areas lizard-centered sites had higher prediction probabilities than random sites (Table 2.11). Lizard-centered sites at the AT study area had a higher prediction probability than lizard-centered sites at the Wake Forest study area. For the second best-fitting hatchling model, both study areas again had higher prediction probabilities at lizard-centered sites than at random sites, but for this model, the lizard-centered sites at the Wake Forest study area had a higher prediction probability than lizard-centered sites at the AT study area (Table 2.12). The differences in probabilities of occurrence between lizard-centered sites and random sites, for both study areas, were more than 12 times greater when applying the "second best" hatchling model than when applying the "best" hatchling model.

DISCUSSION

Variable Selection and Model Performance

The GIS-based model correctly predicted lizard residency at one third of the “suitable” study areas in southwestern Virginia. I found fence lizards on five of 15 suitable study areas and on only one of 15 unsuitable areas. This model is thus useful for identifying potential fence lizard habitat across the southwestern Virginia landscape. Areas most likely to be occupied by fence lizards are characterized by a mixed forest type, southerly aspect, and elevation between 500 - 800 m. While the Virginia Gap Analysis Project predicts the presence of eastern fence lizards in all southwest Virginia counties (Klopfer and McClafferty 2001), my observations indicate that actual distributions are patchy because of preferences for specific landscape- and site- level habitat attributes.

The best-fitting logistic regression models used site-level habitat variables to characterize fence lizard habitat preferences. The best-fitting models included % CWD for adults/juveniles, and number of rocks, % litter, and % CWD (2nd best model only) for hatchlings. Percent coarse woody debris is found in models for each class and likely represents a general preference for this habitat feature. Coarse woody debris indicates some degree of tree cover and itself offers both basking sites and hiding cover. Hatchlings were also associated with a relatively large number of rocks and relatively low amounts of litter. While % bare ground did not appear in the best-fitting models for hatchlings, % bare ground was consistently higher at hatchling-centered sites than at random sites. Nest construction is associated with non-shaded areas of bare substrate (Angilletta 2001) and hatchlings were always found near their oviposition sites. Hatchlings may also prefer these areas for thermoregulation and feeding. Sex and age class differences are typical of *Sceloporus* lizards and reflect social structure and thermoregulatory needs (Adolph 1990, Smith and Ballinger 2001).

The predictive performance of the best-fitting model for adults/juveniles was low, indicating a poor fit of this model to the test data. This model weakly differentiated suitable from unsuitable study areas, but was overall a poor predictor of lizard occupancy at the test areas. These analyses suggest that a relatively high % CWD is not likely to be the only habitat feature that predicts adult/juvenile occupancy. For hatchlings, the second best-fitting model was the best predictor of lizard occupancy, indicating a good fit of this model to the test data. This model more clearly delineated lizard-centered sites from random sites at both study areas than did the "best" model. Thus, a relatively high number of rocks and % CWD, and a relatively low % litter, were good predictors of hatchling presence.

Management Applications

Landscape-level models used in conjunction with site-level habitat models are a modern management tool with broad application to conservation biology and species/habitat management (Garcia-Ripolles et al. 2005, Alexander et al. 2006). Landscape-level variables alone can be used to predict species distributions at coarse scales, but predictions can be improved substantially by incorporating site-level habitat measures into modeling and prediction efforts (Manel et al. 1999, Gibson et al. 2004). I believe that both approaches, covering different ecological scales, were critical to my analyses of fence lizard habitat preferences. Insights gained from GIS and AIC modeling of fence lizard habitat preferences in southwestern Virginia are likely to have broader applicability to fence lizards at other localities or regions and to patchily-distributed species in general. The specific modeling process that I used provides an effective management tool for assessing habit preference.

Habitat models should be based on data available to natural resource managers, and model variables chosen with ease of measurement and/or access to data in mind. Otherwise, models cannot be used by resource managers to predict species or habitat distributions or the potential impact of management actions/proposals (Stauffer 2002, Gibson et al. 2004, Garcia-Ripolles et al. 2005). Models must also be built on a scale pertinent for habitat and/or species conservation to be most useful to natural resource managers (Gibson et al. 2004, Yen et al. 2004). Moreover, habitat models must be treated as working hypotheses and be continually tested and revised as new data are collected (Guisan and Zimmermann 2000, Griffin et al. 2003).

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TABLE 2.1. Landscape- and site-level habitat variables that differentiated adult/juvenile- and hatchling-centered sites from random sites at the Little Creek study area (Chapter 1). Percentage of observations is reported for landscape-level variables – forest type and aspect. Mean ± S. E. (median) is reported for site-level variables and elevation.

Habitat variable	Adults and Juveniles (n=61)	Hatchlings (n=15)
Landscape-level		
Forest type	100 % mixed	100% mixed
Aspect	87% ESE to WSW	93% ESE to WSW
Site-level		
# Rocks	22.4 ± 2.2 (17)	21.2 ± 3.6 (21)
% Coarse woody debris	9 ± 1.2 (5)	8.9 ± 2.1 (7.5)
% Litter	[redacted]	8.3 ± 3.3 (2.5)
% Bare ground	[redacted]	24 ± 5.1 (15)

TABLE 2.2. Landscape-level habitat variables and the related index values for each variable option used to build the GIS-based model.

		Indices			
Variable	Options	0.0	0.3	0.7	1.0
Aspect	northerly (271° -89°), southerly (90° - 270°)	northerly			southerly
Elevation	< 500 m, 500-800 m, > 800 m		> 800 m	< 500 m	500-800 m
Forest type	mixed, deciduous, other		other	deciduous	mixed

TABLE 2.3. *A priori* models and results of model selection process for habitat preferences for adult/juvenile (n=61) and hatchling (n=15) fence lizards in southwestern Virginia. Models were fit using Logistic Regression and evaluated with Akaike's bias-adjusted Information Criterion (AICc). Percentages course woody debris and bare ground are abbreviated as % CWD and % BG, respectively.

Models	K	-2 Log L	AICc	Δ_i	ω_i
<u>Adults/Juveniles</u>					
$Y= \beta_0 + \beta_1$ % CWD + ε	2	155.552	159.65	0.0	0.74
$Y= \beta_0 + \beta_1$ %CWD + β_2 # Rocks + ε	3	155.536	161.74	2.1	0.26
$Y= \beta_0 + \varepsilon$ (*null model*)	1	169.128	171.16	11.5	0.00
$Y= \beta_0 + \beta_1$ # Rocks + ε	2	168.842	172.94	13.3	0.00
<u>Hatchlings</u>					
$Y= \beta_0 + \beta_1$ # Rocks + β_2 % Litter + ε	3	27.764	34.69	0	0.30
$Y= \beta_0 + \beta_1$ # Rocks + β_2 % Litter + β_3 % CWD + ε	4	25.562	35.16	0.5	0.24
$Y= \beta_0 + \beta_1$ # Rocks + ε	2	31.924	36.37	1.7	0.13
$Y= \beta_0 + \beta_1$ # Rocks + β_2 % Litter + β_3 % BG + ε	4	27.764	37.36	2.7	0.08
$Y= \beta_0 + \beta_1$ # Rocks + β_2 % Litter + β_3 % CWD + β_4 % BG + ε	5	25.562	38.06	3.4	0.06
$Y= \beta_0 + \beta_1$ # Rocks + β_2 % BG + ε	3	31.438	38.36	3.7	0.05
$Y= \beta_0 + \beta_1$ % Litter + β_2 % CWD + ε	3	31.560	38.48	3.8	0.05
$Y= \beta_0 + \beta_1$ # Rocks + β_2 % CWD + ε	3	31.904	38.83	4.1	0.04
$Y= \beta_0 + \beta_1$ % Litter + ε	2	35.032	39.38	4.8	0.03
$Y= \beta_0 + \beta_1$ % Litter + β_2 % CWD + β_3 % BG + ε	4	31.154	40.75	6.1	0.01
$Y= \beta_0 + \beta_1$ # Rocks + β_2 % CWD + β_3 % BG + ε	4	31.362	40.96	6.3	0.01
$Y= \beta_0 + \beta_1$ % Litter + β_2 % BG + ε	3	34.572	41.50	6.8	0.01
$Y= \beta_0 + \beta_1$ % BG + ε	2	38.952	43.40	8.7	0.00
$Y= \beta_0 + \varepsilon$ (*null model*)	1	41.588	43.73	9.0	0.00
$Y= \beta_0 + \beta_1$ % CWD + β_2 % BG + ε	6	38.730	45.65	11.0	0.00
$Y= \beta_0 + \beta_1$ % CWD + ε	2	41.542	45.99	11.3	0.00

TABLE 2.4. Lizard captures from 2004 surveys (June – September) of 15 "suitable" study areas and 15 "unsuitable" study areas across Bland, Craig, Montgomery, Wythe, Pulaski, and Giles counties, Virginia. P-value is from Fisher's Exact test comparing the number of "suitable" versus "unsuitable" study areas where lizards were captured.

Study areas	# Lizards captured	Adult/Juvenile (A/J) or Hatchling (H)	# of study areas with lizards	P-value
Suitable	16	15- A/J, 1-H	5/15	0.0843
Unsuitable	1	A/J	1/15	

TABLE 2.5. Comparison of 2005 habitat measurements at suitable and unsuitable study areas. P-values are from Wilcoxon Rank Sum and Chi-square tests (only for forest type and aspect). Percentages coarse woody debris and bare ground are abbreviated as % CWD and % BG, respectively. Mean ± S. E. (Median) is reported.

Habitat variable	Suitable study areas (n=10)	Unsuitable study areas (n=10)	Test Statistic	P-value
Landscape-level				
Forest type	100% mixed	30 % mixed	$\chi^2 = 13.681$	0.003
Aspect	100% ESE to WSW	50% ESE to WSW	$\chi^2 = 8.63$	0.035
Elevation	694.1 ± 14.9 (698.5)	724.4 ± 37.3 (729)	S = 117.0	0.385
Site-level				
% Litter	64.5 ± 10.8 (77.5)	37.6 ± 11.6 (32)	S = 82.0	0.089
% Shrub	6.5 ± 3.8 (1)	7.2 ± 4.9 (1)	S = 108.5	0.811
Slope	19.8 ± 2.5 (19)	16.25 ± 2.5 (19)	S = 93.0	0.381
# Rocks	4 ± 1.1 (3.5)	2 ±0.6 (1.2)	S = 89.5	0.253
% CWD	6.4 ± 1.3 (6.5)	4.7 ± 2.5 (2)	S = 80.0	0.061
% Grass	4.1 ± 3.2 (1)	48.9 ± 14.4 (44.5)	S = 145.5	0.002
% BG	11.6 ± 3.9 (7.5)	8 ± 3.6 (1)	S = 90.5	0.286
% Forb	4.8 ± 1.9 (1)	22.2 ± 8.4 (10.5)	S =130.0	0.055

TABLE 2.6. Prediction probability testing of the ‘best’ logistic regression model, $Y = \beta_0 + \beta_1$ % CWD + ε, for adults/juveniles using 10 ‘suitable’ study areas and 10 ‘unsuitable’ study areas surveyed in 2005. Percentage coarse woody debris is abbreviated as % CWD. Probability of occurrence (P_i) was calculated as: $1/\ 1 + e^{-[\text{intercept} + (\%\ \text{CWD coefficient}\ \ \text{x}\ \%\ \text{CWD})]}$. Study areas are ranked by prediction probability.

Study areas	% CWD	P_i
Unsuitable	26.3	0.900
Suitable	15.0	0.731
Suitable with lizards	8.8	0.583
Suitable	8.8	0.583
Unsuitable	8.8	0.583
Suitable with lizards	7.5	0.549
Suitable	7.5	0.549
Suitable with lizards	5.0	0.482
Suitable with lizards	2.8	0.424
Unsuitable	2.8	0.424
Unsuitable	2.3	0.411
Suitable with lizards	2.5	0.410
Suitable	2.5	0.410
Unsuitable with lizards	2.0	0.408
Unsuitable	1.8	0.398
Unsuitable	1.0	0.377
Suitable	0.8	0.372
Unsuitable	0.8	0.372
Unsuitable	0.5	0.365
Unsuitable	0.0	0.352

TABLE 2.7. Comparisons of prediction probabilities of the adult/juvenile 'best' logistic regression model between 1) suitable study areas and unsuitable study areas and 2) study areas with lizards and unsuitable study areas without lizards. Mean P_i (Median P_i) is reported. Test statistics and P-values are from Wilcoxon Rank Sum tests.

Suitable study areas (n=10)	Unsuitable study areas (n=10)	U	P-value	Study areas with lizards (n=6)	Unsuitable study areas without lizards (n=9)	U	P-value
0.509 (0.516)	0.459 (0.403)	83	0.103	0.476 (0.453)	0.465 (0.398)	59	0.215

TABLE 2.8 a and b. a) Confusion Matrix for 15 'suitable' and 15 'unsuitable' study areas surveyed in 2004 and b) measures of classification accuracy.

a.

Prediction	Lizards present	Lizards absent
Suitable	5	10
Unsuitable	1	14

b.

Correct classification rate	(5 + 14)/ 30= 0.63
False positive rate	10/(10+14) = 0.44
False negative rate	1/(5+1) = 0.17
Kappa	[(5+14) – (((5 +1)(5 + 10) + (10 + 14)(1+14))/30)]/ [30- (((5 +1)(5 + 10)) + (10 + 14)(1 + 14))/30)] = 0.27

TABLE 2.9. Comparisons of hatchling-centered versus random sites at the 2003 AT study area (Chapter 1). Percentage coarse woody debris is abbreviated as % CWD. Percentage of observations is reported for landscape-level variables – aspect and forest type. Mean ± S. E. (Median) is reported for site-level variables and elevation.

Habitat variable	Lizard-centered sites (n=38)	Random site (n=38)	Test statistic	P-value
Aspect	97% ESE to WSW	67% ESE to WSW	$\chi^2 = 0.824$	0.004
Forest type	100% mixed	100% mixed	$\chi^2 = 0.000$	1.000
Elevation	507.4 ± 3.6 (510.5)	505.1 ± 2.2 (507)	W+ = -107.0	0.107
# Rocks	38.9 ± 4 (36)	26.5 ± 4 (20)	W+ = -146.5	0.039
% Litter	57.1 ± 3.8 (57.5)	59.5 ± 4.9 (62.5)	W+ = 74.0	0.308
% CWD	13.1 ± 1.8 (10)	10 ± 2.2 (5)	W+ = -165.0	0.015
% Shrub	2.2 ± 0.6 (0.5)	2.9 ± 1.1 (1)	W+ = -29.5	0.589
% Bare ground	6.7 ± 2.1 (2)	7 ± 2.2 (2.3)	W+ = -14.5	0.757
% Forb	20.6 ± 3 (12.5)	27.8 ± 4 (21.8)	W+ = 84.0	0.228
% Grass	3.5 ± 0.7 (1.5)	2.4 ± 0.4 (1.5)	W+ = -54.5	0.337
Slope	21.6 ± 1.1 (22)	26.1 ± 1 (26.5)	W+ = 212.0	0.001

TABLE 2.10. Comparisons of hatchling-centered versus random sites at the 2003 Wake Forest study area (Chapter 1). Percentage coarse woody debris is abbreviated as % CWD. P-values are from Wilcoxon Signed-Rank and Chi-square (first two variables only) tests. Percentage of observations is reported for landscape-level variables – aspect and forest type. Mean ± S. E. (Median) is reported for site-level variables and elevation.

Habitat variable	Lizard-centered sites (n=28)	Random site (n=28)	Test statistic	P-value
Aspect	96% ESE to WSW	75% ESE to WSW	$\chi^2 = 0.588$	0.003
Forest type	96% mixed	86% mixed	$\chi^2 = 4.809$	0.032
Elevation	672 ± 8.1 (649)	696.4 ± 8.4 (703)	W+ = -73.0	0.079
# Rocks	7.1 ± 2.3 (0)	5.3 ± 1.5 (0)	W+ = -17.5	0.337
% Litter	16.8 ± 4.6 (5)	49.9 ± 8.3 (57)	W+ = 170.0	0.000
% CWD	22.1 ± 5.9 (7.5)	3.5 ± 1.8 (2)	W+ = 170.0	0.000
% Shrub	0.3 ± 0.1 (0)	2.2 ± 1.1 (0)	W+ = 6.5	0.591
% Bare ground	19.5 ± 5.2 (7)	8.6 ± 3.7 (0)	W+ = -125.0	0.001
% Forb	12.7 ± 3.1 (5)	17.9 ± 5.6 (3)	W+ = -25.0	0.486
% Grass	14.9 ± 3.9 (6.3)	12.6 ± 5.4 (1)	W+ = -100.5	0.001
Slope	13.4 ± 2.2 (14)	13.4 ± 1.8 (11)	W+ = 54.5	0.220

TABLE 2.11. Prediction probability testing of the 'best' logistic regression model, $Y = \beta_0 + \beta_1$ # Rocks + β_2 % Litter + ε, for hatchlings using habitat data from the AT and Wake Forest study areas surveyed in 2003. Probability of occurrence (P_i) was calculated as:

$1/\ 1 + e^{-[\text{intercept} + (\#\text{ rocks coefficient x }\#\text{ rocks}) + (\%\text{ litter coefficient x }\%\text{ litter})]}$.

Study areas	Sites	Mean # Rocks	Mean % Litter	P_i
AT	Lizard-centered (n=38)	39	55.95	0.554
	Random (n=38)	27	59.58	0.522
Wake Forest	Lizard-centered (n=28)	7	24.78	0.489
	Random (n=28)	9	66.48	0.474

TABLE 2.12. Prediction probability testing of the '2nd best' logistic regression model, $Y = \beta_0 + \beta_1$ # Rocks + β_2 % Litter + β_3 % CWD + ε, for hatchlings using habitat data from the AT and Wake Forest study areas surveyed in 2003. Percentage coarse woody debris is abbreviated as % CWD. Probability of occurrence was calculated as:

$1/\ 1 + e^{-[\text{intercept} + (\#\text{ rocks coefficient x }\#\text{ rocks}) + (\%\text{ litter coefficient x }\%\text{ litter}) + (\%\text{ CWD coefficient x }\%\text{ CWD})]}$.

Study areas	Sites	Mean # Rocks	Mean % Litter	Mean % CWD	P_i
AT	Lizard-centered (n=38)	39	55.95	13.06	0.678
	Random (n=38)	27	59.58	9.82	0.090
Wake Forest	Lizard-centered (n=28)	7	24.78	22.14	0.797
	Random (n=28)	9	66.48	2.82	0.409

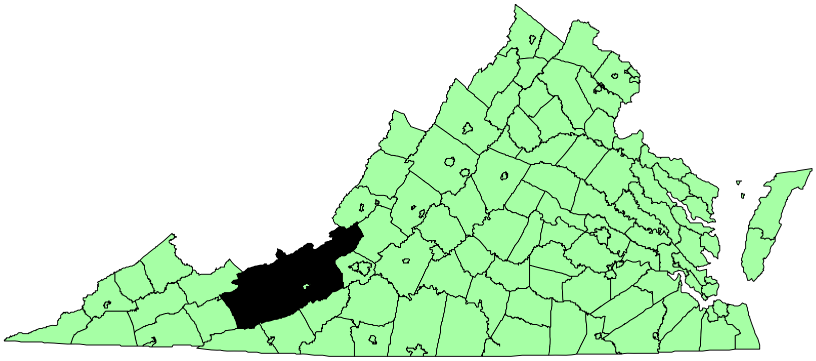

FIGURE 2.1. In Bland, Montgomery, Craig, Giles, Wythe, and Pulaski counties, 15 "suitable" and 15 "unsuitable" locations were surveyed for the presence of fence lizards from 24 June to 29 September, 2004. Image derived from TIGER/Line files (U. S. Census Bureau 2000).

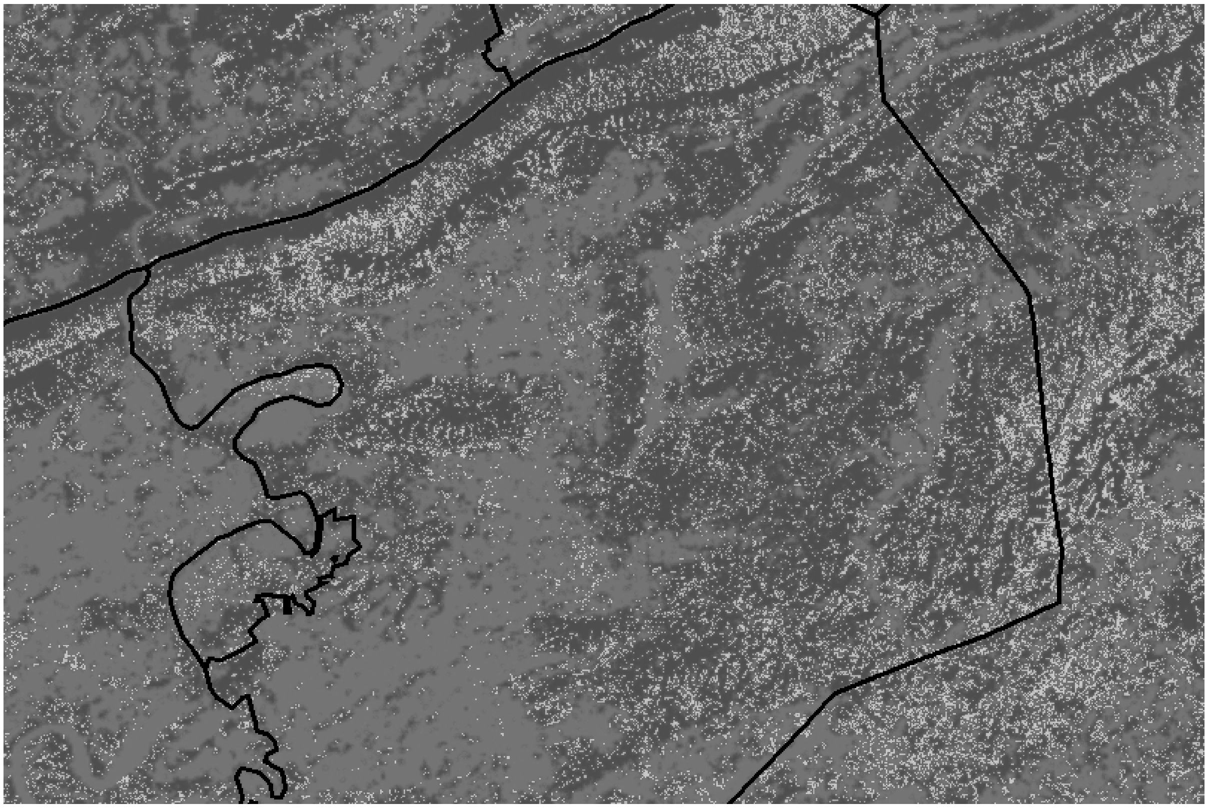

FIGURE 2.2. Geographic Information System image showing forest types for Montgomery County, Virginia, for example (EROS Data Center 2001). Dark gray represents deciduous forest, white represents mixed forest, and medium gray represents coniferous forest and non-forested areas.

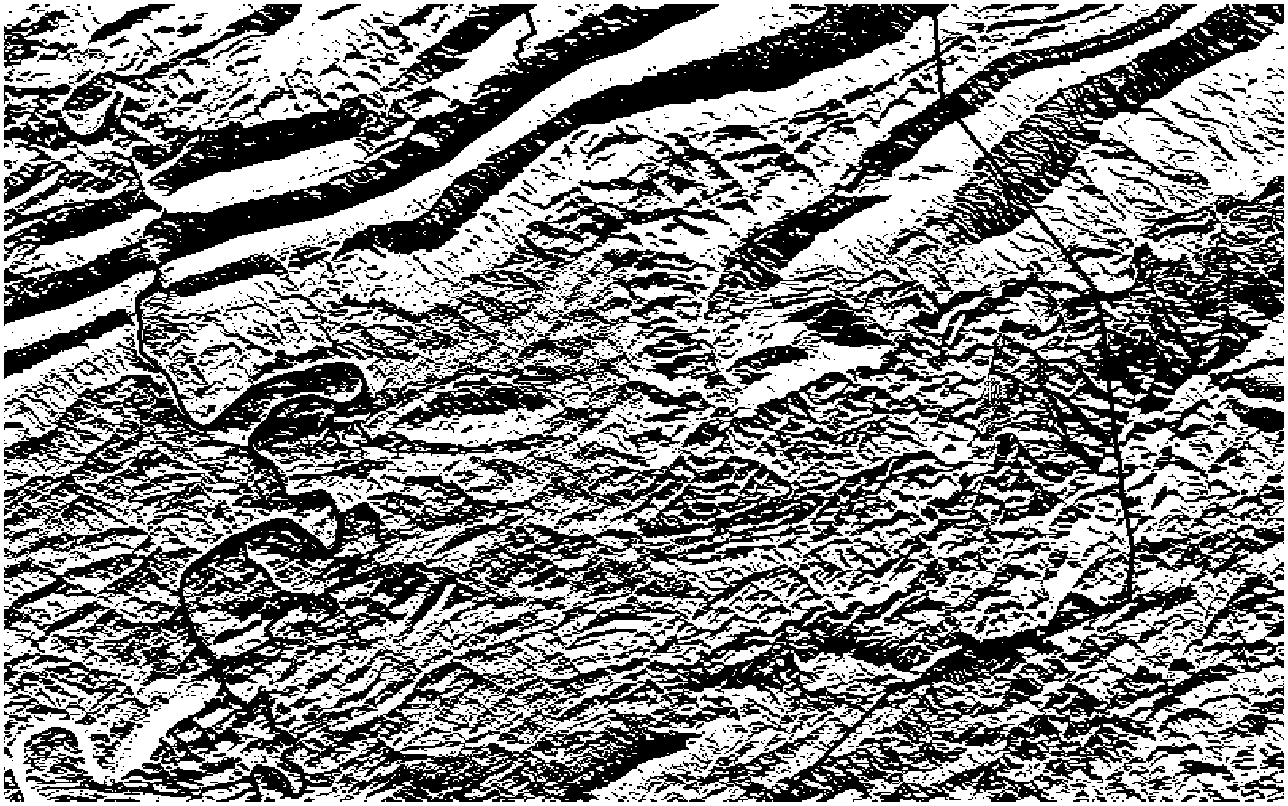

FIGURE 2.3. Geographic Information System image showing aspect classes for Montgomery County, Virginia, for example (EROS Data Center 1999). Black represents areas with a southern aspect (90°-270°) and white represents areas with a non-southern aspect (271°-89°).

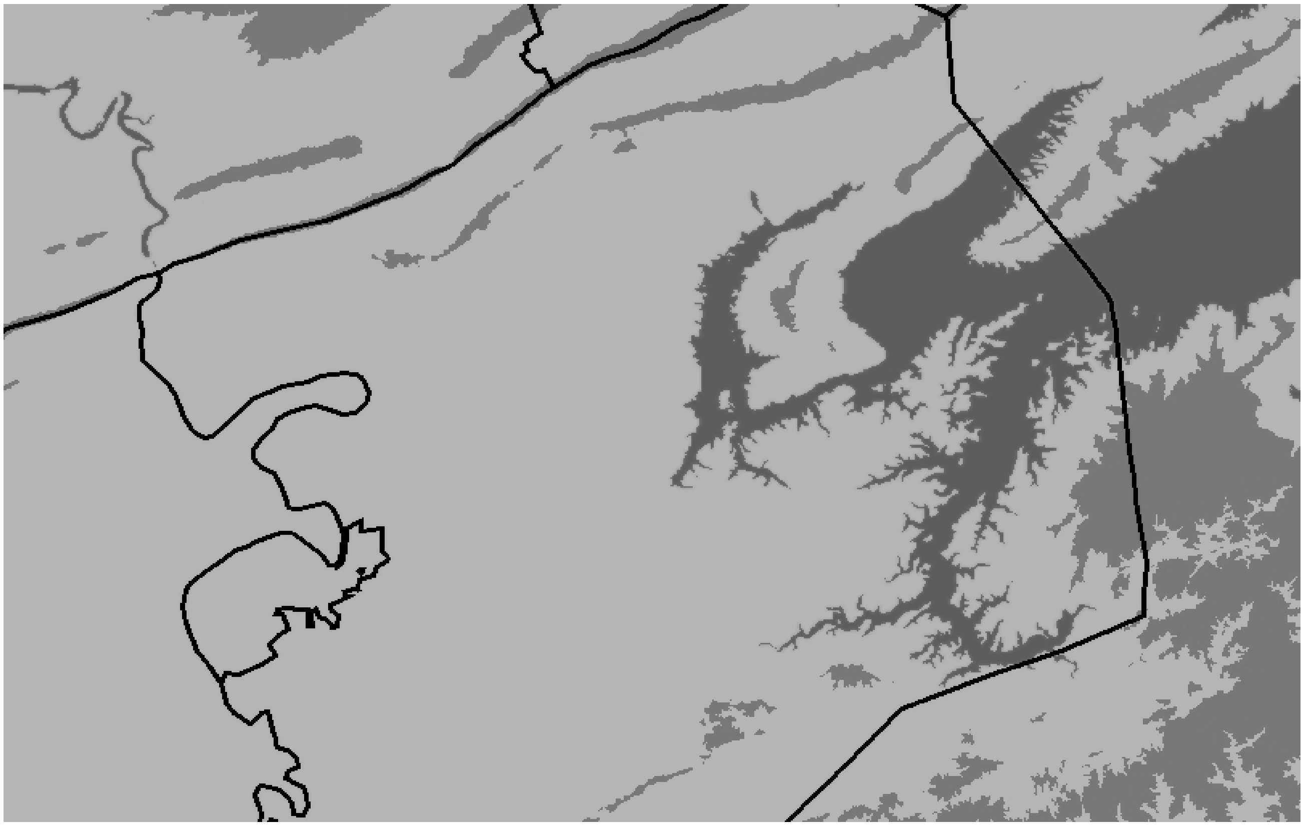

FIGURE 2.4. Geographic Information System image showing elevation levels for Montgomery County, Virginia, for example (EROS Data Center 1999). Dark gray represents elevation greater than 800 m, medium gray less than 500 m, and light gray between 500 m and 800 m.

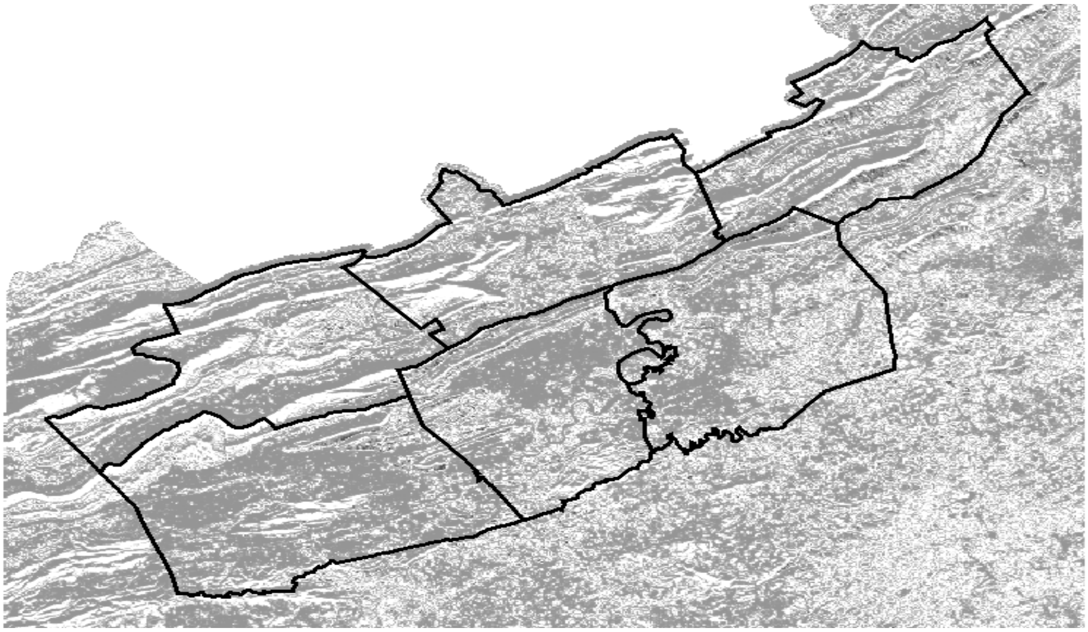

FIGURE 2.5. Geographic Information System image showing habitat suitability, based on forest type, elevation, and aspect combined, for Bland, Giles, Craig, Pulaski, Wythe, and Montgomery counties in southwestern Virginia (EROS Data Center 1999, EROS Data Center 2001). Dark gray represents habitat predicted to be optimally suitable for fence lizards, while lighter shades of gray and white represent habitat predicted to be poorly suited to unsuitable.

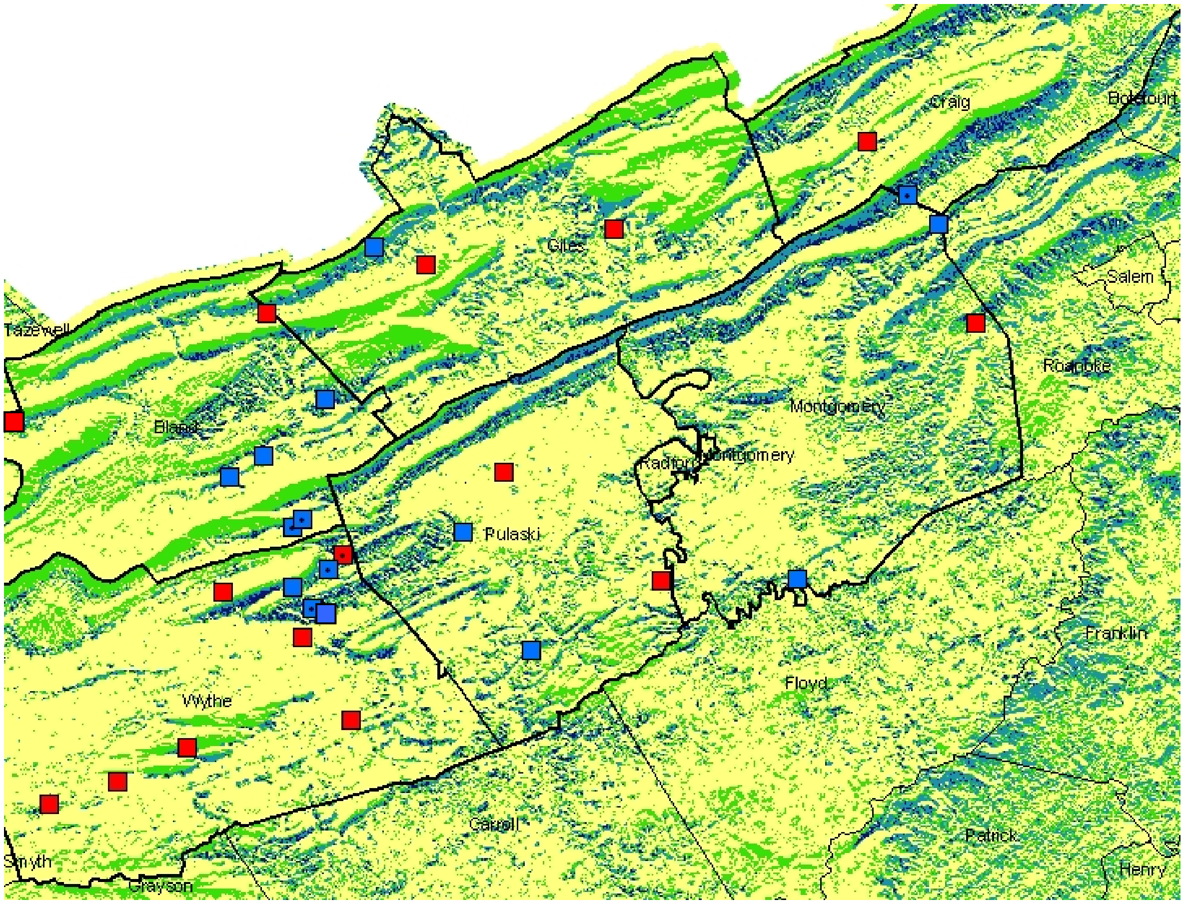

FIGURE 2.6. Across Bland, Giles, Craig, Montgomery, Pulaski, and Wythe counties, blue squares represent the 15 "suitable" study areas surveyed in summer 2004, while the red squares represent the 15 "unsuitable" study areas surveyed (EROS Data Center 1999, EROS Data Center 2001).

APPENDIX A. Universal Transverse Mercator (UTM) locations of 2003 study areas.

	UTM	
Study Areas	**Easting**	**Northing**
Little Creek	0503187 m	4105098 m
Wake Forest- abandoned sawmill	0538847 m	4120361 m
Wake Forest- homesite dump	0538285 m	4121154 m
AT	0571254 m	4138561 m

APPENDIX B. Ranges (including outliers) of all habitat variables measured at the Little Creek study area for lizard-centered sites and random sites. Percent coarse woody debris is abbreviated as % CWD.

Habitat variable	Lizard-centered sites	Random sites
Aspect	E to W-SW	E to W-SW
Elevation (m)	502 - 888	686 - 888
Forest type	mixed only	Pasture, mixed, and deciduous
Slope (°)	0 - 44	1.5 – 39
% Canopy cover	0 - 98.44	0 – 100
Temp. at perch height (°C)	18.2 - 37.2	17.2 - 30.9
# of Rocks	0 - 100	0 – 175
# of Downed trees	0 - 14	0 – 14
Basal area (dbh)	0 - 51.54	0 - 95.94
% Bare ground	0 – 57.5	0 – 90
% Grass	0 – 97.5	0 – 97.5
% Rock	0 - 42.5	0 – 97.5
% Fern	0 - 1	0 – 2.5
% Forb	0 - 85	0.5 – 97.5
% Shrub	0 - 33	0 – 67
% CWD	0 – 47.5	0 – 57.5
% Litter	0 – 97.5	0 – 97.5

APPENDIX C. Counts of overstory and understory tree species dominance at lizard-centered (n=142) and random sites (n=142) from all three study areas. A tree was considered 'dominant' if it offered the predominant canopy coverage over a site.

	Lizard-centered sites		Random sites	
Tree species	# of sites at which this overstory tree was dominant	# of sites at which this understory tree was dominant	# of sites at which this overstory tree was dominant	# of sites at which this understory tree was dominant
Chestnut oak (*Quercus prinus*)	23		31	
Scarlet oak (*Quercus coccinea*)	7		19	
White oak (*Quercus alba*)	7		7	
Black oak (*Quercus velutina*)	6		4	
Shortleaf pine (*Pinus echinata*)	9			
White pine (*Pinus strobes*)	2		7	
Virginia pine (*Pinus virginiana*)		25		11
Pitch pine (*Pinus rigida*)	6		6	
Red maple (*Acer rubrum*)		6		10
Sourwood (*Oxydendrum arboretum*)	6		12	
Black gum (*Nyssa sylvatica*)		6		5
Wild cherry (*Prunus avium*)		8		
Black locust (*Robinia pseudoacacia*)	9			
Other species	12	7	17	13

APPENDIX D. Contrasts of habitat variables at lizard-centered sites at the Little Creek study area for adults (n=42) and juveniles (n=19) (combined) in 'early' (May - July) and 'late' (August - October) seasons of 2003. Hatchlings are not included because they were only captured during the 'late' season. P-values result from Wilcoxon Rank Sum tests. Percent coarse woody debris is abbreviated as % CWD. Mean ± S.E. (Median) is reported.

Habitat variable	Early (n=51)	Late (n=10)	Test statistic (U)	P-value
Slope	13.7 ± 1.1 (14)	16.4 ± 2.1 (16)	353.5	0.284
Temp.at perch height	24.8 ± 0.5 (25)	27.2 ± 0.8 (28)	416.5	**0.019**
% Canopy cover	82.4 ± 2.6 (90)	91.9 ± 2.4 (94)	398	0.057
# Rocks	22.3 ± 3.2 (16)	28.2 ± 6.5 (30)	347.5	0.342
# Downed trees	4.3 ± 0.5 (4)	3.9 ± 0.7 (4)	289.5	0.839
Basal area	16.3 ± 1.7 (17)	27.4 ± 4.1 (32)	400.5	**0.043**
% Bare ground	8.3 ± 2.4 (1)	3.1 ± 2.3 (1)	283.5	0.736
% Grass	6.8 ± 2.3 (0)	7.7 ± 7.1 (0)	292.5	0.877
% Fern	0.0 ± 0.0 (0)	0.0 ± 0.0 (0)	290	0.549
% Forb	20.2 ± 2.5 (13)	12.4 ± 3.4 (8)	236.5	0.260
% Shrub	0.7 ± 0.4 (0)	0.4 ± 0.2 (0)	312	0.761
% Rock	2.8 ± 0.8 (2)	3.1 ± 1.1 (2)	362	0.209
% CWD	9.5 ± 1.4 (5)	6.0 ± 1.5 (5)	260	0.423
% Litter	67.5 ± 5.0 (88)	74.8 ± 10.5 (90)	322	0.655

APPENDIX E. Spearman's Rho (ρ) correlation analyses of all habitat variables from measurements at the Little Creek study area for all age classes combined (n=76). Percentage coarse woody debris is abbreviated as % CWD. Temperature at perch height is abbreviated as TPH. Percentage bare ground is abbreviated as % BG. Percentage canopy cover is abbreviated as % CC. Basal area is abbreviated as BA. Number of downed trees is abbreviated as # DT.

Habitat variable	Slope	TPH	% CC	# Rocks	# DT	BA	% BG	% Grass	% Fern	% Forb	% Shrub	% Rock	% CWD	% Litter
Slope	1.000	0.247	0.013	-0.017	-0.023	-0.229	0.121	-0.046	-0.121	-0.054	0.165	0.176	-0.026	-0.195
TPH	0.247	1.000	0.362	0.007	-0.041	0.127	-0.097	-0.233	0.032	-0.020	0.030	-0.079	-0.067	0.256
% CC	0.013	0.362	1.000	0.073	0.308	0.636	-0.358	-0.557	0.118	-0.015	0.009	-0.068	0.077	0.608
# Rocks	-0.017	0.007	0.073	1.000	0.058	0.054	-0.256	-0.274	-0.015	0.066	-0.021	0.196	0.132	0.137
# DT	-0.023	-0.041	0.308	0.058	1.000	0.249	-0.415	-0.415	-0.004	0.306	-0.031	-0.116	0.315	0.556
BA	-0.229	0.127	0.636	0.054	0.249	1.000	-0.443	-0.405	0.024	-0.170	-0.057	-0.079	0.027	0.589
% BG	0.121	-0.097	-0.358	-0.256	-0.414	-0.443	1.000	0.205	-0.063	-0.246	-0.022	0.154	-0.213	-0.686
% Grass	-0.046	-0.233	-0.557	-0.274	-0.415	-0.405	0.205	1.000	-0.074	-0.286	-0.107	-0.105	-0.306	-0.564
% Fern	-0.121	0.032	0.118	-0.015	-0.004	0.024	-0.063	-0.074	1.000	0.017	-0.039	-0.058	-0.062	0.134
% Forb	-0.054	-0.020	0.015	0.066	0.306	-0.170	-0.246	-0.286	0.017	1.000	-0.149	-0.132	0.159	0.250
% Shrub	0.165	0.030	0.009	-0.021	-0.031	-0.057	-0.022	-0.107	-0.039	-0.149	1.000	-0.038	-0.082	0.088
% Rock	0.176	-0.079	-0.068	0.196	-0.116	-0.079	0.154	-0.105	-0.058	-0.132	-0.038	1.000	-0.133	-0.198
% CWD	-0.026	-0.067	0.077	0.132	0.315	0.027	-0.213	-0.306	-0.062	0.159	-0.082	-0.133	1.000	0.124
% Litter	-0.195	0.256	0.608	0.137	0.556	0.589	-0.686	-0.564	0.134	0.250	0.088	-0.198	0.124	1.000

APPENDIX F. Comparisons between pairs of lizard classes, abbreviated as AF (Adult Female, n= 26), AM (Adult Male, n=16), J (Juvenile, n=17), and H (Hatchling, n=15). Percentage coarse woody debris is abbreviated as % CWD. Test statistics (U) and P-values result from Wilcoxon Rank Sum tests on data from the Little Creek study area.

Habitat variable	AF vs. H		AF vs. AM		AF vs. J		AM vs. H		AM vs. J		J vs. H	
	U	P-value	U	P-value	U	P-value	U	P-value	U	P-value	U	P-value
% Canopy cover	239.5	**0.007**	302.0	0.282	392.5	0.655	211.5	**0.050**	231.5	0.149	190.5	**0.004**
Basal area	236.5	**0.005**	325.5	0.641	373.5	1.000	204.5	**0.025**	261.5	0.719	188.5	**0.003**
% Bare ground	496.5	**0.001**	323.0	0.582	350.5	0.556	331.0	**0.011**	274.0	0.954	375.5	**0.001**
% Grass	502.5	**0.001**	372.5	0.433	392.0	0.632	332.0	**0.010**	277.5	0.844	342.0	**0.011**
% Rock	432.5	**0.022**	296.5	0.218	358.0	0.698	340.0	**0.004**	251.0	0.452	339.5	**0.015**
Slope	402.5	0.132	335.0	0.826	363.0	0.794	302.5	0.151	273.5	0.971	313.5	0.139
# Rocks	310.0	0.385	242.0	0.084	363.0	0.794	311.0	0.079	224.5	0.090	263.0	0.759
# Downed trees	255.0	**0.021**	304.5	0.308	380.5	0.881	245.5	0.492	250.0	0.434	227.0	0.106
Fern	328.0	0.277	328.0	0.277	357.0	0.261	264.0	1.000	272.0	1.000	272.0	1.000
% Forb	282.0	0.110	296.0	0.217	336.0	0.350	258.5	0.849	258.5	0.636	252.5	0.491
% Shrub	322.0	0.514	298.0	0.139	331.5	0.198	283.0	0.335	267.0	0.795	286.0	0.517
% CWD	363.5	0.621	323.0	0.593	434.0	0.138	288.5	0.362	227.5	0.111	248.0	0.394
% Litter	160.0	**0.001**	332.0	0.759	355.5	0.646	176.5	**0.001**	279.0	0.810	163.5	**0.001**

APPENDIX G. Study areas surveyed in southwestern Virginia in summer 2004. Suitable = areas predicted by the GIS to be suitable habitat for fence lizards. Unsuitable = forested areas predicted by the GIS to be unsuitable for fence lizards. "*" beside "County" signifies that this study area was one of those revisited in Fall 2005 for additional data collection.

County	Locale	Suitable/ Unsuitable	Predominant land cover type	UTM Coordinates	
				Easting	Northing
Bland*	Crandon	Suitable	Mixed forest	0496857	4107542
Bland	Hollybrook	Suitable	Mixed forest/ old field	0506003	4115082
Bland	Crandon	Suitable	Mixed forest	0500048	4109641
Bland*	Little Creek	Suitable	Mixed forest	0503882	4103500
Bland*	Little Creek	Suitable	Mixed forest	0502812	4102657
Bland*	Niday	Unsuitable	Mixed forest	0500321	4123286
Bland*	Cove Creek	Unsuitable	Deciduous forest	0476816	4116722
Craig*	Simmonsville	Unsuitable	Pasture/deciduous forest	0558265	4139986
Craig*	Craig Creek	Suitable	Mixed forest	0561128	4135270
Giles*	Narrows	Unsuitable	Deciduous forest	0515638	4128013
Giles	Pembroke	Unsuitable	Scrubland	0533880	4131424
Giles*	Penvir	Suitable	Boulder/ talus field	0510722	4129782
Montgomery	Blacksburg	Suitable	Mixed forest	0565125	4132020
Montgomery*	Riner	Suitable	Mixed forest	0551595	4097655
Montgomery*	Ironto	Unsuitable	Mixed forest	0568647	4122410
Pulaski*	Hiwassee	Suitable	Mixed forest	0525885	4090900
Pulaski*	Dublin	Unsuitable	Pasture/ Deciduous woodlot	0523231	4108012
Pulaski	Snowville	Unsuitable	Pasture	0538309	4097520
Pulaski*	Pulaski	Suitable	Mixed forest	0519345	4102221
Wythe*	Max Meadows	Suitable	Mixed forest	0506256	4098595

APPENDIX G. Continued.

County	Locale	Suitable/ Unsuitable	Predominant land cover type	UTM Coordinates	
				Easting	Northing
Wythe*	Max Meadows	Suitable	Mixed forest	0505055	4095128
Wythe	Max Meadows	Unsuitable	Mowed yard	0503870	4092112
Wythe*	Max Meadows	Unsuitable	Mixed forest	0507905	4100133
Wythe	Max Meadows	Suitable	Mixed forest	0502893	4096930
Wythe	Max Meadows	Suitable	Mixed forest	0504929	4094866
Wythe*	Ft. Chiswell	Unsuitable	Deciduous forest	0508592	4084024
Wythe*	Speedwell	Unsuitable	Field/Scattered trees	0479495	4075955
Wythe*	The Cove	Unsuitable	Deciduous forest	0496154	4096500
Wythe	Stroupes Mtn.	Unsuitable	Deciduous forest	0492770	4081499
Wythe	Stroupes Mtn.	Unsuitable	Grazed pasture	0486078	4078186

APPENDIX H. Spearman's Rho (ρ) correlation analyses of habitat variables that differentiate lizard-centered sites from random sites, for adults/juveniles and hatchlings, at the Little Creek study area. Percentage coarse woody debris is abbreviated as % CWD.

Habitat variables	Hatchlings (n=15)	Adults/Juveniles (n=61)
# Rocks vs. % CWD	0.585	0.073
# Rocks vs. % Bare ground	-0.123	----
# Rocks vs. % Litter	0.442	----
% Bare ground vs. % CWD	-0.330	----
% Bare ground vs. % Litter	-0.384	----
% Litter vs. % CWD	0.065	----

APPENDIX I. Comparisons of habitat measurements taken during 2004 and 2005 surveys at 10 suitable study areas and 10 unsuitable study areas. Test statistics and P-values result from Wilcoxon Signed-Rank tests. Mean ± S.E. (Median) is reported.

Habitat variable	Study areas in 2004 (n=10)	Study areas in 2005 (n=10)	W+	P-value
Suitable areas				
% Litter	58.6 ± 11.3 (68)	64.5 ± 10.8 (77.5)	7.5	0.430
% Shrub	10.4 ± 5.3 (2.5)	6.5 ± 3.8 (1)	-14.0	0.201
Slope	20.5 ± 2.8 (21)	19.8 ± 2.5 (19)	7.5	0.281
Unsuitable areas				
% Litter	38.7 ± 10.4 (31.5)	37.6 ± 11.6 (32)	-7.0	0.508
% Shrub	6.6 ± 3.8 (1.5)	7.2 ± 4.9 (1)	-1.0	0.906
Slope	16.1 ± 2.6 (18.5)	16.25 ± 2.5 (2.5)	-4.0	0.758

CURRICULUM VITAE

Amy Allison Roberts

Education: Master of Science in Biological Sciences, Summer 2007
Virginia Polytechnic Institute and State University
Blacksburg, Virginia, U.S.A.

Bachelor of Business Administration in Finance, May 1988
University of North Florida
Jacksonville, Florida, U.S.A.

Associate of Arts in Accounting, May 1987
University of Florida
Gainesville, Florida, U.S.A.

Professional Experience:

2007 Biological Sciences, Virginia Tech Blacksburg, VA
Research Assistant

- Performed literature reviews, weighed lizard eggs, refilled specimen jars, cleaned lizard cages, graded Evolutionary Biology assignments, etc. as needed by my major professor.

2007 Conservation Management Institute, Virginia Tech Blacksburg, VA
Natural Resource Specialist

- Catalogued websites for NBII, the National Biological Information Infrastructure; performed reptile surveys at Fort Pickett, Blackstone, VA.

2006 Conservation Management Institute, Virginia Tech Blacksburg, VA
Biological Technician

- Trapped, weighed, measured, dye marked, and tagged small mammals in three habitat types at Fort Pickett, Blackstone, VA; performed day and night surveys for amphibians at Ft. Pickett, Blackstone, VA

2005 Conservation Management Institute, Virginia Tech Blacksburg, VA

Biological Technician

- Performed ground surveys, with dogs, for the greater prairie chicken at three study areas on Fort Chaffee, Fort Smith, Arkansas

2005 Conservation Management Institute, Virginia Tech Blacksburg, VA

Graduate Assistant

- Trapped, weighed, measured, and tagged small mammals at Tennessee Army National Guard Training Site, Smyrna, TN

2005 Conservation Management Institute, Virginia Tech Blacksburg, VA

Natural Resource Specialist

- Captured, measured, weighed, and marked with elastomer several species of salamanders and frogs at a MeadWestvaco research forest in West Virginia; supervised two technicians; performed night searches for salamanders along marked transect plots.

2005 Virginia Polytechnic Institute & State University Blacksburg, VA

Natural Resource Specialist

- Organized and maintained the fish, mammal, amphibian, and reptile specimen collections for the Department of Fisheries and Wildlife Science; assisted with laboratory set-up for Wildlife Field Biology course

2004 Virginia Polytechnic Institute & State University Blacksburg, VA

Graduate Teaching Assistant

- Teach 2 sections of Mammalogy Lab; develop and grade exams; teach small mammal trapping and habitat evaluation techniques in the field

2004 Virginia Polytechnic Institute & State University Blacksburg, VA

Independent Contractor

- Counted horseshoe crabs from aerial photographs of sample quadrats, using ArcMap

2003-2004 Conservation Management Institute, Virginia Tech Blacksburg, VA

Graduate Research Assistant

- Performed secondary research on habitat use by mammalian and herpetological species occurring at Fort Chaffee, Arkansas; classified species as to habitat niche and defined niche-representing species; completed three segments of an online ArcView course

2003 Conservation Management Institute, Virginia Tech Blacksburg, VA
Natural Resource Specialist

- Performed secondary research on, and identification of, mammal hair from field work at the Radford Arsenal, Radford, Virginia

2002- 2003 Virginia Polytechnic Institute & State University Blacksburg, VA
Graduate Teaching Assistant

- Taught three General Biology Laboratory sections for two semesters; developed and graded homework assignments, quizzes, and exams; led students on outdoor fieldtrips, covering tree identification and natural resource management issues

2000 Virginia Polytechnic Institute & State University Blacksburg, VA
Program Support Technician Senior

- Identified and catalogued mammal pelts and skulls for the College of Natural Resources's specimen collection

Previous Career:

1999- 2002	Virginia Polytechnic Inst. & State Univ.	Internal Audit Administrative & Program Specialist III
1996-1999	General Injectables & Vaccines Inc.	Corporate Writer/ Market Researcher-Analyst
1991-1996	General Injectables & Vaccines Inc.	Accounts Payable Clerk
1989-1991	Old Dominion Insurance Company	Underwriting Clerk
1988-1989	State Farm Insurance	Accounting Intern

Principle Research Interests:

Reptile ecology
Carnivore ecology

Professional Memberships:

Society for the Study of Amphibians and Reptiles
Virginia Chapter of The Wildlife Society
The Wildlife Society
Virginia Herpetological Society

Grants and Awards Received:

Travel Grant. 2004. Virginia Polytechnic Institute and State University, Graduate Student Assembly.

Travel Award. 2004. Society for the Study of Amphibians and Reptiles.

Grant-in-Aid of Research. 2004. Sigma Xi.

Publications:

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