CHARACTERIZATION OF LANDSCAPE-SCALE HABITAT USE BY TIMBER RATTLESNAKES (*CROTALUS HORRIDUS*) WITHIN THE RIDGE AND VALLEY AND HIGHLANDS REGIONS OF NEW JERSEY

by

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ABSTRACT OF THE THESIS

Characterization of Landscape-scale Habitat Use by Timber Rattlesnakes (*Crotalus horridus*) within the Ridge and Valley and Highlands Regions of New Jersey

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Regulations and a lack of understanding the habitat needs of timber rattlesnakes (*Crotalus horridus*) on a landscape-scale have limited conservation efforts. With better information land managers and planners could implement strategies that protect suitable habitats from development and other human activities. While studies have shown microhabitat characteristics play a role in habitat selection by timber rattlesnakes, it remains unclear if large-scale features, other than rock outcrops, talus slopes and canopy, also impact site selection. I compared the habitat use by two metapopulations of timber rattlesnakes in northern New Jersey with available habitats using GIS data layers to identify the snakes' macrohabitat preferences. The results showed snakes used habitats with slightly more open canopy, closer to rock outcrops, and farther from roads, human development, forest edge (an interface between any habitat and forests with >50% canopy closure) and streams and rivers ($\geq$10m wide) than randomly sampled locations. Additionally, I developed a model and distribution map of potential areas where hibernacula may exist in northern New Jersey by first testing habitat and topographic variables to determine the predictors of suitable habitat for hibernacula. In 2004, elevation, sun index, deciduous wetlands and slopes (0-20%) were the most influential features in predicting suitable habitat for hibernacula. Slopes (0-20%) and deciduous wetlands were negatively associated with hibernacula indicating that areas containing shallow slopes and/or deciduous wetlands were less likely to support hibernacula. Sun index indicated that hibernacula are most likely to be found in areas with steep slopes and southerly aspects, and elevation, having the least influence in predicting suitable habitat for hibernacula, showed the likelihood of hibernacula presence increased with increasing elevation. In 2009, with the addition of interior forest hibernacula in the dataset, only slope (0-20%) and sun index were influential features in predicting suitable habitat for hibernacula indicating that the potential for hibernacula presence increased in areas with steep slopes and southerly aspects. Landscape modeling using GIS-ready habitat features can help biologists identify habitats essential for populations and metapopulations, and target conservation of those habitats and connecting corridors for long-term timber rattlesnake viability.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER 1: INTRODUCTION

Habitat loss continues to be a major factor affecting long-term viability of both native flora and fauna. However, habitat fragmentation is an issue widely accepted in the field of conservation as one of the most detrimental factors impacting our native species (Bennett 1998, 2003, Gibbons et al. 2000). While natural fragmentation does occur, it is often the human-induced division of larger habitat patches into smaller areas that negatively impacts species (Hilty 2006). This could be as obvious as a road bisecting grasslands or as subtle as improper silviculture practices dividing old growth forests with younger stands that may not be suitable for all wildlife (Bennett 1998, 2003).

Roads and development that fragment habitats create passage barriers for wildlife, especially terrestrial-bound species, decreasing their chances of successfully moving from one habitat patch to another. For smaller, slower-moving species such as reptiles and amphibians, a road could be impossible to cross safely. These manmade boundaries often isolate populations, limiting genetic exchange, and in some cases, populations dwindle until they finally disappear (Bennett 1998, 2003, Parent and Weatherhead 2000).

Additionally, linear edge increases as a habitat patch is divided into multiple smaller patches. This in turn, increases the edge effect caused when an area extending from the edge inward is impacted by the events occurring on the exterior of the patch (e.g., traffic, noise, light, increased number of scavengers or predators) (Bennett 1998, 2003). Depending on the size of the patch, the entire area could be affected, negatively impacting the species inhabiting the patch by decreasing their foraging or nesting success, increasing their stress and stress-induced illnesses (i.e., compromising their immune system) and, for water-dependent species, polluting the waters through petroleum run-off from roads or fertilizers from managed lawns.

Although a relatively recent primary goal in conservation is to protect or restore connective corridors between suitable habitats, data gaps remain regarding the requirements of many species (Hilty 2006). Regardless, conservationists agree that efforts must be made to decrease fragmentation and maintain or increase connectivity between populations while continuing to research the habitat requirements of wildlife species in order to refine and/or improve management strategies (Hilty 2006). In addition, researchers must continue to locate critical core habitats in need of connective corridors and target immediate conservation and management efforts to maintain or enhance resident populations, especially for rare flora and fauna.

For a species such as the timber rattlesnake (*Crotalus horridus*), conservation strategies that focus on protecting critical core habitats and travel corridors, while maintaining connectivity to additional populations, can help improve the status of their populations through the northeastern United States. These snakes move from their hibernacula to their foraging grounds, generally the same area each year once they have established their ranges (although slight annual shifting occurs; Reinert and Zappalorti 1988), with males dispersing during the breeding season in search of females. By determining habitat parameters at both the microhabitat level and landscape-scale (also referred to as macrohabitat), habitat management and land-use decisions could be implemented that protect the needs of this species.

Study Species:

The timber rattlesnake (*Crotalus horridus*) is a thick-bodied, slow moving snake that relies heavily on its camouflage for self-defense. Timber rattlesnakes are only found in the eastern half of the United States with its range extending from the northeast to the southeast and on to the mid-west (Galligan and Dunson 1979, Martin 1992b). Declines in northeastern timber rattlesnakes' populations have led to the species being listed as either extirpated, endangered or threatened in all but three of the Northeast states with only one population remaining in New Hampshire and two in Vermont (Michael Marchand, New Hampshire Fish and Game Department, pers. comm.). Most of Massachusetts' population has disappeared (Martin 2002) and the Maine and Rhode Island populations are already considered extirpated (Breisch 1992). New York considers the species threatened, while New Jersey, Connecticut and Maryland list them as endangered. Pennsylvania currently has listed timber rattlesnakes as a species of special concern. The timber rattlesnake (*Crotalus horridus,* formerly *Crotalus horridus horridus*, thus excluding the canebrake rattlesnake) of the northern range of Virginia only has regulatory protection with regard to commercial trade and transport, up to five may be held in captivity. West Virginia offers no protection at any level. Delaware's population is considered extirpated although there are no substantiated historic records of their existence.

The rattlesnakes' life history strategy predisposes them to population declines. Although timber rattlesnakes are generally long lived, some reaching thirty years of age (Ernst and Barbour 1989), they have relatively late reproductive maturity. The average female first reproduces at seven to nine years of age (Martin 1993), requiring females to survive natural and anthropogenic predation and other disturbances over many years before producing a single litter. Females reproduce every three to four years if they have had successful forages and experience appropriate weather conditions and temperatures during gestation (Martin 1993). A typical litter consists of only six to ten young (Ernst and Barbour 1989) and it is unknown how many young survive their first two winters. There are reports indicating that only 55 – 68% of yearlings survive their first year (William H. Martin, pers. comm.).

Additionally, timber rattlesnakes have had a long history of abuse and wanton killings by humans, even the destruction of entire populations (Galligan and Dunson 1979, Furman 2007). As recently as the early 1970's, bounties were still awarded for dead rattlesnakes in New York and Vermont (Furman 2007). As late as the 1960's, rattlesnakes were collected from New Jersey's hibernacula and gestating sites for sale to local zoos, the pet trade and to laboratories for the production of antivenin and simply to kill them. With protection from the New Jersey Endangered and Nongame Species Conservation Act (ENSCA, N.J.S.A. 23:2A-1 to –20) to prevent/minimize illegal collections and mass killings, the most difficult battles in conservation for this rare and unique species in New Jersey are preventing citizens from committing wanton killings and the lack of regulations to protect their critical upland habitats.

As a result of their late reproductive maturity, low fecundity, long intervals between breeding and the lack of habitat protection, in conjunction with human encounters, long-term survival of timber rattlesnake populations remains in jeopardy in New Jersey. Conservation measures to protect the populations must take into account the need to educate society about the important roles of rattlesnakes in our natural world in an effort to prevent or at least minimize wanton killings. Additional measures include the creation and acceptance of regulations that protect upland habitats where rattlesnakes have been documented.

Objectives:

This study uses data gathered from 28 radio-tracked timber rattlesnakes in the deciduous forests of northern New Jersey to identify landscape-scale features of summer ranges that could be used to develop a predictive model of suitable summer range habitats. While habitats identified through the landscape-scale parameters used in this research may not appear to be "preferred" or "optimum" habitat, the study examines habitat actually used by the snakes. Once habitat is identified as suitable foraging areas and/or potential summer range, management strategies can be developed to enhance or restore lands to optimal conditions that also may suit other rare wildlife (e.g., interior forest species such as barred owls, *Strix varia*, red-shouldered hawks, *Buteo lineatus*, and bobcats, *Lynx rufus*). This study also develops a predictive model of suitable habitat for timber rattlesnake hibernacula. By identifying potential areas where hibernacula exist, targeted field reconnaissance could result in newly discovered hibernacula for which management and land-use strategies can be developed to enhance and protect these critical areas. Additionally, it is equally important to identify and protect core foraging areas (and the associated travel corridors) associated with known or newly discovered hibernacula in order for local populations of rattlesnakes to persist.

Background:

Research

There is much literature describing the natural history (Klauber 1956, Galligan and Dunson 1979, Martin 1992b), seasonal cycles, home range (Reinert and Zappalorti 1988, Brown 1992, Martin 1992a) and microhabitat use (Klauber 1956, Reinert 1984a and 1984b, Reinert and Zappalorti 1988) of the timber rattlesnake *(Crotalus horridus)*. Over the past three to four decades the use of radio-telemetry has provided scientists with detailed insight into the movements and behavior of this secretive creature that is otherwise difficult to detect because it is cryptically colored and often sits quiet and still. Information from these studies has proven invaluable in helping scientists and conservationists understand the microhabitat requirements of this species. Use of this knowledge has resulted in the implementation of conservation efforts in most of the northeastern states through public outreach, the protection of dens and state listings affording the rattlesnakes protection under state Endangered Species Acts. However, this species is still considered rare and, regionally, populations remain in jeopardy (Galligan and Dunson 1979, Breisch 1992, Martin 2002, Michael Marchand, New Hampshire Fish and Game Department, pers. comm.). More action will need to be taken to protect them before they are regionally extirpated from the Northeast, including gaining a better understanding of this snake's needs on a landscape-scale in relationship to their selected habitats. Determining the proximity of these sites to human activity may better enable planners and land managers to manage lands suitable for this rare species and minimize human-rattlesnake interaction (Peterson 1990, Brown 1993, Parent and Weatherhead 2000).

Earlier research has provided information on seasonal movements and behavior, including individual snake's core and critical habitats (i.e., foraging areas, dens, gestation and shed sites, transient areas) over a large area. Rattlesnake activity often centers around their hibernacula and gestation sites (Martin 1993), with snakes moving around a "general summer range" during the foraging and breeding season and returning to the same hibernaculum each fall (Landreth 1973, Reinert and Zappalorti 1988). A study of eighteen resident rattlesnakes tracked by radio-telemetry (fifteen over one active season and three over two active seasons) showed that each year, resident snakes used the same path of egress from the hibernaculum and general activity range (Reinert and Rupert 1999). An earlier study that tracked rattlesnakes over one active season found that rattlesnakes used the same path of egress from the hibernaculum due to the topography (Bushar et al. 1988), a finding also supported by Brown et al. (1982) and later by the NJ Division of Fish and Wildlife, Endangered and Nongame Species Program (ENSP), unpubl. data (1999 - 2000). These studies support the theory that the landscape plays a vital role in habitat selection and movement patterns because landscape features influence the path of an individual's movements.

In addition to landscape features guiding directional movements to and from the hibernacula, features can also create barriers that may force snakes to use restricted corridors between preferred habitat patches (Wiegand et al. 1999). These corridors are not necessarily preferred habitat (Wiegand et al. 1999), but are critical because they allow movement through potentially unfavorable areas and connect prime habitat patches (Anderson and Danielson 1997; Wiegand et al. 1999). These corridors also permit genetic exchange between populations, which may be a crucial factor in maintaining healthy populations (Kienast 1993; Bushar et al. 1998).

Although there may be a number of preferred habitat patches, without corridors to reach these areas, they provide little support to the snakes, especially when separated by heavily traveled roads. In addition, this “landscape-guided” directional path of egress may affect the population’s overall distribution, their abundance in a given area and possibly their overall success (Flather and Sauer 1996). For example, the rattlesnakes’ path of travel may influence their choice of habitat use and therefore, the availability of prey, which, in turn can determine their long-term success. Bushar et al. (1998) suggested that male dispersal distances should be far enough to encounter females from other dens to increase genetic exchange and that the encounter rate is influenced by rock outcrop locations and access to the outcrops. This concept also supports the importance of landscape structure in habitat selection and the importance of habitat selection on reproductive success.

Habitat analysis on a landscape level may allow the identification of necessary corridors, or conversely, the lack of corridors, in addition to critical habitat patches throughout an area. By identifying and determining the importance of the corridors (those potentially connecting highly used habitat patches or preferred habitats) and identifying highly used or preferred habitats, land managers, conservation agencies, regulators and conservationists can develop conservation strategies to protect these vital pathways and minimize human activity. Further, with access to Geographic Information Systems (GIS) and satellite imagery since the early 1980s, scientists have been developing wildlife habitat mapping for targeting reconnaissance work, guiding habitat management and evaluating habitat suitability (Aspinall and Veitch 1993, Pereira and Itami 1991, Roseberry et al. 1995 and Rittenhouse et al. 2007).

Habitat Modeling and Conservation

In the 1990's, Alvin Breisch, New York State Department of Environmental Conservation, developed a model and habitat suitability map of timber rattlesnake hibernacula for use in New York state (Alvin Breisch, pers. comm.). The resultant map was broad in scope and identified many areas as suitable habitat. Breisch expressed that the difficulty was not in a lack of knowledge about rattlesnake habitat requirements, but rather the quality of the GIS data layers at that time (Alvin Breisch, pers. comm.). Browning et al. (2005) also developed a model and probability map to depict suitable habitat for hibernacula within a Wildlife Management Area of predominantly oak-hickory and oak-pine forests in northeastern Arkansas. Although confident the model could assist in targeting reconnaissance efforts, they found the areas identified for potential hibernacula varied widely in their suitability according to the analysis with some areas being valued as having a lower probability of presence than others. Browning et al. (2005) suggested the possibility that more refined GIS data layers (i.e., soil properties) might help in future modeling of rattlesnake hibernacula.

While Breisch's model of suitable habitat for hibernacula had the potential to provide useful information and helped focus this present study's efforts to create a similar model, it is unclear if his model has been revisited with more current GIS data layers. Browning's study incorporated thirty-nine hibernacula, thirty-five that appeared to have the standard or typical characteristics as described by Klauber (1956) and Galligan and

Dunson (1979), including sun-exposed slopes of talus and ridgeline with southeast to southwest aspects. Four hibernacula had slightly varying features including two facing north and northeast and two on steeper slopes (Browning et al. 2005). However, with the assistance of radio-telemetry, researchers have discovered “atypical” hibernacula within the interior forest (Howard Reinert, pers. comm., Kathleen Michell, pers. comm.,), some as much as 100m from the nearest basking area (Kathleen Michell, pers. comm., K.A. Schantz, pers. obs.). “Interior forest” hibernacula may be critical to each local population due to the difficulty people have in identifying them, thus decreasing the likelihood of intentional anthropogenic disturbances at these locations. It does not appear that the model developed by Brown et al. (2005) used interior forest hibernacula, and it is unclear if Breisch’s model included similar sites or rather focused on hibernacula satisfying the standard descriptions (Klauber 1956, Galligan and Dunson 1979). Given the limitations of GIS, it is possible interior forest hibernacula, at least those found in New Jersey, will not easily be modeled as they are located under the canopy and at lower elevations than the more typical talus and ridge-based hibernacula, limiting the characteristics discernable through GIS. It may be necessary to use surficial and subsurface data depicted in GIS-ready data layers as they become available. Additionally, a dataset consisting of mostly “typical” hibernacula with fewer interior forest hibernacula may skew the analyses of habitat and topographic features that act as predictors of hibernacula presence, decreasing a model’s ability to identify potential habitats where interior forest hibernacula exist.

Rittenhouse et al. (2007) developed a habitat suitability index model (HSI; HSIs also described in Dijak et al. 2007) to identify the suitable habitat (active season) of timber rattlesnakes in the central hardwoods of the Midwestern United States. They used five variables to value the landscape, including proximity to hibernacula (or hibernacula areas which usually contain multiple den pockets), early successional foraging habitat, distance to roads, woody debris (for shelter and foraging) and the proportion of woody debris to foraging habitat determined by canopy cover. The amount and composition of woody debris was assumed to be correlated to the age of the forest stand with older stands of trees (>100 years) containing more woody debris suitable for rattlesnake foraging and a declining suitability as a stand age decreased. Distance to roads was used as a value of unsuitable habitat with suitability decreasing as distance to roads decreased.

It would be time-intensive and costly to develop broad-scale field documentation confirming the presence of woody debris over a large area. Thus, it is understandable why Rittenhouse et al. (2007) derived a value for woody debris based on stand age. However, while northern New Jersey's forests, the focal area of this study, are not homogeneous, there are few uneven-aged forest stands on public lands where rattlesnakes are found. This is due, in large part, to the lack of timber harvesting and timber stand improvement work being conducted on public lands in New Jersey. The National Park Service does not allow any timber harvests nor do they conduct any timber stand improvement work on the Delaware Water Gap National Recreation Area (located along the Kittatinny Ridge, a portion of the Ridge and Valley Region). The NJ Division of Parks and Forestry conducts very limited timber harvesting or timber stand improvement work on state-owned forests. Given that many of New Jersey's forests on public lands contain older stands rather than uneven-aged forest stands, it would be difficult to develop a gradient representing the amount of woody debris based on the stand age.

Therefore, using a value for woody debris derived from stand age may not be as successful a predictor in all states, specifically New Jersey, as it was in the study by Rittenhouse et al. (2007).

Since dispersal distances of rattlesnakes from their hibernacula have been well documented (Brown 1993), applying the proximity of known hibernacula as a means of identifying suitable habitat will benefit any model. However, it will only assist in areas where documented hibernacula exist and will not provide information regarding potential suitable habitats where snakes have not been observed but may persist.

Additionally, roads themselves are unsuitable for rattlesnakes as the snakes are exposed to predators and at risk of road mortality (Bonnet et al. 1999, Andrews and Gibbons 2005, Andrews et al. 2006). Timber rattlesnakes, in particular, may be at greater risk than other snakes as Andrews and Gibbons (2005) found that while most mature timber rattlesnakes avoided roads, those that approached or attempted to cross, became immobilized 50% of the time as vehicles approached and passed. This makes them very susceptible to both accidental and purposeful road mortality. However, it is unclear if all habitats near or adjacent to roads are also unsuitable or perhaps suitable but avoided by snakes due to road influences affecting their ability to detect prey and predators such as noise pollution, light pollution and increased vibrations (Tuxbury and Salmon 2005, Andrews and Gibbons 2005, Andrews et al. 2006). While Rittenhouse et al. (2007) found the snakes avoided areas near roads, I will further examine this feature as roads are of particular concern for wildlife in New Jersey because of the dense infrastructure within the State.

As urban sprawl continues to pepper New Jersey's landscape, natural resources and wildlife will benefit from informed land managers and planners that better understand life history requirements and how to protect these resources on a larger scale. Timber rattlesnakes, a state endangered species in New Jersey, are protected under the NJ Endangered and Nongame Species Conservation Act (ENSCA, N.J.S.A. 23:2A-1 to -20). However at this time, the act does not explicitly guarantee wildlife the protection of suitable habitat, but rather only protects individuals. Land-use decisions that consider the requirements of the rare and endangered snake may assist in the recovery of the timber rattlesnake in northern New Jersey and perhaps other mountainous northeastern habitats. It is the responsibility of the state wildlife agency in New Jersey to provide the necessary information on the distribution and critical habitats of rare wildlife so that planners and regulators can apply this information when making land-use decisions. As such, the NJ Division of Fish and Wildlife, Endangered and Nongame Species Program (ENSP) developed a regulatory map, *The Landscape Project* (Niles et al. 2001), first released in 2001 and now in Version 2.1, to accomplish this task.

The ENSP continues to revise and refine *The Landscape Project* maps based on continuing research and literature reviews. The habitat suitability index model developed by Rittenhouse et al. (2007) is very similar to *The Landscape Project* in that they both identify suitable habitat based on documented preferred habitats and requirements of the species. *The Landscape Project* map, however, is also based on confirmed observations of rare wildlife and builds upon those observations (Niles et al. 2001, Winkler et al. 2008).

Additionally, the passing of the Highlands Water Protection and Planning Act in 2004 led the Highlands Council to develop a regional master plan to identify areas within its region in New Jersey for development and conservation (New Jersey Highlands Council 2008). The ENSP, in an effort to assist the Highlands Council, created a more specific species-based patch mapping system to value critical habitat within the Highlands Region (*The Landscape Project*, Version 3.0, Highlands; Winkler et al. 2008). By using a species-based patch system, planners and land managers are able to identify habitat parcels critical to rattlesnake persistence at a more precise scale than the former version. The ENSP is working to revise the map for the remainder of the State, but currently uses Version 2.1 outside of the Highlands Region. *The Landscape Project* map and documentation can be found on the Internet at www.njfishandwildlife.com/ensp/landscape/index.htm.

As a regulatory tool, *The Landscape Project* critical habitat mapping was created using documented sightings and minimal extrapolation to habitat typing, and therefore, it can only provide assistance to land stewards, managers and planners in areas where the State has documented, confirmed occurrences. Given the cryptic nature of rattlesnakes and the potential continued decline of populations, a lack of observations does not necessarily mean an absence of snakes (Kéry 2002). An example of this is a hibernaculum discovered during ENSP's research along the Kittatinny Ridge (1999-2000). After approximately twelve visits to and surveys of the area during the fall seasons of 1999 and 2000, and the spring of 2000, the hibernaculum was believed to contain a satellite or depleted population as only a single study snake had been observed in the area. During the spring, 2001, a revisit to collect the snake for transmitter removal and a brief survey of the neighboring talus revealed seven additional rattlesnakes and two northern copperheads (*Agkistrodon contortrix mokasen*). Clearly, this supports the need to protect and manage habitats that fall within the rattlesnakes' distribution and are suitable to sustain them, regardless of whether or not there are reported observations. However, because *The Landscape Project* includes a regulatory map based on valuing potential suitable habitat determined by the ENSP and selected from the habitats described by the NJ Department of Environmental Protection's 2002 Level III Land Use/Land Cover data layer (LU/LC02) with modified descriptions from Anderson (1976), identification of potential "suitable" habitat would value much of the northern region of New Jersey if observations were not used as a basis for the valuation. Given the difficulty to detect the snakes, the timber rattlesnake population recovery and stabilization may depend on the development and implementation of habitat management strategies that benefit timber rattlesnakes in suitable areas regardless of whether or not an observation has been documented. By identifying areas of suitable habitat within the rattlesnakes' distribution in northern New Jersey, land managers and planners could implement management strategies to assist in their recovery.

This research focuses on two components that will assist in the conservation of timber rattlesnakes (*Crotalus horridus*) in northern New Jersey. The first, described in Chapter 2, is to develop a model that depicts suitable habitat for hibernacula. The second, described in Chapter 3, is to identify landscape-scale features and parameters that will be used to develop a future model depicting suitable habitat for the snakes' summer range.

CHAPTER 2:
MODEL DEPICTING SUITABLE HABITAT FOR TIMBER RATTLESNAKE HIBERNACULA

Timber rattlesnakes (*Crotalus horridus*) have strong affinities to their home range, basking areas and hibernacula. Neonatal snakes will scent-trail adult rattlesnakes to their hibernacula typically for their first few winters (Brown and MacLean 1983, H. Reinert, pers. comm.). Occasionally, young rattlesnakes will use different hibernacula during the first two to three years of their lives but will then return annually to one hibernaculum; most often their wintering site for life (H. Reinert, pers. comm.). Brown (1992) reports that hibernacula fidelity is strong but not guaranteed, although ENSP (unpubl. data) supports 100% site fidelity. Regardless, there is clearly a strong attachment to their hibernacula, and for this reason, it is imperative that these sites are protected from development and disturbance, but also that connective corridors to the snakes' summer range are identified and protected as well. To provide such protection, hibernacula (and core summer habitat) must be identified. Due to the difficulty in detecting this cryptic species, this portion of the study focused on the development of a model identifying suitable habitat for hibernacula to help target field reconnaissance to discover new dens.

MATERIALS AND METHODS:

Twenty-one habitat and topographical features identified as potential factors influencing the presence of hibernacula were tested to determine their ability to identify potential habitat where hibernacula may exist in northern New Jersey. The features immediately surrounding known hibernacula were compared to random locations to determine which combination of the features best predicted the presence of hibernacula. The resultant model was applied to northern New Jersey using GIS to produce a distribution map of potential suitable habitat for hibernacula.

Study Area

Data for the model depicting suitable habitat for hibernacula (here after referred to as "hibernacula model" or "model") was collected in the mountainous portions of northern New Jersey where timber rattlesnakes exist including the Kittatinny Ridge (a portion of the Ridge and Valley Region) and areas within the Highlands Region; a study area consisting of more than 502,000 acres (Figure 1). Although the model was developed using known rattlesnake hibernacula locations within these areas, the model has the potential to be used in other mountainous northeastern states inhabited by timber rattlesnakes such as New York, Pennsylvania and New Hampshire.

The New Jersey portion of the Kittatinny Ridge, part of the Appalachian Ridge and Valley, consists of the main Kittatinny Ridge that rises up from the Delaware River at the Delaware Water Gap in Warren County and extends northeast through Sussex County to the New York border. This portion of the study area targets approximately 163,400 acres of which approximately 74,700 acres (46%) are in conservation ownership as public lands held by state and federal governments or are otherwise protected.

The New Jersey Highlands Region extends from western Bergen to eastern Sussex Counties and from the New York border southwest through Morris and Warren Counties. The ridges and valleys in this region are the result of the uplifting of the land that occurred millions of years ago along several faults, primarily the Ramapo and Fyke. Their current character is the result of millions of years of weathering and erosion and glacial advances that have stripped the tops of the ridges of soil materials and deposited them on the lower slopes and in the valleys. Some of the slopes on these ridges are as steep as 40 percent or more and vertical drops where the bedrock has been exposed are not uncommon. This portion of the study area includes approximately 338,630 acres of which approximately 190,886 acres (56%) are in conservation ownership.

The total study area was defined by using all areas, regardless of habitat type, within New Jersey's Ridge and Valley and Highlands Regions $\geq$ 150m (~500') (Brown 1993) in elevation using 10-m resolution digital elevation model (DEM) contour lines (NJ Department of Environmental Protection, Office of Information Resources Management, Bureau of Geographic Information and Analysis 2002).

Data Collection and Compilation

Model Preparation

In preparation of developing the model, GIS data layers of potential habitat types and topographic features that would potentially assist in depicting suitable habitat for hibernacula were gathered to test their significance. In preparation to test these variables (Table 1), known hibernacula locations were compiled and random locations were generated to enable a correlation coefficient analysis of the variables in relation to the used and [assumed] unused locations (heretofore referred to as unused locations, unused habitat or absence locations).

With guidance from Al Breisch's hibernacula model development (pers. comm.), literature reviews (Klauber 1956, Martin 1992b and 2002, Brown 1993) and personal knowledge of rattlesnake habitat, GIS data layers of potential significant features characteristic of hibernacula (or the absence of hibernacula) were compiled from various sources including the New Jersey Department of Environmental Protection (NJDEP) (1995, 2002), the United States Department of Agriculture (USDA), Natural Resource Conservation Service, SSURGO data layers (SSURGO 2004) and digital elevation models (NJDEP 2002) (Table 1).

In addition, hibernacula locations (n = 26) reported to the ENSP prior to 2001 were used to develop a model in 2004. However, ENSP staff had not yet confirmed all of the locations. In 2008, a review of the original hard-copy data of the 26 reported hibernacula, many made prior to 1995, revealed fifteen of these hibernacula were questionable as to their reliability and/or their assessment as hibernacula, transient/staging areas or basking areas. Due to the uncertainty of correctly classifying these locations as hibernacula, they were excluded from the development of the 2009 model. The refined model, 2009, was developed using 32 hibernacula including the remaining eleven of the original 26 hibernacula used in the 2004 model and an additional 21 hibernacula located since 2003 (17 through radio-telemetry and four through volunteer searches; including seven, possibly eight, interior forest hibernacula). The 32 hibernacula ranged in last observation dates from the early 1980's to 2008

A 200m-radius buffer was applied to each hibernaculum to include transient and potential gestation areas; these are areas critical to the each population's persistence. These are surficially similar habitats and Brown (1992) determined that transient areas are often located within 200m of a hibernaculum; findings supported by the NJ's Division of Fish and Wildlife's Endangered and Nongame Species Program's (ENSP), unpubl. data (1999 - 2000).

To develop the model, I used logistic regression to compare the used and unused habitats ($\alpha = 0.05$). However, given the lack of negative data, I used random habitats as assumed unused locations. Random habitat points were computer-generated without overlap of each other, known hibernacula or the associated 200m-radius buffers. I then compared [assumed] unused habitat (also referred to as "absence" locations in this portion of the study) to the known hibernacula areas (also referred to as "presence" locations) using the Animal Movement Extension (Hooge and Eichenlaub 1997) in ArcView 3.2. Ten times as many random points as known hibernacula were generated and the 200m-radius buffer was applied to all of the points (in 2004, n = 260 and in 2009, n = 320).

Vegetation datasets (Table 1) were derived from the NJDEP's 1995/97 (and later, 2002 for use in the 2009 model) Land use/Land cover layers and the soil composition dataset was derived from SSURGO soil layers (SSURGO 2004). Attributes describing the percentage of vegetation and soil composition were calculated for the buffer surrounding each hibernacula and random sample point (here after referred to as "hibernacula buffer" and "random buffer", respectively). Digital elevation models (DEMs) (NJ Department of Environmental Protection, Office of Information Resources

Management, Bureau of Geographic Information and Analysis 2002) were used to obtain elevation information and to derive slope and aspect datasets. The mean elevation and slope were calculated for each hibernacula and random buffer. The slope dataset (percent rise) was classified into four categories: 0-20%, 20-40%, 40-60%, and >60%. An aspect dataset was derived and classified into four categories: 0-90˚ (Northeast), 90-180˚ (Southeast), 180-270˚ (Southwest), and 270-360˚ (Northwest). The proportion of each of the slope and aspect categories found within the hibernacula and random buffers were calculated.

DEMs were also used to derive a sun index, representing a factor that combines both the slope and aspect of the terrain as an indicator of sun exposure. The formula for this calculation as per Wilson et al. (2001, 2002) is as follows:

$$\text{Sun index} = \cos(\text{aspect}) \times \tan(\text{slope}) \times 100$$

The resulting values ranged from – 219.4 to 160.8, so a constant equal to 220 was added to all of the grid cells to obtain positive integers for grid values with low values representing high solar radiation. For example, sun index values decrease with southerly aspects and steeper slopes, features indicative of increased sun exposure and thus preferable wintering habitat for the timber rattlesnake. Conversely, sun index values increase with northerly aspects and shallow slopes. As such, the lower the sun index value, the greater likelihood of the habitat being suitable for hibernacula. The mean sun index was calculated for each hibernacula and random buffer.

Field Reconnaissance

Surveys were conducted during emergence, typically late April through May, 2004 – 2008, using the 2004 resultant probability map with the assistance of trained volunteers and ENSP staff to confirm hibernacula presence. Surveyors targeted areas of highest probability (90-100% likelihood of hibernacula presence) but often also surveyed areas of lower probability surrounding these locations.

ENSP staff and experienced volunteers were provided with the appropriate safety equipment (i.e., chaps/leggings, epi-pens, venom-extractor kits) and given topographic and aerial maps with an overlay of the probability map. Volunteers always surveyed with another person (volunteer or staff); staff occasionally surveyed alone. Geographic Positioning Systems (GPS; Garmin eTrex Legend) were uploaded with a centroid point of each highest probability polygon to guide field observers to the target areas. However, surveyors were required to survey all suitable habitats leading to and from the centroid point, extending from ridge-tops to lower elevation slopes, in effect surveying transect belts of undetermined and varying widths. Surveyors were required to record both presence and potential absence findings between centroid points (with centroids used as points of reference); all rattlesnake (and northern copperhead, *Agkistrodon contortrix mokasen*) observations were recorded and captured using a GPS.

In 2006, surveys were targeted to the highest-probability areas that lie within 1 mile of the New York border because rattlesnake occurrences that crossed the NJ-NY line could be subject to habitat protection under New York State Department of Environmental Conservation (NYS DEC) regulations. Since activities adjacent to the border could potentially impact New Jersey rattlesnake populations during the snakes' summer movements, surveys were conducted in an effort to gather useful information to provide to the NYS DEC that would assist them in regulatory decisions and potentially protect New Jersey's snakes.

Model Development

In 2004, the relationships of 21 habitat and topographic variables (Table 1) were explored and all variables that were collinear or invariant were eliminated. Point biserial correlations were also calculated for each variable in relation to whether it was associated with a hibernaculum or a randomly selected point location to determine which variables alone were most correlated with presence and absence. Invariant variables and the variable from a pair of collinear variables that showed a weaker correlation to presence and absence were not used for model development. Logistic regression models were created using SPSS 12.0.1 (SPSS Inc., Chicago, Illinois) with the binary response variable of presence and absence and the habitat variables for every combination of the final variables. Backwards selection was employed during model development wherein the variable with the highest p-value was eliminated until each of the remaining variables had a p-value of <0.05.

The best model was selected based on classification success of used (presence) and unused (absence) locations by comparing the predicted values from the logistic regression models with a probability cut-off value that distinguished suitable from unsuitable habitat. Relative operating characteristic (ROC) graphs/ plots were used to derive the cut-off value that would successfully classify the maximum proportion of true positives (used habitats) while minimizing the proportion of incorrectly classified sites

(Fielding and Bell 1997, Pearce et al. 2000). The area under the curve (AUC) was used to evaluate the success of the model based on a value of 0.5 representing a poor classification through 1.0 representing perfect classification (Pearce et al. 2000 and Gibson et al. 2004). However, once the data was applied and the classification success determined, it was necessary to adjust the cut-off value in order to maximize correctly classified data and minimize incorrectly classified data (Fielding and Bell 1997, Pereira and Itami 1991)

RESULTS:

The final 2004 hibernacula model with the best classification success contained four variables (Table 1). The same four variables were analyzed in 2009 using logistic regression in SPSS 12.0.1, but only two were found significant.

The logistic equation and associated inverse logistic transformation of the final 2004 hibernacula model is as follows:

$$Y = (31.169) - (.195(\text{deciduous wetland})) - (.171 * (\text{slope } 0\text{-}20\%)) + (.005 * (\text{elevation})) - (.117 * (\text{sun index}))$$

$$\text{Probability of occurrence} = \exp(Y)/(1+\exp(Y))$$

The most influential variable was slope (0-20%) with a negative influence on predicting hibernacula as shallow slopes were less likely to support hibernacula. Sun index was the next most influential variable, also having a negative influence, but in this case, lower sun index values represented an increase in sun exposure and solar radiation, a preferred habitat for overwintering rattlesnakes. Therefore, as sun index decreased in value it became a better predictor of hibernacula presence. Deciduous wetlands also had a negative influence on predicting hibernacula with the presence of deciduous wetlands decreasing the likelihood of hibernacula existing in a given area. Finally, elevation was the least influential variable when predicting hibernacula, but showed higher elevations had a greater likelihood of hibernacula presence.

Using a "cut-off value" of 0.50, the 2004 model correctly predicted 99.2% (258/260) of absence locations and 84.6% (22/26) of presence locations. In an attempt to minimize the number of incorrectly classified absence while maximizing the number of correctly classified presence locations, using an altered cut-off value of 0.460 resulted in 98.8%

(257/260) correctly classified absence locations and 88.5% (23/26) presence locations (Table 2a). ROC plots yielded an area under the curve (AUC) of 0.993 $\pm$ 0.004 indicating that the model could correctly distinguish between presence and absence 99% of the time. Encouragingly, field reconnaissance over four emergence periods (2003 – 2008) using the 2004 hibernacula model resulted in two newly discovered hibernacula located within areas designated as having the highest probability of presence locations.

Given the accuracy of the 2004 model, the same four variables were used to build the 2009 model. However, the deciduous wetlands data layer was updated in 2002. A comparison of proportional deciduous wetlands within reused hibernacula buffers (buffers used to build both the 2004 and 2009 models) revealed little or no change in the proportion according to the NJDEP's 1995/97 Land use/Land cover layer and the 2002 coverage. Two hibernacula buffers had slight changes; one included 4.03% and 4.02% deciduous wetlands in 2004 and 2009, respectively, and the second had 21.09% and 21.07%, respectively. These were not considered to constitute important differences and therefore the updated LU/LC02 coverage was applied to all 32 dens.

The final 2009 model using the new hibernacula coverage and updated deciduous wetlands variable contained only two of the variables that were in the final 2004 model, slope (0-20%) and sun index (Table 2b). Elevation resulted in a p-value of 0.078 and was reconsidered for inclusion. However, its inclusion resulted in the model not classifying presence and absence as well as when it was excluded. Therefore, with both a p-value higher than the defined limit of 0.05 and its failure to enhance the model, it was excluded.

The logistic equation and associated inverse logistic transformation of the 2009 hibernacula model is as follows:

$$Y = (26.318) - (.125(\text{slope 0-20\%})) - (.088 * (\text{sun index}))$$

$$\text{Probability of occurrence} = \exp(Y)/(1+\exp(Y))$$

As with the 2004 model, the most influential variable was slope (0-20%) with areas including shallow slopes being less likely to contain hibernacula. Sun index was also an influential variable, with sun exposure and solar radiation increasing as the sun index values decreased. Therefore, as sun index decreased in value it became a better predictor of hibernacula presence.

Using logistic regression and a cut-off value of 0.50, the model correctly predicted 99% of absence locations but only 62% (20/32) of presence locations. Again, in an effort to achieve the most successful predictive model, all cut-off values between 0 and 1 were evaluated (Figure 2). With the optimal cut-off value of 0.11, the 2009 model correctly predicted 296/320 (92.5%) of absence locations and 29/32 (90.6%) of presence locations. ROC plots yielded an area under the curve (AUC) of 0.996 $\pm$ 0.015 indicating that the model could correctly distinguish between presence and absence 99% of the time.

GIS was used to apply the resultant final models to every possible 200m-radius buffer at 10m intervals in the study area and produce a map displaying the predicted relative probability of occurrence of hibernacula (Figures 3 and 4). An evaluation of these predictive maps revealed the 2004 hibernacula model valued approximately 16,553 acres (3.31% of study area) as suitable hibernacula habitat and the 2009 model valued approximately 36,939 acres (7.39% of study area) as suitable hibernacula habitat, of which 16,278 acres were also captured in the 2004 model. Of those areas deemed suitable by the 2004 and 2009 models, 12,509 acres (75.57%, using NJDEP's pre-2008 open space data layer) and 26,797 acres (72.55%, using NJDEP's 2008 open space data layer), respectively, were/are located on conserved lands.

DISCUSSION:

Both the 2004 and 2009 models were able to correctly classify a large percentage of both used and [assumed] unused habitats for timber rattlesnake hibernacula. The 2004 model and resultant predictability map, however, were developed using a dataset of identified hibernacula that fit the more typically characterized hibernacula including sun-exposed areas along talus or ridgelines at higher elevations with steep slopes. As such, the model identified similar habitats as potential sites for hibernacula although these features could have been delineated using aerial photography, topographic maps, minor field reconnaissance and a basic knowledge of rattlesnake habitat. The 2009 model, however, was developed using a dataset that included interior forest hibernacula and excluded questionable hibernacula that had been used in the 2004 model. This resulted in altering the habitat and topographic features that influenced the predictability of the model and a predictability map that identified potential ridge and talus hibernacula in addition to other potential interior forest hibernacula. These sites are virtually impossible to locate without the use of radio-telemetry due to their uncharacteristic features (compared to that described in the literature). Such information will guide targeted surveys to locate these somewhat hidden, but critical sites.

Model Suitability

The 2004 and 2009 models were statistically significant given the classification results, although they differed with regard to the variables influencing the presence of hibernacula. The 2004 model was developed using four habitat and topographic variables. Slope at 0-20% rise and deciduous wetlands were negatively associated with hibernacula as areas with shallow slopes and/or the presence of deciduous wetlands decreased the likelihood of hibernacula presence. Sun index was also negatively associated with hibernacula, however, since the lower sun index values represented an increase in sun exposure and solar radiation, a decrease in the sun index value increased the likelihood of hibernacula presence. Additionally, the sun index indicated that hibernacula are most likely to be found in areas with steep slopes and southerly aspects. Elevation had the least influence in predicting suitable habitat for hibernacula, but showed an increased likelihood of suitable habitats for hibernacula at higher elevations. The 2004 model's inclusion of sites that meet the typical characteristic features of hibernacula (often including sun-exposed rocky areas at or near ridge tops) and the availability of GIS data layers for such habitats and features may have enabled the model to result in a more refined map (valuing fewer acres) than the 2009 model, although not necessarily more accurate. More than half of the hibernacula used to build the map had not been confirmed and it is possible that the 2004 model is identifying potential hibernacula (or hibernacula areas including multiple den pockets) in addition to suitable transient or basking areas given the similarities in features. Although not the objective of the model, this information could still assist in targeting survey efforts given the rattlesnakes' behavior and propensity to bask at their dens and nearby transient areas upon emergence, therefore improving the potential to successfully identify these critical areas.

In 2009, only the sun index and slope (0-20% rise) demonstrated an association with hibernacula presence. Elevation may have been excluded as a significant feature because of the inclusion of interior forest hibernacula in this model's development which, in this dataset, were located along slopes at lower elevations within the forest rather than along or just below ridge tops. In addition, because these interior forest dens were at lower elevations, the areas surrounding the hibernacula often contain level ground and therefore, have a greater ability to support deciduous wetlands within the hibernacula buffer. This may have impacted the influence of the lack of deciduous wetlands depicting potential suitable habitat of hibernacula.

The inclusion of at least seven interior forest hibernacula may have resulted in the 2009 model more than doubling the acreage valuing suitable habitat for hibernacula. However, because these areas are under the canopy, GIS data is limited by information gathered through DEMs and SSURGO data layers (SSURGO 2004). Habitat data layers developed through the interpretation of aerial photography or satellite imagery, for example, may not be accurate, and may have limited the usable variables for this analysis. This may have caused the resultant model with a slightly broader scope, one that captured 98% of the habitat identified in 2004 in addition to potential interior forest hibernacula/ hibernacula areas.

A review of the resultant probability maps shows the increase in acreage of the 2009 model included capturing additional area around the sites identified in 2004 as high probability in addition to numerous small, isolated forested areas. Although broader in scope, the 2009 model has identified potential interior forest hibernacula areas (and likely, the associated open-canopy transient areas) where targeted reconnaissance may result in the discovery of additional populations. I propose that these interior forest hibernacula that are difficult to locate and therefore, inadvertently protected from intentional anthropogenic disturbances, may play a critical role in connecting known populations and therefore, increasing genetic exchange. By locating additional interior forest hibernacula, habitat management strategies could be developed and implemented to improve the success and likelihood of populations interacting (e.g., creating open canopies at rock outcrops). In addition, because this model was developed using variables derived from nationally available digital elevation models, other northeastern states could easily build this model and test these variables with their own data to evaluate the success at appropriately classifying suitable habitat for hibernacula.

Although not tested in this study, it may be beneficial to test additional SSURGO data layers such as soil porosity and duration of wet periods, depth of soil horizon and the density of rocks of varying size ranges between the surface and soil horizon, some of which proved successful for Browning et al. (2005). These, in addition to factors such as tree roots, may also dictate whether a snake is able to reach below the frost line, suitability of the subsurface area and the conditions a snake would endure during emergence as it moves to the surface and could help refine the model.

Although the current models can focus future survey efforts, the many hours that volunteers and staff dedicated to surveying suitable habitats as identified by the 2004 model resulted in only two newly discovered hibernacula. With the development of the 2009 model, it remains that a large area is valued as potential habitat for timber rattlesnake hibernacula that would require repeated surveys under optimal weather conditions and seasonal timing to observe the snakes upon emergence. Without more precise mapping, radio-telemetry, perhaps, remains the most accurate, successful and cost efficient method to locate hibernacula although it often requires invasive surgical transmitter implantation.

The ENSP intends to continue to conduct field reconnaissance and radio-telemetry studies to locate additional hibernacula with the help of trained volunteers. Additional samples in addition to testing other potential parameters may help refine this model.

Implications for Management of Rattlesnakes

Although the models valued a large portion of land as suitable habitat for hibernacula, an area still too large to generate substantial survey results in a short period of time, the 2009 model can still be used to protect potential hibernacula. In New Jersey, any activity conducted on State lands must undergo an internal review by all offices/ programs whose work/species may be impacted by the activity, whether it be trail reroutes or creation, prescribed burns or recreational mountain or dirt bike races. ENSP staff could use the data to determine if targeted survey efforts are needed in a particular area when reviewing these permit requests and make recommendations accordingly.

Other states, however, such as New York, that provide habitat protection for rare species could also apply this model to identify targeted locations for surveys when reviewing permit applications for development. Currently, the regional offices of the NYS DEC rely on partial data of species' location information retained in the regional offices as data retained by their Natural Heritage Program (species' observation database) is not easily accessible by the regional offices. As such, decisions to require surveys in a particular area are limited by the regional office staff's knowledge and data of known rattlesnake hibernacula within the area. This model could be tested on a state level, in an effort to increase the dataset and thus improve the accuracy, and then regional offices could consider the information when reviewing applications to determine if surveys should be conducted.

Additionally, the data could be used, by any state for which the model successfully classifies habitat, to help provide guidance to conservation partners (e.g., National Park Service, water utility companies, nonprofit organizations) that wish to avoid and/or manage sensitive areas or specifically, manage habitat for timber rattlesnakes regardless of documented occurrences. The model could also serve as a mutual template to model habitat suitability for other snakes as many of the habitat variables are similar.

CHAPTER 3:
IDENTIFYING LANDSCAPE-SCALE FEATURES AND PARAMETERS OF SUMMER RANGE

Timber rattlesnakes (*Crotalus horridus*), in addition to using the same hibernacula throughout their lives, also return to the same general summer range including foraging grounds and basking and shed sites, although Reinert and Zappalorti (1988) reported slight annual shifting of each snake's overall range. Males and nongravid females generally use similar forest habitats, although nongravid females typically have smaller ranges and spend more time in more open, sun-exposed areas than males (Reinert 1984a, Martin 1992a). Gravid females, in northern New Jersey, forage early in the season but move to open, rocky areas with shelter rocks where they will gestate for the majority of the season, giving birth in late August to mid-September (under appropriate weather and temperature conditions). Given the snakes' fidelity to their summer ranges, it is important that such areas are protected and disturbance minimized to increase their chance of long-term survival. However, suitable habitats within the snakes' distribution, where observations have not been documented, may also play an important role in the population's persistence, and possibly, genetic exchange as they may connect known populations. Identifying landscape-scale features and parameters could be used to develop a habitat suitability map to identify these areas where habitat management strategies could be implemented.

MATERIALS AND METHODS:

Data collected over the course of six years was used to develop landscape-scale (macrohabitat) parameters to help identify suitable summer ranges of timber rattlesnakes. For the purpose of this analysis, sites are identified as Sites 1 (Kittatinny Ridge) and 2 (Highlands Region).

Study Area

This study focuses on the habitats surrounding twelve known hibernacula for which radio-telemetry was used on 28 timber rattlesnakes to collect microhabitat and location data. All thirteen hibernacula are confined to the study area described in the *Den Model* section of this paper (Chapter 2, Figure 1).

Site 1, Kittatinny Ridge

This study site is located in the New Jersey Ridge and Valley Region and includes the area surrounding one hibernaculum along the Kittatinny Ridge in Hardwick Township, Warren County, New Jersey (ENSP unpubl. data, 1999 and 2000). As the majority of a single hibernaculm's population will include home ranges within a 1.5mi-radius of the hibernaculum (Brown 1993), random habitat points used to determine the available habitat were confined to within that area, excluding the Delaware River adjacent to the Kittatinny Ridge.

It is important to note that this portion of the research was part of an earlier study conducted by the ENSP in partnership with the National Park Service, 1999 - 2000. As such, the type of data collected and the generation of random habitat points varied slightly.

Site 2, Highlands Region

This study site includes the areas surrounding eleven hibernacula (including two sets of two with a high degree of overlap) within the Highlands Region, specifically within eastern Sussex, Passaic, western Bergen and northern Morris Counties. As with Site 1, because the majority of the summer activity range of snakes from a hibernaculum will be encompassed in a 1.5mi-radius of the hibernaculum (Brown 1993), random habitat points used to determine the available habitat were confined to within a 1.5mi-radius around each hibernacula used in this study.

Both regions have undergone various transformations over the last century. European settlement brought farmers and miners who cleared the forests. Much of the Kittatinny Ridge (a portion of the Ridge and Valley Region) was then designated as a national recreational area, and the forests were allowed to rejuvenate, while the Highlands have become a combination of development, state and non-government organizations' protected lands and private lands of water utility companies. The forests are a mixture of deciduous hardwoods and hemlock stands. Lowbush blueberry (*Vaccinium vacillans*) and mountain laurel (*Kalmia latifolia*) appear to dominate the understory at high elevations; and higher still are numerous rock outcrops.

By identifying suitable summer ranges within these areas, regardless of documented occurrences, land managers and planners could implement strategies to manage and protect these critical habitats. Landscape-scale features and parameters, used to identify suitable summer range areas for timber rattlesnakes in northern New Jersey, will be determined by comparing snake-used versus potential available habitats. While landscape-scale (macrohabitat) features will help identify usable habitats, they cannot necessarily guide habitat management for a species that relies on conditions dictated by microhabitat (e.g., temperature and humidity or foraging locations such as downed logs and rocks). As such, microhabitat data collected from both sites at snake-used and available (random) locations are analyzed to determine if the microhabitats at and between sites differ. Such information will help guide future habitat management when evaluating the snakes' needs at a State regional level (i.e., New Jersey's physiographic regions).

Radio-telemetry

Radio-telemetry was used to gather microhabitat and location data of 28 rattlesnakes. Although "long-term" (spanning at least one active season) radio-telemetry studies require the surgical implantation of transmitters, an invasive and risky procedure, the data collected provides valuable insight into the habitat requirements of timber rattlesnakes in northern New Jersey.

Transmitters

All transmitters were purchased raw and the ENSP biologists prepared the final product following techniques described by Reinert (1992). All final packaged peritoneal transmitters weighed a maximum of 12.5 grams at Site 1 (Kittatinny Ridge) and 11.0

grams at Site 2 (Highlands Region). The target proportional weights of transmitters were to be less than 3% of a snake's body weight, an acceptable limit that would not impede their movement and activity (Kathleen Michell, New York Center for Turtle Rehabilitation and Conservation, Inc., pers. comm.). The ENSP staff surgically implanted packaged peritoneal transmitters in anesthetized snakes following the technique described by Reinert and Cundall (1982) and Reinert (1992), and the ENSP staff training by H. Reinert in the spring of 1999. Appendix 1 includes a detailed account of capture, implant and release dates and transmitter details.

Site 1 (Kittatinny Ridge)

All transmitters were manufactured by AVM Instrument Co., Ltd. (G-3 and SM-1). All but three snakes were implanted with transmitters weighing less than 3% of each snake's body weight. The three snakes whose transmitters were greater than 3% of their body weights included a female that provided additional data to the study, a male that did not recover from surgery and another male whose transmitter failed immediately upon release and the snake was lost in a crevice. In addition, a third male's transmitter failed prior to emergence in 2000. It is important to note that eight of the study snakes endured multiple surgeries that may have impacted their habitat selection and movements.

Site 2 (Highlands Region)

Either AVM Instrument Co., LTD. (G-3 and G3-1V) or L.L. Electronics (LS-1) manufactured all transmitters used at this location. All snakes at Site 2 received transmitters that weighed less than 3% of the snakes' body weights. Of the nineteen snakes implanted with transmitters during the 2003 and 2004 active seasons, three transmitters failed during hibernation and two others shortly after emergence, providing only partial seasonal data; all were unscheduled failures. Additionally, four snakes provided no data to the study. A gravid female and a male were killed shortly after their releases; the female's remains were recovered, but the male's transmitter was found in the leaf litter with no sign of his remains. Another female was removed from the study within two and a half months due to a battery leak and potential injury. A mature male's transmitter signal became irregular shortly after release and failed. Fifteen snakes provided data for use in these analyses; a total of 28 snakes between the two study sites.

Snake Capture and Implantation

Snakes were captured using snake hooks and cotton pillowcases or snake bags (Midwest Tongs, Inc., Greenwood, MO); carrying one snake per clean bag. The bags were marked if multiple snakes were captured in a given day. When in captivity, all snakes were kept solitary in sterilized tanks with fresh water and heating pads in areas with minimal to no human activity. All views were obscured to minimize stress. Snakes held in captivity for a week or longer were taken outdoors on warm days to bask. Prolonged periods in captivity were the result of ENSP staff time constraints and difficulty in coordinating schedules.

Site 1, Kittatinny Ridge

Eleven snakes were implanted in 1999 and six in 2000. Biologists captured six snakes (four adult males, one sub-adult male and 1 female) basking during emergence in the spring, 1999, and implanted them with transmitters. The remaining eleven study snakes (four males and seven females) were captured in the field through random observations or in close proximity to study snakes during the 1999 and 2000 field seasons. Five of these snakes (2 males, one nongravid female, two gravid females) were not used for any part of this analysis. One male's transmitter failed upon release, the second did not recover from surgery. The gravid females' habitat selection is different than that used during foraging by males and nongravid females, and would likely bias the data. The remaining nongravid female spent the majority of her summer at or adjacent to the hibernacula even after shedding. As I could not determine why she remained so close to the area upon recent review of the data, I decided to exclude her from the analysis in case she was recovering from an injury that I had not realized in 2000. Of the remaining six snakes tracked through hibernation, it was determined that one female was from the same study hibernaculum as the initial six snakes captured during emergence, 1999, but three females and two males were from four newly discovered hibernacula. Of the snakes to be included in this analysis (n = 13), there is GIS-based information (macrohabitat) for seven snakes with complete seasons and three snakes (females) for only partial seasons due to a computer failure and loss of 2000 digital data. "Partial season" data refers to data sets that include fewer than ten observations during one or more seasonal periods; pre-breeding (emergence – June 30), breeding (July 1 – August 15, capturing the peak of the breeding season in New Jersey) and/or post-breeding (August 16 – ingress, which also includes the waning breeding season) (K.A. Schantz, pers. obs.). Microhabitat data is available for all thirteen snakes (Appendix 2).

Site 2, Highlands Region

Due to the geographical expanse this study area covered, ENSP biologists focused on capturing study specimens from two known dens and a third potential hibernaculum during emergence in the spring of 2003. Biologists captured three snakes suitable for peritoneal transmitters (two adult males, one sub-adult male). The remaining sixteen snakes implanted with transmitters included 10 adult males, three sub-adult males and three females (one gravid, one post-partum and one nongravid), all captured during the 2003 and 2004 field seasons through random sightings and with the assistance of the ENSP's volunteer Venomous Snake Response Team. These volunteers are trained to safely remove venomous snakes from private lands or human-occupied sites (e.g., campgrounds) upon request and, in this case, were able to provide the ENSP with additional study specimens. One male's transmitter (H26) was replaced in 2005 in order to obtain a full season of data and enable the biologist to locate the snake for transmitter removal the following spring.

Reproductively mature (or nearly mature) males were targeted for this study (Site 2; ENSP Highlands Timber Rattlesnake Project, 2003-2006) for two reasons. First, adult males travel further from their hibernacula than nongravid or gravid females. While gravid females may forage in forested habitat early in the season, they will move to gestation sites located at open, basking areas where they remain for most of the summer, thus using different habitat than that of foraging males and nongravid females. However, males and nongravid females use similar habitats, although not exactly the same, during the active season (Reinert 1984a, 1984b). As such, the ability to identify summer-activity ranges around hibernacula for males will likely capture the habitats used by nongravid females. In addition, there is an inherent risk when any animal undergoes surgery. Since the rattlesnake population is endangered in New Jersey and the resultant findings of this study will be applicable to nongravid females, it seemed an unnecessary risk to include females in the radio-telemetry study. However, under certain circumstances, females were implanted with transmitters during the study conducted in the Highlands Region. Three females were implanted with transmitters; two were found adjacent to an area where few observations had been made and therefore, increased the value of locating the hibernacula since there was no guarantee we would collect a male from the area. One of these females was the "injured female" mentioned previously that was removed from the study. The third (a gravid female) was captured at a site in close proximity to a residential community known to have rattlesnakes but the hibernacula location had not been confirmed. Again, not knowing if we would locate a mature male, the decision to implant her was made to better enable the ENSP to work with the local community to guide residents away from the critical area through trail reroutes and/or work with the landowner to enforce restricted public access. She was killed shortly after release.

At Site 2, macro- and microhabitat data are available for fifteen snakes including one nongravid female. There is partial season data for ten snakes and complete season data for five snakes (Appendix 2).

Tracking

Field technicians used two types of receivers to track the transmitter-implanted snakes; the AVM Instrument, Ltd., LA12-Q Portable Telemetry Receiver and the Advanced Telemetry Systems, Inc., R2000 Scanning Receiver, each in conjunction with a 3 or 4-element hand-held collapsible Yagi antenna. Snakes were tracked, on average, once every two days throughout the active season; active season being any time the snakes were not in hibernation, generally mid-April through early-October.

Site 1, Kittatinny Ridge

In addition to active season tracking, staff monitored transmitter function one to two times during the winter months from varying distances. Staff did not track to dens until spring, beginning in mid-April of each season, visiting and surveying all hibernacula locations on average once per week until May 1 when the regular tracking schedule resumed.

Site 2, Highlands Region

Staff tracked to the dens one to two times during winter months targeting periods after warm spells to 1) confirm transmitters were functioning properly, 2) check on study snakes to make sure they remained in their hibernacula and did not emerge for a mid-winter bask resulting in predation and 3) confirm the hibernacula location, in case any late-season shifting occurred. Staff tracked to dens prior to emergence, approximately one to two times per week beginning in mid-late April depending on the season's weather conditions, to gauge emergence. Surveys were conducted at alternating locations to minimize disturbance at any one hibernacula. Hibernacula were selected for early survey depending on their directional face and sun exposure (Martin 1992a) and the type of hibernacula (i.e., vertical or horizontal fissure within a large geomorphic structure, open talus or geomorphic features within the interior of the forest), all of which can cause variation in emergence dates.

Generating Random Sampling Points

Randomly generated sampling points enabled the collection of data regarding the available habitat at both study sites. This information was used to characterize the habitats, to compare snake-used and available habitats for both microhabitat and landscape-level features.

Microhabitat

Site 1, Kittatinny Ridge

To collect microhabitat data, using the same method described by Reinert and Zappalorti (1988), random habitat points (n = 100) were generated within this study area (1.5mi-radius around the hibernaculum, excluding the Delaware River). The coordinates for each point were selected from a random numbers table after overlaying the study area with a 100m x 100m grid.

Site 2, Highlands Region

Random sample size was determined by using the habitat data collected at snake-observed locations. Using the data variable that had the highest variation, in this case, canopy closure ranging from 0-100% or, proportionally, 0-1, and applying a 10% allowable error. The following formula

$$n = 4 * s^2 / AE^2$$

provided the required sample size of random points to be surveyed (n = 295) (Appendix 3).

Once the sample size was established, random habitat points were generated for each 1.5mi-radius hibernacula buffer (N=11) by first determining the percentage of each vegetation type as classified by the NJ Department of Environmental Protection's 2002 Level III Land Use/Land Cover data layer (LU/LC02) within each buffer. Using Animal Movement Extension (Hooge and Eichenlaub 1997) in ArcView 3.2, the required number of random points was generated proportionally to their surrounding landscape using stratified sampling and maintaining a buffer greater than 10m between random and snake-observed points to avoid overlap and duplicative data.

Macrohabitat

To collect macrohabitat data for both study sites, computer-generated random sample points were confined to the areas within each of the established hibernacula buffers (1.5mi-radius around each hibernacula). A 100m x 100m grid overlay on the hibernacula buffers was used to systematically generate random points within each grid cell, resulting in a combined sample set (regardless of overlapping hibernacula buffers, Figure 5) (n = 12,592), that excluded sample points falling outside of NJ's terrestrial border (i.e., the Delaware River and New York State).

Data Collection

Microhabitat data were collected to characterize the available habitat type and compare snake-used habitats to the available (random) habitats to determine if they are different. A comparison between the two sites was conducted to determine if there were regional differences in the habitats snakes are using as well as in the available habitats. This information will help provide a better understanding to both physiographic differences/similarities between New Jersey's two northern metapopulations of timber rattlesnakes as well as the potential rigidity in microhabitat parameters of suitable habitat.

Location data of radio-tracked rattlesnakes were used in conjunction with GIS data layers to determine the snakes' proximities to landscape-scale (macrohabitat) features, Table 3 (i.e., roads, human activity, streams and forest edge). Proximity to streams and rivers were determined from the centerlines of waterways ≥10m wide. Similarly, proximity to roads was also determined from the centerlines of paved roads of any level (e.g., park, local, county, interstate, etc.) but excluded residential driveways. Human activity and human-occupied areas were compiled from the LU/LC02 (Appendix 5) and "forest edge" included an interface between any habitat and forest with >50% canopy closure. A canopy closure of 50% was used as the limiting factor since literature and previous research has shown male and nongravid female rattlesnakes' affinities for canopy closure >50% during their active season, excluding basking activities associated with emergence, shedding and gestating (Reinert 1984a and 1984b, Reinert and Zappalorti 1988). Additionally, data on canopy closure and proximity to the nearest rock outcrop and talus (within 50m of observations and random locations) were collected along with the microhabitat data, but will be analyzed as macrohabitat. As with the microhabitat data, the macrohabitat data will be used to determine if there are differences between snake-used and available habitats both at and between study sites. By identifying landscape-scale features that help define suitable rattlesnake summer range, we can further refine predictive maps of suitable habitat that can help guide land management and land-use decisions. Moreover, if the same landscape-scale features are available in GIS data layers in other northeastern states, the information could be used regionally (northeastern United States) to help identify important habitats that cross state boundaries.

Snake Locations and Microhabitat

Locations within two to three meters of a snake observation were collected using a Geographic Positioning System (GPS); Trimble GeoExplorer at Site 1 (Kittatinny Ridge) and a Garmin eTrex Legend at Site 2 (Highlands Region). GPS locations were only to be collected when a snake moved more than 10m from the original observation point in a given area unless there was a noticeable change in the habitat (e.g., forest to field). It seemed reasonable that such an incremental change would not show a noticeable shift in the snake's directional movement. In addition, surveyors at Site 2 were advised to attempt to acquire a GPS accuracy reading of < 25ft (< approximately 7.62 meters) before recording the location.

GPS data collected using the Trimble was downloaded and differentially corrected using Trimble GPS Pathfinder Pro XR and base files obtained from the NJ Department of Environmental Protection, Bureau of Geographic Information System's website. Once data were corrected, they were exported into ArcView 3.2 as a shapefile. GPS data collected using the Garmin eTrex Legend were downloaded using the DNR Garmin Extension (Minnesota Department of Natural Resources 2004) in ArcView 3.2.

Microhabitat data was only collected if the snake moved more than one meter from its originally observed location in a given area. It seemed reasonable that such a movement was indicative of a snake selecting for a particular microclimate or to improve foraging success, rather than simply repositioning itself. Due to limited resources, data collection was conducted at the time of observation, risking disturbance to and possibly, behavioral adjustments of the snakes, and potentially forcing them to move. When approaching study snakes, surveyors were advised to move slowly, tread lightly and to attempt to approach the snakes from behind to minimize the possibility of startling the snakes or triggering their movement into a self-defense response. In addition, note documentation and data collection for both the Kittatinny study (1999 – 2000) and Highlands study (2003 – 2006), in the proximity of snakes, were conducted in a sequence that would attempt to minimize disturbance to the snake; collecting the data that could cause the most disturbance last. Datasheets can be viewed in Appendices 4a and 4b.

1. All notes, comments and vegetation identifications were recorded three to five meters from a study snake and occasionally more than five meters. When possible, the observer would conceal him/herself behind a tree/vegetation. GPS locations were typically collected at two to three meters from a snake, depending on the observer and the location of the snake (i.e., within a crevice where less disturbance would occur versus when the snake was exposed).
2. At Site 2 (Highlands Region), distance measures to the nearest rock outcrop or talus slope (within 50m of a location) were collected using a Keson Open Reel tape measure (metric units). Although this information could be considered a macrohabitat variable, GIS data layers are not complete as they cannot capture

outcrops under the canopy and therefore, those data are not available for random sampling at a large scale. Given the importance of such locations to the snakes, data collected during microhabitat sampling were used to compare snake-used and available habitats. These results are included under *Macrohabitat*.

3. A Lufkin diameter at breast height tape (metric units) was used to determine the diameter at breast height (DBH) of the nearest overstory tree.
4. Although slope can be considered a macrohabitat feature, it was collected in the field for better accuracy than that obtained through GIS data layers. The slope at a snake's location was collected at Site 2 using a Suunto optical reading clinometer (PM-5/360 PC) with the observer standing between three to five meters from the snake but remaining on the same slope. These data were evaluated with other microhabitat data.
5. The observer collected additional distance measurements by dropping the lead of the tape measure in close proximity to, but not touching, the snake and slowly extending the tape measure and moving away from the snake towards the target object. Measures of interest included the following items taken from Reinert (1984a, 1984b):
    a. Distance to the nearest rock (>25 cm on shortest side),
    b. Distance to the nearest, downed woody log (≥5.0cm diameter),
    c. Distance to the nearest overstory tree (≥ 7.5 cm dbh), and
    d. Distance to the nearest understory tree or shrub (≤ 7.5 cm dbh and ≥ 2.0 m height).

Minor adjustments were made to the rock length regarding length of shortest side and the downed log diameter during the development of the study at the Kittatinny Ridge (1999 – 2000). It is unclear why these adjustments were made however, these same parameters were used during the Highlands Study (2003 – 2006) to obtain comparable data for analysis of and between the two study sites.

6. Additional microhabitat measurements collected at both sites included ambient and surface temperature and humidity above and near each snake, and at Site 1 (Kittatinny Ridge), soil temperature and moisture at 10cm from each snake and illumination at the snake's location were also collected. None of these data will be used in this analysis. However, it is important to note the additional data collection as it could have influenced the snakes' behavior and limited length of time at a given location.
7. The observer recorded a subjective measure, an estimate of the visibility of the snake (percentage of body visible) from an overhead view. This was done for a short time at Site 1, but regularly at Site 2. These data will not be used in this analysis, but again is important to note as it required observers to approach each snake.
8. The canopy closure at each snake observation was measured using a Forestry Suppliers, Inc. spherical (convex) densiometer. Observer stood next to the snakes to gather this information per the instructions provided by the manufacturer and as described by Lemmon (1956). Canopy closure could be considered a micro- or macrohabitat variable given the canopy closure could

change over short distances and can be altered through habitat management in addition to providing large-scale guidance through GIS. Since GIS data layers are available categorically through NJDEP LU/LC02 (broad categories including 10-50%, >50% canopy), measures were taken in the field for use in developing future management strategies, but analysis results will be included under *Macrohabitat* since categorically, canopy closure could be used in model development through GIS.

9. After leaving each snake at Site 2, the observer documented each snake's behavior upon approach, exit and during data collection.

Random Locations and Microhabitat

All applicable aforementioned microhabitat data were collected at the random locations (sample size varied with habitat feature). This information was used to compare the snake-used and available habitats to determine if the snakes are selecting for particular habitats or merely using what is available to them as characterized by these random samples.

Site 1, Kittatinny Ridge

Random habitat points were located using a Trimble GeoExplorer. Surveyors were typically able to locate the point with high accuracy (within < 3m), although on two occasions, due to dense canopy closure and difficulty obtaining satellites, the surveyor was forced to pace off the remaining distances (up to 30m) using a compass from the last readable location.

Site 2, Highlands Region

Random habitat points were located using a Garmin eTrex Legend. Surveyors were advised to obtain GPS accuracy of <25ft to locate random points and to document the final accuracy reading prior to data collection.

Snake Locations and Macrohabitat

GPS locations were only to be collected when a snake moved more than 10m from the original observation point unless there was a noticeable change in the habitat. It seemed reasonable that GIS data layers, when focusing on large-scale features would not show a noticeable difference within such a small area. Limited by data availability and quality, GIS data layers of four potential landscape-scale features that could influence a snake's occupancy of an area were compiled (Table 3).

When an individual snake or multiple snakes were within 10m of another observation, only one was used to conduct the final analysis to develop landscape-scale parameters in an effort to avoid overlap and duplicative information. In an effort to randomly select the point to include in the analysis, the points were selected based on 1) which location had the most complete micro-dataset (an unknowing "random" determination by field technicians) or 2) the first date of observation at that shared or semi-shared location.

Using X-tools Extension (DeLaune 2003) in ArcView 3.2, a 10m-radius buffer was generated around each snake observation allowing overlapping buffers surrounding snakes to remain in the study sample to provide additional data of "snake-used" habitats.

Proximity measures were gathered using X-tools Extension (DeLaune 2003) in ArcView 3.2 and proximity tools in ArcGIS 9.2.

Random Locations and Macrohabitat

Randomly generated points also received a 10m-radius buffer and the same macrohabitat data was compiled for each random location (n = 12,592). This information was used to characterize the available habitat within the twelve hibernacula buffers captured within this study area (including both Sites 1 and 2). This allowed a comparison of the snake-used and available habitats to determine if the snakes are selecting for particular habitats or merely using what is available to them as characterized by these random samples.

Analysis

Analyses conducted on the available and snake-used habitats focused on the similarities and differences of microhabitats at and between the two study sites will provide a better understanding of the snakes' needs on a finer scale for future develop of management strategies. The second part of the analysis focused on the landscape-scale (macrohabitat) features and identifying parameters that could be used in the future development of a distributional map of potential suitable summer habitat.

All data collected pertaining to gravid females or injured snakes were excluded from all analyses as their habitat selection is significantly different than that used for foraging by males and nongravid females. Observations of transient/ traveling snakes were excluded from these analyses because these observations cannot be confirmed as selected or preferred habitats, the focus of this research, but rather could have been corridors connecting suitable habitats. In addition, seven snakes moved outside their associated 1.5mi-radius study area buffer (hibernacula buffer). Since random points were confined to the 1.5mi-radius buffer around each hibernaculum, the combined twenty-seven stationary observations outside the buffers were excluded from all analyses to appropriately evaluate the relationship between used and available habitat. Randomly observed snakes were also excluded from this study as they were often found in open basking areas, where they are more exposed and easier to find, which could potentially bias the dataset. In addition, the six snakes from Site 1 (Kittatinny Ridge; M07 - M11 and M17) that were not from the original study hibernaculum have been used in the analyses as their hibernacula and all but one of their observations were contained within the 1.5mi-radius of the original study hibernaculum and therefore included selected habitats from the same available habitat as that used by snakes from the original site. Their inclusion has provided additional sampling to increase the accuracy of the analyses and interpretation of the data.

Micro- and Macrohabitat

Sites 1 and 2

Histograms and quantile-quantile (Q-Q) plots of micro- and macrohabitat data resulted in severely skewed data sets for habitat sampling at both snake observations and random points (Appendix 6a and 6b). All attempts to normalize the data (e.g., transformations, removal of outliers) failed. As such, all data were analyzed using the Mann-Whitney U-Wilcoxon nonparametric two-sample test (SAS Institute 9.1) to determine if habitat availability or snake habitat selection within or between the two sites showed statistical differences for any of the habitat features.

Snake location data were used to generate scatter plots to identify potential categories that define large-scale feature preferences and/or aversions (Table 4). Analysis to compare used and unused habitats both within and between the two study sites underwent ten different rounds of data grouping (Table 5) including the inclusion and exclusion of nongravid females, repetitive observations (multiple observations at the same location) and healing-related observations.

Repetitive and “healing-related” observations were included/excluded from analyses to determine if they would “weigh”/ skew the dataset. “Healing-related” observations, in this study, pertain to the stages prior to and the period when snakes undergo ecdysis approximately four – six weeks following surgical implantation (Kathleen Michell, New York Center for Turtle Rehabilitation and Conservation, Inc., K.A. Schantz, pers. obs.). In this analysis, they also include the movements to reach their basking/shed sites. Snakes that had undergone surgery in late July – early August typically denned prior to shedding, but showed signs of pre-ecdysis and healing-related behavior (i.e., basking or moving to basking areas) and began ecdysis immediately after egress the following spring.

In addition, although *The Landscape Map* (Version 3.0, Highlands; Winkler et al. 2008) already uses LU/LC02 types to identify critical habitats, I used this study’s location data of snake-used habitats to evaluate the success of *The Landscape Map* (Version 3.0, Highlands; Winkler et al. 2008) in valuing suitable (and used) habitats. I also determined the proportional acreage of each landcover type within each hibernacula buffer and the expected and actual number of snake observations per landcover type (LU/LC02) to evaluate if the LU/LC02 data will provide additional insight into habitat selection at a large scale (i.e., habitat types to include/exclude from the current *Landscape Map*) and for the development of a future summer range suitability map.

RESULTS:

Tracking Successes and Failures

Snakes were successfully tracked at Site 1 (Kittatinny Ridge) in 1999 – 2000 and at Site 2 (Highlands Region) in 2004 – 2005. Although a few snakes were tracked in 2003 at Site 2, data is sparse as the observer had difficulty locating the transmitter-implanted snakes and often neglected to collect the data when the snakes were found. However, the little data that is available for observations in 2003 was used in the micro- and macrohabitat analyses. Data collected from 28 radio-tracked snakes were used in these analyses. See Appendices 7a, 7b and 8a, 8b for details of overall tracking success per site.

There were a total of 248 “healing-related” observations recorded at the two study sites, 151 of which are also considered repetitive observations (multiple observations at a given location) and the remaining 97 were associated with single, stationary observations. There are 164 observations at repeated locations leaving only 13 unrelated to post-surgical healing behavior. Observers documented traveling or apparent traveling by snakes 167 times, although this data will not be used for analysis as it is unclear if these locations represent a part of the snakes’ preferred habitat or are travel corridors between suitable habitat patches.

Microhabitat Analysis

Analyses were conducted on the different microhabitat variables using the data subsets described previously under *Analysis* and can be viewed in Table 5. Analyses of the microhabitat data using the Mann-Whitney U-Wilcoxon nonparametric two-sample test (SAS Institute 9.1) revealed the random locations (representing available habitat) between the two sites were significantly different only with regard to distance to the nearest rock and understory tree, and that snake-used habitats were significantly different for all the variables tested regardless of the data subset except distance to the nearest rock and nearest log. Distance to the nearest rock was different between the two sites for all data subsets except the test including males and females and repetitive and healing-related observations (Test 5, Table 5). Distance to the nearest log was different for three out of the eight tests including Tests 3 and 7, both of which include repetitive but excluded healing-related observations (one with males only, the other with males and females). This variable was also different between sites for Test 5 (described above).

Additionally, sensitivity analyses run to test the effects of healing-related observations on the outcome of the statistical significance within and between sites appeared to play a small role. The statistical significance of the variables (or lack of) often, but not always, did not change with regard to the inclusion or exclusion of healing-related observations at either site.

Random (available) locations were different than snake-used habitats for specific variables under certain conditions (i.e., inclusion/exclusion of females, healing-related or repetitive observations) at and between Sites 1 and 2 and when comparing all snake-used habitats to all available habitats. The majority of variables showed a difference between all snake-used habitats versus all available habitats (Table 7e), however a greater variation of the statistical results occurred within each site dependent upon the variable and data subset. These results can be reviewed in Tables 7a – 7e, but the summary is as follows:

- A comparison of random and snake-used locations at Site 1 (Kittatinny Ridge), Table 7a
    - o Random locations were different from snake-used habitats for distance to rock and nearest log regardless of the inclusion/exclusion of females, healing-related or repetitive observations (sample size varied with data subsets and habitat feature/variable; samples from random locations included a minimum of n = 83 and a maximum of n = 89 and samples from snake-used locations included a minimum of n = 233 and a maximum of n = 593).
    - o Random locations were different from snake-used habitats for distance to nearest overstory tree for all data subsets except when females were included in conjunction with excluded repetitive and healing-related observations (random, n = 93; snakes, n = 273-596; sample size varied with data subset).
- A comparison of random and snake-used locations at Site 2 (Highlands Region), Table 7b
    - o Random locations were significantly different from snake-used habitats for all data subsets when testing distance to nearest log or overstory tree (random, n = 246-251; snakes, n = 234-513; sample size varied with data subset and habitat feature/variable).
    - o Random locations were significantly different from snake-used habitats for distance to nearest rock for all but one data subset, Test 2 (males only, excluding both repetitive and healing-related observations; random, n = 231 or 237; snakes, n = 254-512; sample size varied with data subset).

- Distance to nearest understory tree was the only habitat feature that demonstrated a pattern in the results with regard to the data subset. The used and available habitats were different for Tests 2, 4, 6 and 8; only when repetitive observations were excluded from the data subset (random, n = 251; snakes, n = 235-354; sample size varied with data subset).
- Slope showed significant difference for all data subsets except when both repetitive and healing-related observations were excluded with male only observations (random, n = 249; snakes, n = 243-460; sample size varied with data subset).

Overall, microhabitat analyses revealed that the available and snake-used habitats are different within and between the physiographic regions (Kittatinny Ridge and the Highlands Region). Although the available habitats are somewhat unique to each region, the snakes are selecting for specific habitats different from what is available to them and from what the other snake population is using.

Microhabitat Dataset

Site 1, Kittatinny Ridge

Data were collected at 94 of the 100 randomly generated points. The remaining six were excluded as two were located within cornfields, two in open fields, one on a road and the last in a building. If I had used the same method to determine the appropriate number of random sample points necessary to characterize the available habitat as I had used at Site 2 (Highlands Region), a survey of 94/100 points would have resulted in an allowable error (AE) of 5.0%.

The sample size of the data collected at snake observations varied with each variable (excluding repetitive observations at a given location, n = 545 to n = 801 with an average n = 762 and median of 800 samples) (Appendix 9a). These figures include male, female and healing-related observations, but exclude observations at hibernacula and repetitive observations (multiple observations at the same location, a maximum of 13 observations not overlapping with healing-related observations), although repetitive observations were used as part of the data subsets in the analysis.

Site 2, Highlands Region

Data were collected for 246 – 251 randomly generated locations (Appendix 9a), however only 238 of these were a part of the required 295 randomly generated points to meet an allowable error (AE) of 10%. The additional locations were generated and surveyed within one of the hibernaculum buffers due to a miscalculation of the number of points required for that area (Appendix 3). The 57 remaining points that were excluded from the required data collection were excluded for various reasons (Table 6) resulting in an AE of 10 – 15% for six of the nine hibernacula buffers and 10% or lower for the remaining three (Appendix 3). However, the additional data collection will be used in this analysis to increase the sample size and better characterize the available habitat of the Highlands Region. GPS accuracy to locate these points had a mean and 95% CI (2SE) of 22.88m ± 0.46m.

The sample size of the data collected at snake observations varies with each variable (n = 321 to n = 370 with an average n = 352 and median of 368 samples) (Appendix 9a). These figures include male and female stationary observations and healing-related observations but exclude observations repeated at the same location (a maximum of 13 observations not overlapping with healing-related observations) and observations at hibernacula. GPS accuracy recording snake locations had a mean and 95% CI (2SE) of 22.63m ± 0.23m.

Macrohabitat Analysis

Analyses were conducted on each of the macrohabitat variables using the data subsets described previously under *Analysis* and can be viewed in Table 5. Analysis of the macrohabitat data using the Mann-Whitney U-Wilcoxon nonparametric two-sample test (SAS Institute 9.1) revealed the random locations (representing available habitat) were significantly different for all variables except proximity to paved road, for both sites. Snake-used habitats were significantly different between the sites for canopy and proximity to forest edge for all data subsets, regardless of the inclusion or exclusion of females or repeated and healing-related observations. The sites' snake-used habitats varied for proximity to roads and human activity depending on the data subset and were not different with regard to proximity to water (stream/river), see Tables 8a-8e for results.

A comparison of the snake-used and available habitats at each site showed the habitats were statistically different for canopy closure and proximities to roads and human activity at both sites. Site 1 (Kittatinny Ridge) showed no statistical difference between snake-used and available habitat with regard to proximity to water while Site 2 (Highlands) showed differences for this variable across all data subsets. Proximity to forest edge, for both sites, showed little difference between used and available habitats with both sites showing a difference when testing with males and included both healing-related and repetitive observations. Additionally, Site 2 showed a difference in regard to forest edge proximity for the data subset that included males and healing-related observations, but excluded repetitive observations.

Further testing often revealed snake-used habitats were different than available habitats; results can be reviewed in Tables 8a-8k, but the summary is as follows:

- Canopy closure was different between snake-used and random locations for all data subsets within and between the study sites (Tables 8f-8j). Statistical means revealed that available habitats had higher percentages of canopy closure (less open habitat) than those habitats selected by the snakes. Additionally, the available habitats at Site 1 (Kittatinny Ridge) showed a higher percentage mean of canopy closure than available habitat at Site 2 (Highlands Region) and subsequently, snake observations at Site 1 (Kittatinny Ridge) had a higher percentage mean of canopy closure than did snakes at Site 2 (Highlands Region).
- Random and snake-used locations at Site 2 were significantly different with regard to their proximity to rock outcrops (within 50m of the snake or random point location) regardless of the data subset (Table 8k) (sample size varied with data subsets and habitat feature/variable; samples from random locations, n = 150 and samples from snake-used locations included a minimum of n = 172 and a maximum of n = 382). However, due to a lack of observations of snakes near talus (<5 during the foraging period), this variable has been excluded from the analysis.

- Sensitivity analyses run to test the effects of healing-related observations on the outcome of the statistical significance within and between sites again appeared to play a small role.
  - At Site 1 (Kittatinny Ridge), only Test 1 (Table 5: males, stationary observations including repetitive and healing-related) showed a change in statistical significance with regard to the proximity to forest edge with the inclusion of both repetitive and healing-related observations, but not with either individually (Table 8a; random, n = 1,793; snakes, n = 198).
  - At Site 2 (Highlands Region), the changes again occurred with regard to the proximity to forest edge (Table 8b). All tests showed insignificant values except for Tests 1 (described above; random, n = 10,799; snakes, n = 525) and 4 (males, stationary observations including healing-related but excluding repetitive locations; random, n = 10,799; snakes, n = 339).
  - A comparison between the used locations of both sites showed significant difference in the proximity to forest edge for all tests, no significance regarding proximity to streams and rivers, but varying results for proximity to human activity and roads regardless of the inclusion/exclusion of healing-related observations (or repetitive observations and females), Table 8c.
  - A comparison between the available habitats of both sites showed differences in the proximities to streams and rivers, forest edge and human activity, while proximity to roads revealed no difference (Table 8d).

Overall, macrohabitat analyses revealed that the available and snake-used habitats are somewhat different within and between the physiographic regions (Kittatinny Ridge and the Highlands Region). The Highlands Region showed the most differences between snake-used and available habitats. However, this data does not provide enough information to guide management strategies. As such, I used a contingency table (SAS Institute 9.1) to identify, categorically (described in Table 4), the proximity to large-scale features and the canopy closure snakes are selecting for in an effort to characterize summer habitats. This part of the analysis was conducted using the dataset that includes stationary, healing-related and repetitive locations and tested the inclusion/exclusion of nongravid females and revealed the following:

- All categorical findings remained the same regardless of the inclusion or exclusion of nongravid females' locations.
- The majority of the used and available habitats for both sites were captured within Category 5 (81-100%) of canopy closure.
- Site 2 showed statistical difference between used and available habitats with regard to proximity to streams and rivers however, the majority of snake observations and random points at both sites were captured in Category 1 for proximity to streams and rivers (0 – 200m).
- With regard to proximity to human activity or human-occupied areas, the majority of snakes and random points were captured in Category 2 (0 – 500m) for Site 1. At Site 2, however, the majority of random locations (45.35%; 4,897/10,799) were within Category 2, and 51.17% (285/557 with males and females) and 49.9% (262/525 with males only) snakes were observed at distances within Category 3 (>500 – 1000m).
- Proximity to roads had a similar effect. The majority of snakes (31.42%, males and females; 30%, males only) and random locations (53.09%; 5,733/10,799) at Site 2

were captured in Category 1 (0 – 500m) as well as most of the random locations (51.76%; 928/1,793) from Site 1. However, most snake observations (59.36%, males and females; 60.60%, males only) at Site 1 were made at ranges that fall within Category 3 (>1000 – 1500m).

- Regarding proximity to forest edge, the majority of snakes and random locations at both Sites 1 and 2 were located within Category 1 (0 – 200m from the forest edge). At Site 1, 58.6% of random locations and 46.29% (males and females) and 43.43% (males only) of snake observations were captured within Category 1. At Site 2, 46.4% of random locations and 42.9% (males and females) and 44.19% (males only) of snake observations were found within this range.
- At Site 2, measures collected regarding proximity to nearest rock outcrop (within 50m of a snake observation or random point) revealed the majority of random locations (available habitat; 58.8%, 99/249) were captured within Category 5 (>50m). However, most of the snake observations whereby surveyors recorded this data (65.38%, males and females, 304/465; 65.52%, males only) were within ranges defined by Category 1 (0 – 2.0m).

The categorical data enabled me to identify the proximity and percentage ranges whereby the majority of snake were observed and random locations were found. However, I could not determine from this information if the snakes were showing an aversion or an attraction to these features. As such, the means and 95% CI (2SE) (Tables 9a – 9f) were calculated for each category for which the majority of snake observations and random locations were found to better understand the differences/similarities between the habitats and to evaluate the snakes' aversions or attractions related to the landscape features (macrohabitat variables). Given the lack of significant differences between analyses when including or excluding nongravid females, they have been included in the summary of measures (Tables 9a - 9f) to provide additional sampling data and strengthen the accuracy of the results.

The means (Tables 9a-9f) revealed the snakes showed an aversion to human-occupied areas and paved roads, a slight aversion to streams and rivers (≥10m wide) and a very slight aversion to forest edge. The snakes selected for habitats with >50% canopy as shown in previous research, but also selected for habitats with slightly more open canopies than what was available to them. Within the Highlands Region, proximities to rock outcrop and talus were also collected. Since <5 snakes came within 50m of talus, this variable was excluded from the analysis. However, snakes showed a strong attraction to rock outcrops regardless of the inclusion or exclusion of healing-related observations which are most often associated with rock outcrops.

To further understand habitat selection by the timber rattlesnake on a large scale, I evaluated the proportional expected and actual number of snake observations per habitat type (LU/LC02) for each hibernaculum buffer based on the percentage of each LU/LC02 within each buffer (Appendix 10). It is important to note that the snakes' healing-related and repeated observations at a given location were also included in this part of the analysis to better understand habitat preferences. The majority of snake observations (551/756; 72.9%) for which GIS data was available were found within deciduous forests with >50% canopy closure. The figures decline precipitously with only 91 observations located within deciduous forests with 10-50% canopy closure, 35 observations within deciduous wooded wetlands and 17 observations within mixed forests that have >50% coniferous species and >50% canopy closure. The remaining 62 observations are in a few additional habitat types (Appendix 10) with $\leq$10 observations in each. Using *The Landscape Project* map (Version 3.0, Highlands; Winkler et al. 2008), I reviewed the habitat valued by the species-based patch system and confirmed that approximately 93.4 % of the study snakes' locations during this research in the Highlands Region (2003-2006) were captured within the newer species-based patch system (see Appendix 11 for observations within habitats not valued by this system).

Macrohabitat Dataset

Site 1 and Site 2

Proximity data were compiled for computer-generated random sampling points (Site 1, n = 1,793 and Site 2, n = 10,799; total of n = 12,592) and snake-observed locations (excluding repetitive observations at a given location, Site 1, n = 191 and Site 2, n = 358; total of n = 549) to compare large-scale features of snake used and available habitats (Appendix 9b). However, the sample size of the data at snake and random observations for canopy closure and distance to the nearest rock outcrop within 50m varied. Canopy closure data was gathered at Site 1's snake locations (n = 431) and random locations (n = 93) and at Site 2's snake locations (n = 369) and random locations (n = 246) for a total of 800 samples at snake locations and 339 at random locations. Distance to the nearest rock outcrop was only collected at Site 2 (Highlands Region) and resulted in 485 samples from snake locations (321 when repetitive observations are excluded) and 249 from random locations. Although distance to nearest talus within 50m was not significant in these analyses, data were collected at Site 2's snake locations (n = 322 with <5 within 50m of talus) and random locations (n = 250).

DISCUSSION:

This study indicates that timber rattlesnakes select particular microhabitats and – climates, as have been previously found (Reinert 1984a and 1984b, Martin 1992a). The macrohabitat data analysis was more complex, with statistical significance of each landscape-scale feature varying dependent upon the data subset (i.e., females, healing-related or repetitive observations at a single location) and comparative tests (comparing used and available habitats at and between study sites). However, ultimately, the analyses did show that the snakes are selecting for landscape-scale features including the avoidance of paved roads and human-occupied areas and suggests they may also tend to avoid forest edge and waterways $\geq$10m wide (if possible).

Micro- and Macrohabitat Play a Role in Site Selection

Microhabitat data, although not playing a significant role in this research, did reveal the snakes are clearly selecting for habitats as there are significant differences at each site between available and used habitats for many of the features for which data were collected. Random habitats were different between the sites for two variables (*distance to rock and understory tree*), yet snake-used locations were different for all variables except *distance to log* between Sites 1 and 2, indicating that regionally, the snakes are selecting [in part] for specific microhabitat features from what is available to them and is different from each other.

Although healing-related observations were excluded as part of a sensitivity analysis for both micro- and macrohabitat, these locations are critical to the snakes given that snakes return to their same basking/shed sites annually. For this reason, these locations were included in the analyses to determine categorical proximities and the means and standard errors to better depict important habitats throughout the snakes' summer range. Similarly, multiple observations made at the same location were also included in these analyses as these locations may represent preferred habitat (or critical habitat, in the case of basking areas) given the snakes spend multiple days at these sites.

Additionally, consideration must be given to the fact that three of the macrohabitat variables (proximity to human activity, roads and forest edge) are interrelated and therefore, analyses will reflect this correlation. Proximity to human activity and human-occupied areas and roads were different between used and available habitats at and between sites regardless of the data subset used, although not for all data subsets when comparing only the snake-used habitats between the sites. A comparison of random locations (available habitat) between the sites revealed they were different for proximity to human activity but not for proximity to roads. The results of this study indicate that, regionally, the snakes are selecting for habitat that is not typical of their areas, characterized by the random habitat sampling, with regard to proximity to human activity and roads and in fact, are showing an aversion to these areas when not traveling. The means and standard errors of these results (Tables 9c and 9d) suggest the snakes are selecting habitat that maintain a further distance from these areas than what is potentially available to them (distances determined by random points).

In New Jersey, roads and infrastructure create barriers for wildlife movement. Animals, particularly snakes, may well choose habitats with less edge; thus they may avoid roads for the most part. However, snakes not only cross roads but bask on paved and sand roads in the early morning and late evening hours to assist with thermoregulation (H. Reinert, pers. comm., K.A. Schantz, pers. obs.). Steen et al. (2007) found timber rattlesnakes of Georgia selected habitats with less edge (defined as the boundary between habitat types) and few roads (road density within the area). New Jersey's rattlesnakes in this study selected for similar characteristics (i.e., avoiding roads), supporting the findings of Steen et al. (2007) and Andrews and Gibbons (2005) (see Table 8k, 9d and 9e). Further, the data in this study indicate that the only remaining hibernacula and core foraging habitats of mountainous populations of timber rattlesnakes are on public or otherwise conserved lands with roads often circling or minimally fragmenting the lands, potentially isolating populations and/or jeopardizing the lives of dispersing males and young.

Roads present a direct danger to snakes; slow-moving species like the timber rattlesnake are particularly vulnerable (Andrews and Gibbons 2005). However, roads present other concerns, such as light pollution (Tuxbury and Salmon 2005) and noise pollution that can bleed into the forest, affecting the behavior of snakes and/or their prey that results in decreased foraging success and causing other indirect impacts (Andrews and Gibbons 2005, Andrews et al. 2006). Other indirect effects may include an increased number of scavengers or predators along the roads (Bennett 1998, 2003) and increased off-road vehicle access (Andrews et al. 2006) which in itself can lead to the destruction of habitat, additional noise pollution and accidental or purposeful killings of snakes as their habitat is invaded.

Few tests showed a difference between random and snake locations with regard to forest edge. Although the means indicate a slight avoidance of such areas (Table 9e), the differences appear to be minimal and therefore, not particularly useful when characterizing summer habitats. This study did not use the same definition of edge as Steen et al. (2007), but rather valued “forest edge” as a boundary between a forest with >50% canopy and any other habitat type. It is possible the results would vary if “forest edge” within this study also included forested habitats with 10-50% canopy closure, the second most used LU/LC02 type (Appendix 10).

Canopy closure showed statistical differences between used and available habitats among all data subsets and comparative tests, clearly indicating the snakes are selecting for particular canopy closure, or conversely, opening. Statistical means of snake-used and available habitats within and between study sites indicate the snakes selected for habitats with slightly more open canopies than what was available to them. Literature also supports the notion that canopy closure plays a role in habitat selection for seasonal activities (foraging, shedding, gestating and hibernacula), although it is difficult to determine if this study supports the literature given all tests were significantly different and the data was not analyzed by season. Even though snake-used and available habitats showed statistical and mean differences, random and snake-used habitats at both sites fell within the 81%-100% canopy closure category. However, this study measured canopy closure using a convex spherical densiometer, as opposed to making an estimate of canopy “cover” as described by Jennings et al. (1999). Cook et al. (1995) reported that such a unit could overestimate the canopy “cover” by 30-40%. It is unclear if Cook et al. (1995) considered the two, canopy cover and closure, as the same concept and therefore, having the same inaccuracies. Given the densiometer was used at both study sites for snakes’ and random locations, the measures can still be used in comparison as to whether or not the snakes used what was available or sought specific habitats, but should not be used to develop large-scale parameters of preferred habitat.

Within the hibernacula buffers of the Highlands Region, the proximities to rivers and streams and to rock outcrops were different between used and available habitats among all data subsets. In addition, the two study sites (one hibernacula buffer of the Kittatinny Ridge and a compilation of the 11 hibernacula within the Highlands) were statistically different with regard to river/stream proximity. The difference between the sites in this regard may be related to the difference in topography. The study site along the Kittatinny Ridge falls within an area that consists of the main ridge with many terraced slopes that have southeast and northwest aspects, suitable for streams and rivers towards the lower elevations on either side. The Highlands is a region characterized by a series of discontinuous, steep-sided ridges and narrow valleys through which numerous streams and rivers flow, making it more likely for more of the systematically-generated random locations throughout the hibernacula buffers to be in closer proximity within the Highlands Region study site than those generated at the Kittatinny Ridge. As a result, it is possible that the random locations used in these analyses simply have a higher proportion in closer proximity to streams and rivers than the somewhat clustered snake-observed locations as individual snakes will forage in a given area rather than disperse throughout the entire hibernacula buffer. Although statistically different, the mean distances of the random and snake locations were not very different but suggest some avoidance by snakes of these waterways (Table 9b).

Literature supports the value of rock outcrops to rattlesnake populations (discussed in the introduction of this paper). In this analysis, proximity to rock outcrops, sampled within the hibernacula buffers of the Highlands Region study site, was different between used and available habitats on all tests with snakes staying in closer proximity to outcrops than what is generally available to them. This may be an indication that [some] outcrops, away from human activity, should be managed to maintain sun exposure with shrubby edge habitats for thermoregulation and foraging opportunities.

Overall, the results of these analyses indicate the snakes are selecting for particular micro- and macrohabitats compared to what is available. With regard to macrohabitats, the snakes showed aversions to human-occupied areas, paved roads and streams and waterways ≥10m wide and an attraction to rock outcrops. However, analyses of large-scale information are limited by data quality and availability. For example, the road coverage did not include a number of local roads and therefore, some of the roads within and surrounding each hibernaculum buffer had to be hand-digitized to complete the database. This would not be feasible at a regional scale. In addition, the stream coverage did not capture streams less than 10m wide. There are many small, intermittent streams extending down the mountains and through the valleys of both study sites. Observers witnessed snakes at these locations many times either in close proximity to or drinking from them. Do these smaller streams play a more significant role than larger streams given the ease to traverse them? Given the success of identifying potential large-scale features that impact habitat or foraging area selection, it could be beneficial to continue to search for and test additional landscape-scale features as GIS data layers become available.

A commonly used data layer by the ENSP is NJDEP's Land use/ Land cover data layer. This data layer was used to determine the expected proportional number of observations per LU/LC02 type within each hibernaculum buffer. Although this study excluded forest habitats with <50% canopy within the *Proximity to forest edge* variable, the actual observations (97) within coniferous habitat with 10-50% canopy exceeded the expected number of observations (28) (Appendix 10). However, this is, in part, representative of the inclusion of the healing-related and repetitive observations made at open canopy basking areas. By excluding healing-related observations (which also removes 151/164 repetitive observations), the number of snake observations within this LU/LC02 drops to 64, but still exceeds the expected number of observations, indicating the snakes are selecting summer habitats with canopy closures of <50%.

Since vegetation structure represents and can dictate the microhabitat and micro-climate with regard to soil structure and type, humidity, temperature, geology, shade versus sun exposure, etc., large-scale vegetation mapping may also provide an understanding of a prey base and optimal conditions for the snakes while providing an easily accessible database to evaluate the landscape. The use of LU/LC02 has proven to be a successful means of identifying suitable habitat based on species observations with the development of *The Landscape Project* (Version 3.0, Highlands) (Winkler et al. 2008) that uses species-based patches. However, as discussed previously, this is only useful when observations have been reported and confirmed. It does not provide guidance to conservationists implementing habitat management strategies in areas where rattlesnakes may exist but have not been reported. By applying additional landscape-scale parameters, I could identify suitable areas at a finer scale regardless of reported rattlesnake observations, which could improve and focus rattlesnake conservation and habitat management.

Although this study has identified site selection by the timber rattlesnakes, this study is an example of pseudoreplication as the sample set includes few snakes with many observations. Snakes, as with other animals, can show individual preferences for habitat based on their own history (i.e., foraging success, basking, finding mates) and therefore multiple observations of each snake do not necessarily represent the population or the metapopulation. However, it is virtually impossible to conduct a properly replicated study with rare wildlife given the difficulty in finding specimens, and the inherent risk to the animals involved in any study whether it is surgery or simply the repetitive disturbance directly and indirectly affecting their behavior and overall health.

Potential Biases in Data Collection

The 2003 tracking season was not as successful as 2004 and 2005 because the observer (# 3) often neglected to collect microhabitat data and incorrectly collected location data using a GPS, resulting in deletions from the dataset and therefore, limiting the availability of macrohabitat sampling. Two observers (observers 1, K. Schantz, and 2) collected the majority of the data at snake observations and random locations. In addition, observer 2 trained under observer 1 for weeks until individual data collection measures were [nearly] equivalent. Excluding observations of traveling snakes, repetitive and hibernacula-associated observations and observations of gravid and injured females, there were 832 single, stationary observations, of which 708 (85%) were made by observers 1 and 2. Observer 3, in 2003, made 84 observations while ENSP staff surveyed the remaining 40 observations. Of the 345 random habitat locations, observers 1 and 2 collected the majority of the data (59%) while observer 4, in 2000, surveyed 18% (at Site 1), and the remainder were surveyed by ENSP staff.

It is difficult to determine the impact our data collection procedure had on the snakes. Clearly, it is not preferred to collect data at such close proximity to a study specimen when the intention is to evaluate habitat selection associated with behavior. However, out of 1,316 observations where the observers recorded the snakes' responses to their presence, snakes moved during 123 observations (<10%), in some cases moving closer to the observer crawling over our boots or into our grounded backpacks. For 41 observations (3%), snakes rattled, in some cases holding their ground and in others, we interrupted their travel. Travel often continued after a few minutes. Twenty of those observations overlap with the observations where we caused the snakes to move but were not related to interrupted travel. Nine times (<1%), snakes enlarged their bodies in self-defense, three of which also rattled.

Certainly, the snakes could have moved after the observer(s) had left. But our presence at the time did not appear to cause a major disturbance. We may have however, influenced their foraging success given the skittish nature of rodents. Our presence may have prevented rodents from passing through the snakes' foraging areas, which in turn could have resulted in the snake seeking a more productive foraging site.

Although it does not appear that we disturbed the snakes, it did seem that study snakes became somewhat habituated to our presence. While randomly observed snakes often demonstrated an alertness upon our approach, the study snakes often appeared to ignore us or perhaps, simply "wait us out" before behaving in a "normal" fashion. There were some behavioral differences associated with seasonal activities, such as males protecting females during courtship, rattling or quickly taking cover during ecdysis and so forth. However, none of these activities appeared to be any different than how a snake would react in the presence of any predator during these seasonal physiological stages.

Future Research

Future research should focus on an evaluation of habitat selection based on seasonal movements (pre-breeding, breeding and post-breeding) to determine if habitat and location parameters varies by season and by sex and/or age class, although this will require, minimally, one complete season of data for all study snakes. The limited data for a number of snakes in this study for one, two or all seasons (Appendices 7b and 8b) may result in an inaccurate interpretation of the preferred habitats and locations and therefore, this type of analysis was excluded from this study. However, Waldron et al. (2006) demonstrated seasonal variation in both home range size and habitat selection for both males and nongravid females of canebrake rattlesnakes (*Crotalus horridus,* formerly *Crotalus horridus atricaudatus*). If northeastern timber rattlesnakes also display micro- and macrohabitat seasonal preferences, such information could be useful in conservation and management efforts especially with regard to public lands and season-based recreational activities that could be diverted to alternate areas in an effort to minimize anthropogenic disturbances and injuries to snakes and snake deaths. Understanding a local snake population's core areas could help guide such management efforts and certainly, the use of radio-telemetry greatly enhances our knowledge of snake-used territories. However, the surgical procedure to implant the transmitters is invasive and both the trauma of surgery and the handling of a snake may impact its behavior, at least temporarily.

Displacement of snakes as a result of capture and release and/or relocation has been documented to cause irregular and long-distance movements (Galligan and Dunson 1979, Reinert and Rupert 1999; also see citations) following the release. Many of the snakes in the Highlands portion of this study were relocated to nearby forests (typically <200m from their capture locations) after transmitter implantation rather than their capture site because many were captured on private lands adjacent to public lands. In addition, one of the snakes (H26) was relocated multiple times as he moved into close proximity of private residences of a community that had expressed concern about an increase in the number of rattlesnakes on nearby private lands (from one to three in consecutive years). While this study was not designed to analyze the effects of "releases" or "relocations," it appeared that while some snakes had erratic movements after release, others did not. It is certainly logical to assume a relocated snake (as with any animal) will require time to reorient themselves especially given the rattlesnakes' affinity for their foraging grounds, basking areas, etc. However, it appeared the irregular and long-distance movements occurred prior to the snakes' "healing" periods weeks after surgical implantation of the transmitters and release, whereby snakes moved to their basking sites.

Since this study was not designed to evaluate such information, all stationary observations made after a snake was released or relocated were included in the analysis (excluding only the actual point of release). The assumption was that the snakes will find foraging or suitable resting habitats along their travels regardless of whether or not they are reorienting themselves and therefore, the selected habitat is assumed to be their preferred habitat in this study. Sensitivity analyses on "healing" locations (and direct line movements to those locations) were conducted to determine the effects of those observations on evaluating optimal foraging habitat given these locations are often quite different (i.e., open canopy, rock outcrops or talus versus forest). Selecting the observations considered to be part of the healing process was somewhat subjective. Repeated observations at basking areas and shed sites following surgery clearly are a part of the healing process. Movements to those locations, however, were difficult to discern. In some cases, snakes made straight-line movements to their basking areas, clearly indicating an urgency to bask, heal and shed. In other cases, however, they circumvented or even bypassed the site only to backtrack and return to shed. In these cases, movements were selected based on a timeline and the snake's previous behavior and propensity for the area. The use of radio-telemetry in this study therefore may have resulted in additional preference to basking areas weeks after implantation and release. Over the course of the active season, though, this presumably would not have created an inordinate bias for those areas, but could impact a season-based (i.e., pre-breeding, breeding and post-breeding) analysis.

Given the limitations of peritoneal transmitters with regards to weight and longevity, it may be appropriate to test post-release displacement by using externally attached transmitters, using an improved technique developed by Kathleen Michell, New York Center for Turtle Rehabilitation and Conservation, Inc. and first field tested by Edward McGowan, Palisades Interstate Park Commission (McGowan et al. 2006). By doing this, researcher(s) could eliminate the healing variable and focus solely on the snakes' trauma and stress of being handled and reorientation.

Future Applications

While much research has been conducted on timber rattlesnakes, this study focused on the development of landscape-scale parameters that may be used to develop a model and refine predictive habitat maps and therefore, help guide population research and conservation efforts. Although GIS data layers are limited, it does appear that the few landscape-scale features tested here could provide additional insight into habitat selection or avoidance. While measures provided insight into usable summer habitat, it is important that buffers remain in tact to minimize the "edge-effect." In this case, edge being an area along a road, human-occupied habitat or stream/river $\geq$ 10m wide as the snakes revealed aversions to these sites. For example, a snake may select foraging habitat 265m from a paved road, but the habitat between the snake and road acts as a buffer. As that buffer decreases, the snakes' core habitat will decrease. Although the buffer must remain in tact, land managers could target habitat management (creating optimal conditions) on suitable (potentially used) habitats within the core area. Additionally, large-scale, GIS-available features must continue to be reviewed and analyzed to refine this effort.

Other northeastern states with similar GIS data layers could test these features to develop a model and evaluate its success based on their known hibernacula and [assumed] foraging range of 1.5mi-radius from the hibernacula. States that have already developed predictive models could integrate this information to potentially refine their current information. Such information could help protect this rare species at a regional (northeastern United States) scale.

Although New Jersey currently does not protect upland habitats based on rare species' observations, the ENSP and conservation partners are working towards this effort. Data that will enable the ENSP to potentially refine the current model used for timber rattlesnake habitat in *The Landscape Project* may ease the transition (and public perception) of no protection for habitat to regulated lands. In addition, the development of a predictive map of potential rattlesnake summer range can be used to target surveys, educate and recruit local citizens to report observations, work with land stewards of conserved lands to manage habitat that will benefit timber rattlesnakes and possibly provide input regarding lands in question for state acquisition.

TABLES

Table 1. Potential habitat predictors of hibernacula using a 200m radius around all hibernacula and available (random) locations and their resultant significance.

Variables	Description	2004[c]	2009
Deciduous forest (>50% crown closure)[a]	Proportion of area with deciduous forest	X[d]	
Coniferous forest (>50% crown closure)[a]	Proportion of area with coniferous forest	X	
Deciduous wetlands[a]	Proportion of area with deciduous wetlands	X[de]	X[e]
Cropland/pastureland[a]	Proportion of area with cropland/pastureland	X	
Aspect: NE	Proportion of area with 0 - 90 degree aspects	X[d]	
Aspect: SE	Proportion of area with 90 - 180 degree aspects	X	
Aspect: NW	Proportion of area with 270 - 360 degree aspects	X	
Aspect: SW	Proportion of area with 180 - 270 degree aspects	X[d]	

X – Indicates the variable was tested for significance to determine the final variables to be used to develop the model.

[a]LU/LC types as identified by NJ Department of Environmental Protection (1995) for the 2004 hibernacula model and NJ Department of Environmental Protection (2002) for the 2009 hibernacula model.

[b]Soil data and descriptions as identified by the US Department of Agriculture, Natural Resource Conservation Service, SSURGO data layers (2004).

[c]Point biserial correlations were calculated for each variable in relation to whether it was associated with a hibernaculum point location or a randomly selected point location to determine which variables alone were most correlated with used and unused locations.

[d]Resultant variables used to build the model.

[e]Variables that showed statistical significance in model development and were used to develop the final predictive map in 2004 and to build the model in 2009.

[f]Variables that showed statistical significance in model development, 2009, and were used to develop the final predictive map.

Table 1, continued.

Variables	Description	2004[c]	2009
Bare rock	Proportion of area with bare rock	X	
Rocky soil[b]			
Unweathered bedrock	Proportion of area with unweathered bedrock	X	
STV-FSL ("more than 3% of the surface is covered with rock fragments greater than 10" in diameter"; fine sandy loam)	Proportion of area with soil type STV-FSL	X	
STV-L ("more than 3% of the surface is covered with rock fragments greater than 10" in diameter"; loam)	Proportion of area with soil type STV-L	X	
STX-FSL ("extremely stony"; fine sandy loam)	Proportion of area with soil type STX-FSL	X	
STX-L ("extremely stony"; loam)	Proportion of area with soil type STV-L	X[d]	

X – Indicates the variable was tested for significance to determine the final variables to be used to develop the model.

[a]LU/LC types as identified by NJ Department of Environmental Protection (1995) for the 2004 hibernacula model and NJ Department of Environmental Protection (2002) for the 2009 hibernacula model.

[b]Soil data and descriptions as identified by the US Department of Agriculture, Natural Resource Conservation Service, SSURGO data layers (2004).

[c]Point biserial correlations were calculated for each variable in relation to whether it was associated with a hibernaculum point location or a randomly selected point location to determine which variables alone were most correlated with used and unused locations.

[d]Resultant variables used to build the model.

[e]Variables that showed statistical significance in model development and were used to develop the final predictive map in 2004 and to build the model in 2009.

[f]Variables that showed statistical significance in model development, 2009, and were used to develop the final predictive map.

Table 1, continued.

Variables	Description	2004[c]	2009
Slope: 0-20%	Proportion of area with slopes 0 - 20%	X[de]	X[ef]
Slope: 20-40%	Proportion of area with slopes 20 - 40%	X	
Slope: 40-60%	Proportion of area with slopes 40 - 60%	X	
Slope: > 60%	Proportion of area with slopes >60%	X	
Slope: mean	Mean slope within area	X	
Elevation: mean	Mean elevation within area	X[de]	X[e]
Sun Index: mean	Mean sun index within area	X[de]	X[ef]

X – Indicates the variable was tested for significance to determine the final variables to be used to develop the model.

[a]LU/LC types as identified by NJ Department of Environmental Protection (1995) for the 2004 hibernacula model and NJ Department of Environmental Protection (2002) for the 2009 hibernacula model.

[b]Soil data and descriptions as identified by the US Department of Agriculture, Natural Resource Conservation Service, SSURGO data layers (2004).

[c]Point biserial correlations were calculated for each variable in relation to whether it was associated with a hibernaculum point location or a randomly selected point location to determine which variables alone were most correlated with used and unused locations.

[d]Resultant variables used to build the model.

[e]Variables that showed statistical significance in model development and were used to develop the final predictive map in 2004 and to build the model in 2009.

[f]Variables that showed statistical significance in model development, 2009, and were used to develop the final predictive map.

Table 2a. Final habitat selection model, 2004. Model coefficient (B), standard error of the coefficient (SE) and probability value (P) are shown for each variable that remained in the model.

Variable	B	SE	P
Deciduous wetlands	-0.195	0.085	0.021
Slope 0-20%	-0.171	0.033	<0.001
Elevation	0.005	0.002	0.007
Sun index	-0.117	0.047	0.013
Constant	31.169	10.513	0.003

Table 2b. Final habitat selection model, 2009.

Variable	B	SE	P
Slope 0-20%	-0.125	0.019	<0.001
Sun index	-0.088	0.026	0.001
Constant	26.318	5.827	<0.001

Table 3. Landscape-scale variables tested for significance at snake-used versus available habitat testing within and between study sites.

Description	Source(s)
Proximity to streams and rivers (centerline of streams, minimum 10m width)	NJ DEP, Bureau of Geographic Information Systems, 2002 Stream Coverage
Proximity to human activity[a]	NJDEP, LU/LC02
Proximity to forest edge[a] (forest with >50% canopy)	NJDEP, LU/LC02
Proximity to paved roads (center line of roads)	NJ Department of Transportation (2008) and hand digitization of missing roads using NJDEP 2002 aerial photographs

[a]Appendix 5 contains a complete list of LU/LC02 types included in these categories.

Table 4. Categorical ranges of measures for large-scale features generated by using snake location data and scatter plots.

Categories	Proximity to streams and rivers (m)	Proximity to human activity (m)	Proximity to forest edge, forest = >50% canopy (m)	Proximity to roads (m)	Proximity to rock outcrop, within 50m (m)	Canopy closure (%)
1	0 - 200	In human-occupied area[a]	0 - 200	0 - 500	0 - 2	0 - 20
2	>200 - 400	0 - 500	>200 - 400	>500 - 1,000	>2 - 20	21 - 40
3	>400 - 600	>500 - 1,000	>400 - 600	>1,000 - 1,500	>20 - 40	41-60
4	>600 - 800	>1,000 - 1,250	>600	>1,500 - 2,000	>40 - 50	61-80
5	>800	>1,250	Outside forest with >50% canopy[a]	>2,000	>50	81-100

[a]Areas selected from NJDEP LU/LC02 (2002); see also Appendix 5.

Table 5. Data subsets used with Mann-Whitney U-Wilcoxon nonparametric two-sample test to compare used and available habitats at and between the study sites.

	Males	Nongravid females	Stationary observations	Repeat observations (excluding healing-related observations overlap)[a]	Healing-related observations[b]
Test 1	X		X		
Test 2	X		X	X	X
Test 3	X		X	X	
Test 4	X		X		X
Test 5	X	X	X		
Test 6	X	X	X	X	X
Test 7	X	X	X	X	
Test 8	X	X	X		X
Test 9	Kittatinny snakes vs. Highlands snakes (following data subsets of Tests 1 - 8) and Kittatinny available habitats vs. Highlands available habitats.				
Test 10	All snakes (following data subsets of Tests 1 through 8) vs. all available habitats				

[a]Repeat observations were included and excluded to determine if multiple observations at a given location would impact the statistical significance of the variable in habitat selection.

[b]Healing observations were included and excluded as part of a sensitivity analysis.

X = Variable included in test.

Table 6. Random sample points excluded from Site 2 (Highlands Region) data collection and the reason for their exclusion.

Habitat description/ reason for exclusion	Qty.
Golf course green	2
Maintained easement	2
Maintained garden within road median	1
Maintained field	1
No access	1
No access; construction site	1
House	11
Marsh	6
No access, private pasture	6
No access, private property	2
No access, private property - lawn	9
Road	2
Water: lake or stream	12
No access, private pasture - data collected but excluded to maintain consistency in data collection effort	1
TOTAL	**57**

Table 7a. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used versus available habitats within the Kittatinny Ridge study site (α = 0.05).

Observations included in analysis	Sex	Distance to rock	Distance to log	Distance to overstory tree	DBH of (same) overstory tree	Distance to understory tree	Slope
Test 1. All stationary observations including repetitive & healing-related locations.	♂	z = 3.0412; p = 0.0024 (Sn = 352; Rn = 83)	z = 2.8508; p = 0.0044 (Sn = 414; Rn = 89)	z = -3.2271; p = 0.0013 (Sn = 421; Rn = 93)	-	-	-
Test 2. Stationary observations excluding both repetitive & healing-related locations.	♂	z = 2.1456; p = 0.0160 (Sn = 233; Rn = 83)	z = 3.3761; p = 0.0004 (Sn = 270; Rn = 89)	z = -2.1245; p = 0.0168 (Sn = 273; Rn = 93)	-	-	-
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations.	♂	z = 2.2742; p = 0.0230 (Sn = 302; Rn = 83)	z = 3.6352; p = 0.0003 (Sn = 345; Rn = 89)	z = -2.3197; p = 0.0204 (Sn = 348; Rn = 93)	-	-	-
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations.	♂	z = 2.5259; p = 0.0115 (Sn = 252; Rn = 83)	z = 2.9545; p = 0.0031 (Sn = 296; Rn = 89)	z = -2.4671; p = 0.0136 (Sn = 302; Rn = 93)	-	-	-
Test 5. All stationary observations including repetitive & healing-related locations.	♂, ♀	z = 3.2964; p = 0.0010 (Sn = 537; Rn = 83)	z = 3.0753; p = 0.0021 (Sn = 593; Rn = 89)	z = -3.0650; p = 0.0022 (Sn = 596; Rn = 93)	-	-	-
Test 6. Stationary observations excluding both repetitive & healing-related locations.	♂, ♀	z = 1.9930; p = 0.0463 (Sn = 344; Rn = 83)	z = 3.5360; p = 0.0004 (Sn = 381; Rn = 89)	-	-	-	-
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations.	♂, ♀	z = 2.2476; p = 0.0246 (Sn = 462; Rn = 83)	z = 3.7990; p = 0.0001 (Sn = 506; Rn = 89)	z = -2.3977; p = 0.0165 (Sn = 505; Rn = 93)	-	-	-
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations.	♂, ♀	z = 2.5271; p = 0.0115 (Sn = 372; Rn = 83)	z = 3.2037; p = 0.0014 (Sn = 414; Rn = 89)	z = -2.1060; p = 0.0352 (Sn = 419; Rn = 93)	-	-	-

Sn = Snake observations' sample size
Rn = Random locations' sample size
- = Not statistically different

Table 7b. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used versus available habitats within the Highlands Region study site (α = 0.05).

Observations included in analysis	Sex	Distance to rock	Distance to log	Distance to overstory tree	DBH of (same) overstory tree	Distance to understory tree	Slope
Test 1. All stationary observations including repetitive & healing-related locations.	♂	z = 5.4148; p < .0001 (Sn = 481; Rn = 237)	z = 5.0480; p < .0001 (Sn = 483; Rn = 246)	-	z = 4.4553; p < .0001 (Sn = 479; Rn = 251)	-	z = -3.7452; p < .0001 (Sn = 429; Rn = 249)
Test 2. Stationary observations excluding both repetitive & healing-related locations.	♂	-	z = -5.4237; p < .0001 (Sn = 235; Rn = 246)	-	z = -3.8332; p < .0001 (Sn = 234; Rn = 251)	z = -2.7311; p = 0.0063 (Sn = 235; Rn = 251)	-
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations.	♂	z = 3.7372; p = 0.0002 (Sn = 299; Rn = 231)	z = 4.5645; p < .0001 (Sn = 300; Rn = 246)	-	z = 4.0516; p < .0001 (Sn = 299; Rn = 251)	-	z = -3.1145; p = 0.0009 (Sn = 286; Rn = 249)
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations.	♂	z = 2.0692; p = 0.0193 (Sn = 332; Rn = 237)	z = 5.7961; p < .0001 (Sn = 334; Rn = 246)	-	z = 3.6761; p = 0.0002 (Sn = 330; Rn = 251)	z = 2.3261; p = 0.0200 (Sn = 334; Rn = 251)	z = -2.4679; p = 0.0136 (Sn = 291; Rn = 249)
Test 5. All stationary observations including repetitive & healing-related locations.	♂, ♀	z = 5.6386; p < .0001 (Sn = 512; Rn = 237)	z = 5.1704; p < .0001 (Sn = 513; Rn = 246)	-	z = 4.8337; p < .0001 (Sn = 510; Rn = 251)	-	z = -4.2188; p < .0001 (Sn = 460; Rn = 249)
Test 6. Stationary observations excluding both repetitive & healing-related locations.	♂, ♀	z = 2.0722; p = 0.0191 (Sn = 254; Rn = 237)	z = 5.6435; p < .0001 (Sn = 254; Rn = 246)	-	z = 4.2361; p < .0001 (Sn = 254; Rn = 251)	z = 2.6204; p = 0.0088 (Sn = 255; Rn = 251)	z = 2.4852; p = 0.0129 (Sn = 243; Rn = 249)
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations.	♂, ♀	z = 4.1895; p < .0001 (Sn = 329; Rn = 237)	z = 4.7360; p < .0001 (Sn = 329; Rn = 246)	-	z = 4.5648; p < .0001 (Sn = 329; Rn = 251)	-	z = -3.7589; p = 0.0002 (Sn = 316; Rn = 249)
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations.	♂, ♀	z = 2.4882; p = 0.0128 (Sn = 352; Rn = 237)	z = 5.9561; p < .0001 (Sn = 353; Rn = 246)	-	z = 4.0020; p < .0001 (Sn = 350; Rn = 251)	z = 2.2613; p = 0.0237 (Sn = 354; Rn = 251)	z = -2.9731; p = 0.0029 (Sn = 311; Rn = 249)

Sn = Snake observations' sample size
Rn = Random locations' sample size
- = Not statistically different

Table 7c. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test comparing used habitats of the Kittatinny Ridge versus Highlands Region study sites ($\alpha = 0.05$).

Observations included in analysis	Sex	Distance to rock	Distance to log	Distance to overstory tree	DBH of (same) overstory tree	Distance to understory tree	Slope
Test 1. All stationary observations including repetitive & healing-related locations.	♂	$z = 5.4779$; $p < .0001$ (Sn @ Kittatinny = 352; Sn @ Highlands = 481)	-	$z = 4.4959$; $p < .0001$ (Sn @ Kittatinny = 421; Sn @ Highlands = 485)	$z = 4.8209$; $p < .0001$ (Sn @ Kittatinny = 420; Sn @ Highlands = 479)	$z = 10.5716$; $p < .0001$ (Sn @ Kittatinny = 422; Sn @ Highlands = 481)	$z = -12.1546$; $p < .0001$ (Sn @ Kittatinny = 243; Sn @ Highlands = 429)
Test 2. Stationary observations excluding both repetitive & healing-related locations.	♂	$z = 2.8151$; $p = 0.0049$ (Sn @ Kittatinny = 233; Sn @ Highlands = 234)	-	$z = -2.3920$; $p = 0.0168$ (Sn @ Kittatinny = 273; Sn @ Highlands = 236)	$z = -4.6035$; $p < .0001$ (Sn @ Kittatinny = 272; Sn @ Highlands = 234)	$z = -10.1364$; $p < .0001$ (Sn @ Kittatinny = 274; Sn @ Highlands = 235)	$z = -8.2144$; $p < .0001$ (Sn @ Kittatinny = 133; Sn @ Highlands = 223)
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations.	♂	$z = -4.7753$; $p < .0001$ (Sn @ Kittatinny = 302; Sn @ Highlands = 299)	$z = 1.9956$; $p = 0.0460$ (Sn @ Kittatinny = 345; Sn @ Highlands = 300)	$z = -2.0479$; $p = 0.0406$ (Sn @ Kittatinny = 348; Sn @ Highlands = 301)	$z = -4.4569$; $p < .0001$ (Sn @ Kittatinny = 347; Sn @ Highlands = 399)	$z = -9.7149$; $p < .0001$ (Sn @ Kittatinny = 349; Sn @ Highlands = 298)	$z = -10.5160$; $p < .0001$ (Sn @ Kittatinny = 188; Sn @ Highlands = 286)
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations.	♂	$z = 2.9855$; $p = 0.0028$ (Sn @ Kittatinny = 252; Sn @ Highlands = 332)	-	$z = 2.4077$; $p = 0.0161$ (Sn @ Kittatinny = 302; Sn @ Highlands = 336)	$z = 4.3481$; $p < .0001$ (Sn @ Kittatinny = 301; Sn @ Highlands = 330)	$z = 10.4420$; $p < .0001$ (Sn @ Kittatinny = 303; Sn @ Highlands = 334)	$z = -8.9712$; $p < .0001$ (Sn @ Kittatinny = 156; Sn @ Highlands = 291)
Test 5. All stationary observations including repetitive & healing-related locations.	♂, ♀	-	$z = -4.5274$; $p < .0001$ (Sn @ Kittatinny = 596; Sn @ Highlands = 515)	$z = -5.0376$; $p < .0001$ (Sn @ Kittatinny = 596; Sn @ Highlands = 510)	$z = -12.8988$; $p < .0001$ (Sn @ Kittatinny = 601; Sn @ Highlands = 512)	$z = 10.4420$; $p < .0001$ (Sn @ Kittatinny = 303; Sn @ Highlands = 334)	$z = -12.9039$; $p < .0001$ (Sn @ Kittatinny = 358; Sn @ Highlands = 460)
Test 6. Stationary observations excluding both repetitive & healing-related locations.	♂, ♀	$z = -4.1257$; $p < .0001$ (Sn @ Kittatinny = 344; Sn @ Highlands = 254)	-	$z = -2.2283$; $p = 0.0259$ (Sn @ Kittatinny = 383; Sn @ Highlands = 256)	$z = -4.4800$; $p < .0001$ (Sn @ Kittatinny = 383; Sn @ Highlands = 254)	$z = -11.4027$; $p < .0001$ (Sn @ Kittatinny = 385; Sn @ Highlands = 255)	$z = -8.8639$; $p < .0001$ (Sn @ Kittatinny = 197; Sn @ Highlands = 243)

Sn = Snake observations' sample size
- = Not statistically different

Table 7c, continued.

Observations included in analysis	Sex	Distance to rock	Distance to log	Distance to overstory tree	DBH of (same) overstory tree	Distance to understory tree	Slope
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations.	♂, ♀	z = -6.3002; p < .0001 (Sn @ Kittatinny = 462; Sn @ Highlands = 329)	z = 2.1471; p = 0.0318 (Sn @ Kittatinny = 506; Sn @ Highlands = 329)	z = -2.5628; p = 0.0104 (Sn @ Kittatinny = 505; Sn @ Highlands = 330)	z = -4.8043; p < .0001 (Sn @ Kittatinny = 505; Sn @ Highlands = 329)	z = -11.6542; p < .0001 (Sn @ Kittatinny = 510; Sn @ Highlands = 328)	z = -11.0017; p < .0001 (Sn @ Kittatinny = 290; Sn @ Highlands = 316)
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations.	♂, ♀	z = -3.9700; p < .0001 (Sn @ Kittatinny = 372; Sn @ Highlands = 352)	-	z = -2.0583; p = 0.0396 (Sn @ Kittatinny = 419; Sn @ Highlands = 356)	z = -4.0374; p < .0001 (Sn @ Kittatinny = 419; Sn @ Highlands = 350)	z = -11.8238; p < .0001 (Sn @ Kittatinny = 421; Sn @ Highlands = 354)	z = -9.7013; p < .0001 (Sn @ Kittatinny = 223; Sn @ Highlands = 311)

Sn = Snake observations' sample size
- = Not statistically different

Table 7d. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test comparing available habitats of the Kitattinny Ridge versus Highlands Region study sites (α = 0.05).

Observations included in analysis	Sex	Distance to rock	Distance to log	Distance to overstory tree	DBH of (same) overstory tree	Distance to understory tree	Slope
All available habitat (Site 1, Kittatinny Ridge) vs. all available habitat (Site 2, Highlands Region)	-	z = 4.0735; p < .0001 (Sn @ Kittatinny = 83; Sn @ Highlands = 237)	-	-	-	z = 5.2325; p < .0001 (Sn @ Kittatinny = 93; Sn @ Highlands = 251)	-

Rn = Random locations' sample size
- = Not statistically different

Table 7e. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used habitats of both study sites (Kitattinny Ridge and Highlands Region) versus the available habitats of both study sites (α = 0.05).

Observations included in analysis	Sex	Distance to rock	Distance to log	Distance to overstory tree	DBH of (same) overstory tree	Distance to understory tree	Slope
Test 1. All stationary observations including repetitive & healing-related locations.	♂	z = 5.0190; p < .0001 (Sn = 833; Rn = 320)	z = 5.9453; p < .0001 (Sn = 897; Rn = 335)	z = -2.8881; p = 0.0039 (Sn = 906; Rn = 344)	z = 3.5524; p = 0.0004 (Sn = 899; Rn = 345)	-	-
Test 2. Stationary observations excluding both repetitive & healing-related locations.	♂	-	z = 6.6845; p < .0001 (Sn = 505; Rn = 335)	-	z = 2.1599; p = 0.0308 (Sn = 506; Rn = 345)	-	-
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations.	♂	z = 2.7780; p = 0.0055 (Sn = 601; Rn = 320)	z = 6.4386; p < .0001 (Sn = 645; Rn = 335)	z = -2.4168; p = 0.0157 (Sn = 649; Rn = 344)	z = 2.7156; p = 0.0066 (Sn = 646; Rn = 345)	-	-
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations.	♂	z = 2.3046; p = 0.0212 (Sn = 584; Rn = 320)	z = 6.5175; p < .0001 (Sn = 630; Rn = 335)	z = -2.2751; p = 0.0229 (Sn = 638; Rn = 344)	z = 2.4807; p = 0.0131 (Sn = 631; Rn = 345)	-	-
Test 5. All stationary observations including repetitive & healing-related locations.	♂, ♀	z = 4.7094; p < .0001 (Sn = 1,049; Rn = 320)	z = 6.3690; p < .0001 (Sn = 1,106; Rn = 335)	z = -2.9831; p = 0.0029 (Sn = 1,111; Rn = 344)	z = 3.8644; p = 0.0001 (Sn = 1,106; Rn = 345)	z = -3.3794; p = 0.0007 (Sn = 1,113; Rn = 344)	-
Test 6. Stationary observations excluding both repetitive & healing-related locations.	♂, ♀	-	z = 7.1143; p < .0001 (Sn = 635; Rn = 335)	-	z = 2.7564; p = 0.0058 (Sn = 637; Rn = 345)	z = -2.8815; p = 0.0040 (Sn = 640; Rn = 344)	-
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations.	♂, ♀	z = 2.2842; p = 0.0224 (Sn = 791; Rn = 320)	z = 6.9857; p < .0001 (Sn = 835; Rn = 335)	z = -2.5813; p = 0.0098 (Sn = 835; Rn = 344)	z = 3.1369; p = 0.0017 (Sn = 834; Rn = 345)	z = -3.5539; p = 0.0004 (Sn = 838; Rn = 344)	-
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations.	♂, ♀	z = 2.1489; p = 0.0316 (Sn = 724; Rn = 320)	z = 6.9219; p < .0001 (Sn = 767; Rn = 335)	z = -2.0313; p = 0.0422 (Sn = 775; Rn = 344)	z = 3.0201; p = 0.0025 (Sn = 769; Rn = 345)	z = -2.3379; p = 0.0194 (Sn = 775; Rn = 344)	-

Sn = Snake observations' sample size
Rn = Random locations' sample size
- = Not statistically different

Table 8a. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used versus available habitats within study site 1 (Kittatinny Ridge) for proximities to water, human activity, forest edge and roads (α = 0.05). Random habitats at Site 1, n = 1,793.

Observations included in analysis	**Sex**	**Proximity to water**	**Proximity to human activity**	**Proximity to forest edge**	**Proximity to roads**
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes, n = 198)	♂	-	z = 2.5667; p = 0.0103	z = -2.4860; p = 0.0129	z = 11.3159; p < .0001
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 142)	♂	-	z = 2.5656; p = 0.0103	-	z = 8.4491; p < .0001
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 185)	♂	-	z = 3.1132; p = 0.0019	-	z = 10.4942; p < .0001
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 147)	♂	-	z = 2.4345; p < 0.0149	-	z = 8.1019; p < .0001
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes, n = 283)	♂, ♀	-	z = 6.0866; p < .0001	-	z = 14.8608; p < .0001
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 184)	♂, ♀	-	z = 4.8693; p < .0001	-	z = 11.2424; p < .0001
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 249)	♂, ♀	-	z = 6.1782; p < .0001	-	z = 13.8461; p < .0001
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 195)	♂, ♀	-	z = 4.9173; p < .0001	-	z = 11.1061; p < .0001

n = sample size
\- = Not statistically different

Table 8b. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used versus available habitats within study site 2 (Highlands Region) for proximities to water, human activity, forest edge and roads ($\alpha = 0.05$). Random habitats at Site 2, n = 10,799.

Observations included in analysis	Sex	Proximity to water	Proximity to human activity	Proximity to forest edge	Proximity to roads
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes, n = 525)	♂	z = 4.1215; p < .0001	z = 8.9261; p < .0001	z = 2.5124; p = 0.0120	z = 14.5786; p < .0001
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 232)	♂	z = 4.0502; p < .0001	z = 2.3680; p = 0.0179	-	z = 4.8912; p < .0001
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 330)	♂	z = 4.8399; p < .0001	z = 3.6221; p = 0.0003	-	z = 6.4120; p < .0001
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 339)	♂	z = 2.8089; p = 0.0050	z = 5.3747; p < .0001	z = 2.4952; p < 0.0126	z = 8.8392; p < .0001
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes, n = 557)	♂, ♀	z = 4.9142; p < .0001	z = 9.5212; p < .0001	-	z = 13.8362; p < .0001
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 251)	♂, ♀	z = 4.6120; p < .0001	z = 3.0055; p = 0.0027	-	z = 4.2952; p < .0001
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 361)	♂, ♀	z = 5.7094; p < .0001	z = 4.5499; p < .0001	-	z = 5.6643; p < .0001
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 358)	♂, ♀	z = 3.3321; p = 0.0009	z = 5.8347; p < .0001	-	z = 8.2581; p < .0001

n = sample size
- = Not statistically different

Table 8c. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test comparing used habitats within the Kitattinny Ridge and Highlands Region study sites for proximities to water, human activity, forest edge and roads (α = 0.05).

Observations included in analysis	Sex	Proximity to water	Proximity to human activity	Proximity to forest edge	Proximity to roads
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes @ Kittatinny, n = 283; Snakes @ Highlands, n = 557)	♂	-	z = -6.2231; p < .0001	z = -5.5549; p < .0001	-
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes @ Kittatinny, n = 142; Snakes @ Highlands, n = 232)	♂	-	-	z = -3.5077; p = 0.0005	z = 2.7694; p = 0.0056
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes @ Kittatinny, n = 185; Snakes @ Highlands, n = 330)	♂	-	z = -1.9849; p = 0.0472	z = 4.3498; p < .0001	z = 3.8014; p = 0.0001
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes @ Kittatinny, n = 147; Snakes @ Highlands, n = 339)	♂	-	z = -3.7304; p = 0.0002	z = -4.3678; p < .0001	-
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes @ Kittatinny, n = 283; Snakes @ Highlands, n = 557)	♂, ♀	-	z = -4.4813; p < .0001	z = -3.0286; p = 0.0025	-
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes @ Kittatinny, n = 184; Snakes @ Highlands, n = 251)	♂, ♀	-	-	z = -2.1550; p = 0.0312	z = 4.8731; p < .0001
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes @ Kittatinny, n = 249; Snakes @ Highlands, n = 361)	♂, ♀	-	-	z = -2.3694; p = 0.0178	z = 6.3894; p < .0001
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes @ Kittatinny, n = 195; Snakes @ Highlands, n = 358)	♂, ♀	-	z = -2.3019; p = 0.0213	z = -3.0305; p = 0.0024	z = 2.1994; p = 0.0278

n = sample size
- = Not statistically different

Table 8d. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test comparing available habitats within the Kitattinny Ridge and Highlands Region study sites for proximities to water, human activity, forest edge and roads ($\alpha = 0.05$). Random habitats at Site 1, Kittatinny Ridge, n = 1,793; random habitats at Site 2, Highlands Region, n = 10,799.

Observations included in analysis	Sex	Proximity to water	Proximity to human activity	Proximity to forest edge	Proximity to roads
All available habitat (Site 1) vs. all available habitat (Site 2)	-	z = 9.9599; p < .0001	z = -3.5277; p = 0.0004	z = -10.6953; p < .0001	-

n = sample size
- = Not statistically different

Table 8e. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used habitats of both study sites (Kitattinny Ridge and Highlands Region) versus the available habitats of both study sites for proximities to water, human activity, forest edge and roads (α = 0.05).

Observations included in analysis	Sex	Proximity to water	Proximity to human activity	Proximity to forest edge	Proximity to roads
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes, n = 722; Random, n = 12,592)	♂	z = 3.6248; p = 0.0003	z = 8.6805; p < .0001	-	z = 17.4994; p < .0001
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 355; Random, n = 12,592)	♂	z = 3.9956; p < .0001	z = 3.3334; p = 0.0009	-	z = 9.4688; p < .0001
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 488; Random, n = 12,592)	♂	z = 4.5218; p < .0001	z = 4.4715; p < .0001	-	z = 11.4956; p < .0001
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 486; Random, n = 12,592)	♂	z = 2.5191; p = 0.0118	z = 5.5017; p < .0001	-	z = 11.1779; p < .0001
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes, n = 839; Random, n = 12,592)	♂, ♀	z = 5.7346; p < .0001	z = 10.6535; p < .0001	-	z = 18.7284; p < .0001
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 416; Random, n = 12,592)	♂, ♀	z = 5.8072; p < .0001	z = 5.1150; p < .0001	-	z = 10.6101; p < .0001
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 582; Random, n = 12,592)	♂, ♀	z = 7.0987; p < .0001	z = 6.8494; p < .0001	-	z = 12.8566; p < .0001
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 553; Random, n = 12,592)	♂, ♀	z = 4.2088; p < .0001	z = 7.0355; p < .0001	-	z = 12.2773; p < .0001

n = sample size

Table 8f. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used versus available habitats within Site 1 (Kittatinny Ridge) for canopy closure ($\alpha = 0.05$).

Observations included in analysis	Sex	Canopy closure
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes, n = 417; Random, n = 93)	♂	z = 4.3154; p < .0001
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 273; Random, n = 93)	♂	z = 2.5172; p = 0.0118
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 344; Random, n = 93)	♂	z = 3.0927; p = 0.0020
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 302; Random, n = 93)	♂	z = 3.1636; p = 0.0016
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes, n = 594; Random, n = 93)	♂, ♀	z = 4.2612; p < .0001
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 385; Random, n = 93)	♂, ♀	z = 2.4008; p = 0.0164
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 506; Random, n = 93)	♂, ♀	z = 3.1712; p = 0.0015
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 421; Random, n = 93)	♂, ♀	z = 3.0360; p = 0.0024

n = sample size

Table 8g. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used versus available habitats within Site 2 (Highlands Region) for canopy closure (α = 0.05).

Observations included in analysis	Sex	Canopy closure
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes, n = 484; Random, n = 246)	♂	z = 7.6390; p < .0001
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 235; Random, n = 246)	♂	z = -4.5717; p < .0001
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 300; Random, n = 246)	♂	z = 6.2739; p < .0001
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 335; Random, n = 246)	♂	z = 4.8541; p < .0001
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes, n = 515; Random, n = 246)	♂, ♀	z = 7.7801; p < .0001
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 255; Random, n = 246)	♂, ♀	z = 4.8506; p < .0001
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 330; Random, n = 246)	♂, ♀	z = 6.5381; p < .0001
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 355; Random, n = 246)	♂, ♀	z = 5.0621; p < .0001

n = sample size

Table 8h. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test comparing used habitats within Sites 1 (Kittatinny Ridge) and 2 (Highlands Region) for canopy closure ($\alpha = 0.05$).

Observations included in analysis	Sex	Canopy closure
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes @ Kittatinny, n = 417; Snakes @ Highlands, n = 484)	♂	z = 3.7900; p = 0.0002
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes @ Kittatinny, n = 273; Snakes @ Highlands, n = 235)	♂	z = -3.1914; p = 0.0014
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes @ Kittatinny, n = 344; Snakes @ Highlands, n = 300)	♂	z = -3.9458; p < .0001
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes @ Kittatinny, n = 302; Snakes @ Highlands, n = 335)	♂	z = 2.7376; p = 0.0062
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes @ Kittatinny, n = 594; Snakes @ Highlands, n = 515)	♂, ♀	z = -5.0644; p < .0001
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes @ Kittatinny, n = 385; Snakes @ Highlands, n = 255)	♂, ♀	z = -4.2265; p < .0001
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes @ Kittatinny, n = 506; Snakes @ Highlands, n = 330)	♂, ♀	z = -5.0644; p < .0001
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes @ Kittatinny, n = 421; Snakes @ Highlands, n = 355)	♂, ♀	z = -3.7141; p = 0.0002

n = sample size

Table 8i. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test comparing available habitats within Sites 1 (Kittatinny Ridge) and 2 (Highlands Region) for canopy closure (α = 0.05).

Observations included in analysis	Sex	Canopy closure
All available habitat (Site 1) vs. all available habitat (Site 2). (Snakes @ Kittatinny, n = 93; Snakes @ Highlands, n = 246)	-	z = 2.7835; p = 0.0054

n = sample size
- = Not applicable

Table 8j. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used habitats of both study sites (Kitattinny Ridge and Highlands Region) versus the available habitats of both study sites for canopy closure (α = 0.05).

Observations included in analysis	Sex	Canopy closure
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes, n = 901; Random, n = 339)	♂	z = 8.0847; p < .0001
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 508; Random, n = 339)	♂	z = 4.1349; p < .0001
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 644; Random, n = 339)	♂	z =5.7734; p < .0001
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 637; Random, n = 339)	♂	z = 5.1612; p < .0001
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes, n = 1,109; Random, n = 339)	♂, ♀	z = 7.8314; p < .0001
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 640; Random, n = 339)	♂, ♀	z = 3.8155; p = 0.0001
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 836; Random, n = 339)	♂, ♀	z = 5.6198; p < .0001
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 776; Random, n = 339)	♂, ♀	z = 4.8938; p < .0001

n = sample size

Table 8k. Results of Mann-Whitney U-Wilcoxon nonparametric two-sample test on used versus available habitats at Site 2 (Highlands Region) regarding proximity to nearest rock outcrop; random locations ($\alpha = 0.05$), n = 150.

Observations included in analysis	**Sex**	**Proximity to nearest rock outcrop, within 50 m (m)**
Test 1. All stationary observations including repetitive & healing-related locations. (Snakes, n = 172)	♂	z = 4.3573; p < .0001
Test 2. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 353)	♂	z = 7.2827; p < .0001
Test 3. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 230)	♂	z = 5.3131; p < .0001
Test 4. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 222)	♂	z = 5.1689; p = 0.0050
Test 5. All stationary observations including repetitive & healing-related locations. (Snakes, n = 382)	♂, ♀	z = 7.5420; p < .0001
Test 6. Stationary observations excluding both repetitive & healing-related locations. (Snakes, n = 190)	♂, ♀	z = 4.8599; p < .0001
Test 7. Stationary observations including repetitive observations, but excluding healing-related locations. (Snakes, n = 258)	♂, ♀	z = 5.7504; p < .0001
Test 8. Stationary observations including healing-related observations, but excluding repetitive locations. (Snakes, n = 240)	♂, ♀	z = 5.5605; p = 0.0009

n = sample size

Table 9a. Percentage means and 95% CI (2SE) of snake and random locations' canopy closure representing the category containing the largest sample sizes of each group. Used and available canopy closure were statistically different for all subsets of data although the majority of the data collected were captured within Category 5 (81 – 100% canopy closure). Means reveal the snakes selected for slightly more open canopies than what was available to them.

Category	Canopy closure (%)			
	Site 1		Site 2	
	Snake observations (N = 379)	Random locations (N = 79)	Snake observations (N = 284)	Random locations (N = 218)
Category 5	93.80 ± 0.58	95.37 ± 1.16	92.57 ± 0.65	93.08 ± 0.66

Table 9b. Distance means and 95% CI (2SE) of snake and random locations' proximities to streams and rivers representing the category containing the largest sample sizes of each group. The proximity to streams and rivers showed statistical differences between used and available habitats within the Highlands Region (Site 2) but not along the Kittatinny Ridge (Site 1). The majority of all samples were within 0 – 200m (Category 1) of a stream or river >10m wide. Means reveal the snakes showed a slight aversion to streams and rivers ≥10m wide.

Category	Proximity to streams and rivers (m)			
	Site 1		Site 2	
	Snake observations (N = 119)	Random locations (N = 698)	Snake observations (N = 252)	Random locations (N = 5338)
Category 1	118.10 ± 8.65	99.70 ± 4.35	110.07 ± 6.54	93.66 ± 1.59

Table 9c. Distance means and 95% CI (2SE) of snake and random locations' proximities to human-occupied areas representing the categories containing the largest sample sizes of each group. Proximity to human activity/ human-occupied areas was statistically different among all data subsets testing used and available habitat, but varied when comparing snakes between Sites 1 and 2. The majority of the samples collected were captured within Categories 2 (0 – 500m) and 3 (500 – 1000m). Means reveal the snakes showed an aversion to human-occupied areas.

Category	**Proximity to human activity/ human-occupied areas (m)**			
	Site 1		**Site 2**	
	Snake observations (N = 161)	**Random locations (N = 970)**	**Snake observations (N = 222)**	**Random locations (N = 4897)**
Category 2	278.54 ± 18.37	201.14 ± 9.71	-	196.73 ± 4.37
Category 3	-	-	785.40 ± 14.70	-

Table 9d. Distance means and 95% CI (2SE) of snake and random locations' proximities to paved roads representing the categories containing the largest sample sizes of each group. Proximity to roads was statistically different among all data subsets testing used and available habitat, but varied when comparing snakes between Sites 1 and 2. The majority of the samples collected were captured within Categories 1 (0 – 500m) and 3 (1000 – 1500m). Means reveal the snakes showed an aversion to paved roads for stationary behaviors (e.g., foraging, basking, resting).

Category	**Proximity to roads (m)**			
	Site 1		**Site 2**	
	Snake observations (N = 168)	**Random locations (N = 928)**	**Snake observations (N = 175)**	**Random locations (N = 5733)**
Category 1	-	222.67 ± 9.43	265.87 ± 21.13	181.17 ± 3.86
Category 3	1165.77 ± 14.88	-	-	-

Table 9e. Distance means and 95% CI (2SE) of snake and random locations' proximities to the forest edge without exiting the forest, representing the category containing the largest sample sizes of each group. The statistical significance of the proximity to the forest edge varied among the data subsets with no clear distinction of the determining factor, however most of the samples were located within 0 – 200m (Category 1) of the forest edge (forest having >50% canopy closure). Means revealed the snakes show a slight aversion to the forest edge.

Category	**Proximity to forest edge (m)**			
	Site 1		**Site 2**	
	Snake observations (N = 131)	**Random locations (N = 1054)**	**Snake observations (N = 239)**	**Random locations (N = 5007)**
Category 1	71.35 ± 10.52	68.98 ± 3.51	82.69 ± 8.54	76.53 ± 1.64

Table 9f. Distance means and 95% CI (2SE) of snake and random locations' proximities to the nearest rock outcrop (within 50m) representing the categories containing the largest sample sizes of each group. The proximity to rock outcrops at Site 2 showed statistical difference for all subsets of data. Snake observations and random locations' distances to rock outcrops did not fall within the same category; snake observations lying within 0 – 2m (Category 1) and random locations at distances >50m (Category 5). Means revealed the snakes show an attraction to or affinity for rock outcrops.

Category	**Proximity to rock outcrop (m)**			
	Site 1		**Site 2**	
	Snake observations (N = 0)	**Random locations (N = 0)**	**Snake observations (N = 304)**	**Random locations (N = 99)**
Category 1	n/a	n/a	0.03 ± 0.02	-
Category 5	n/a	n/a	-	> 50

ILLUSTRATIONS

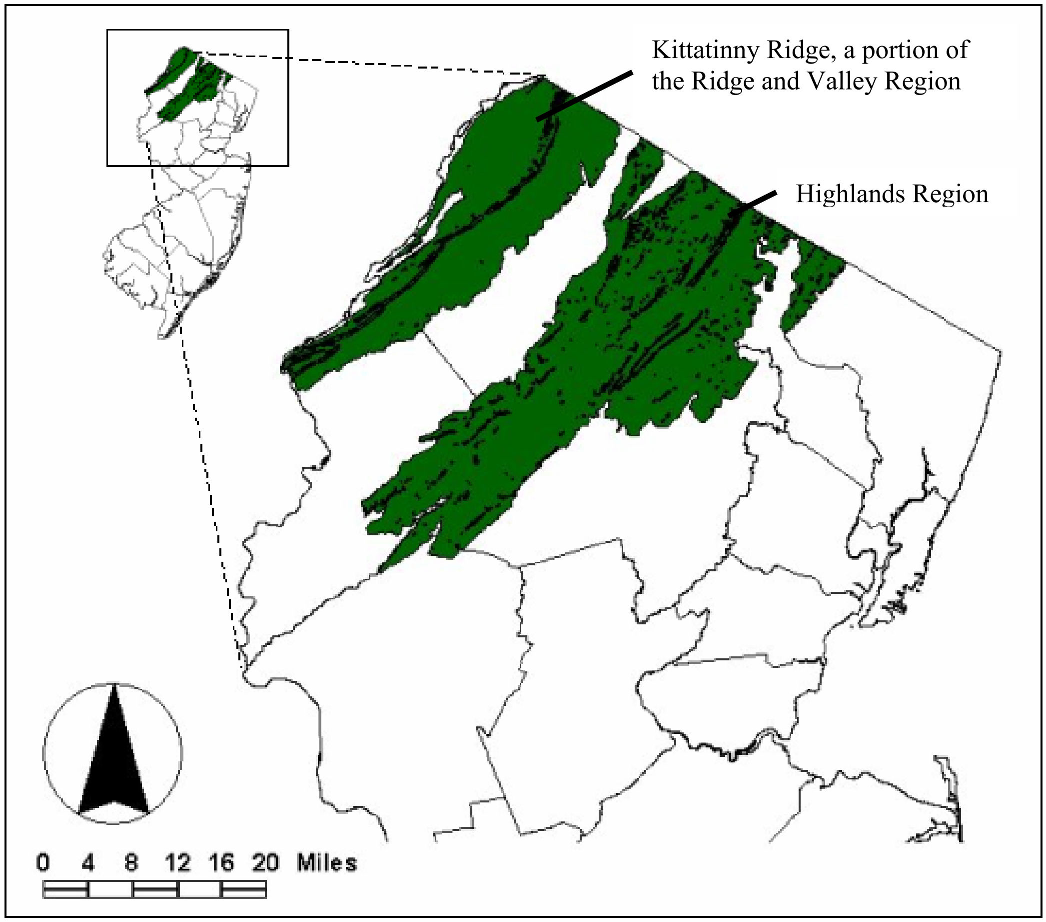


Figure 1. Study area within northern New Jersey.

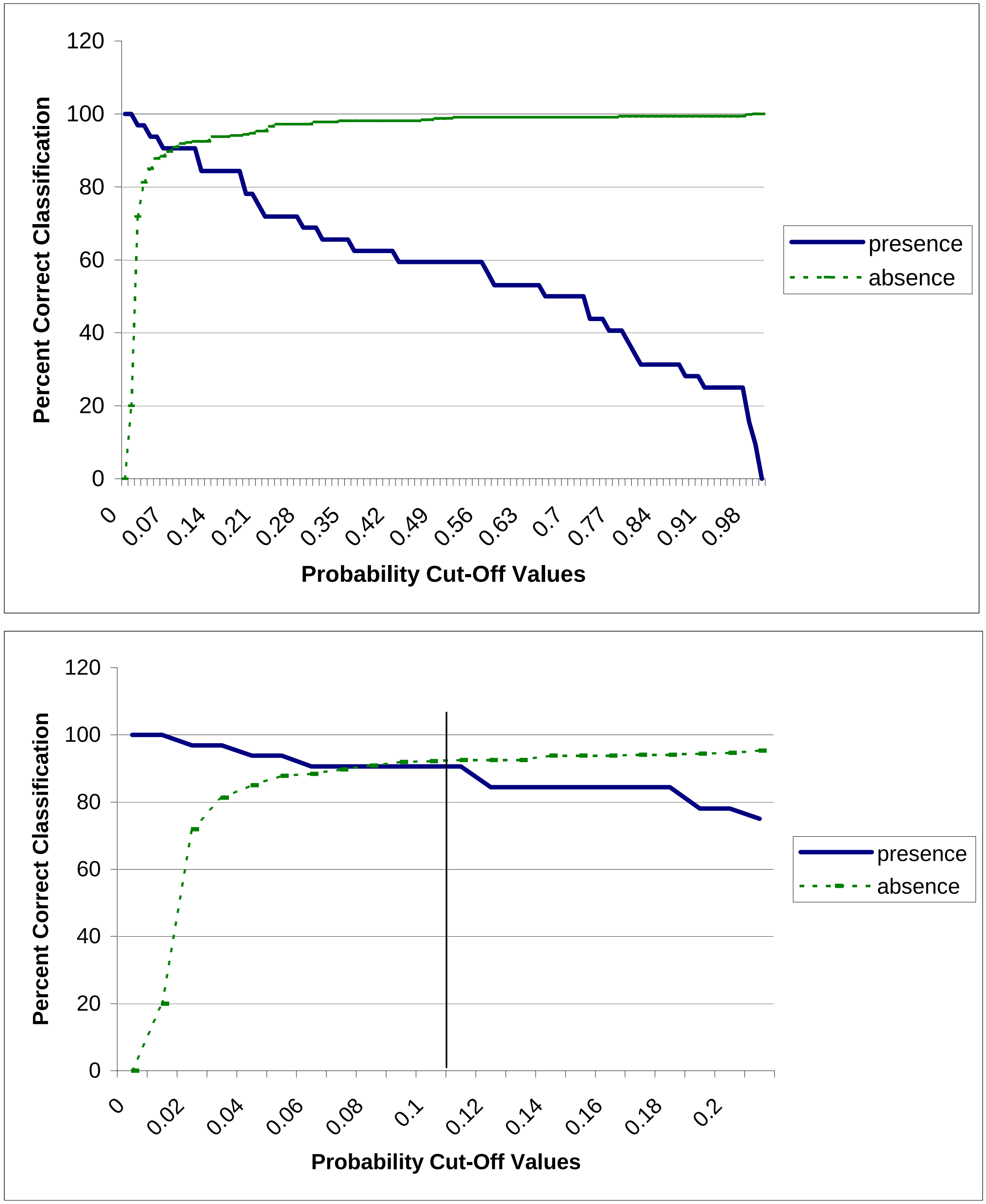


Figure 2. Classification error rates (% locations correctly classified as used or unused) for rattlesnake hibernacula model, 2009. Lines represent error rates for used locations (———) and unused locations (-------). The lower figure is a subset of the upper figure. The vertical line (bottom) represents the optimal probability cut-off value (0.11), minimize the number of incorrectly classified absence locations (assumed unused habitat) while maximizing the number of correctly classified presence locations (used habitat).

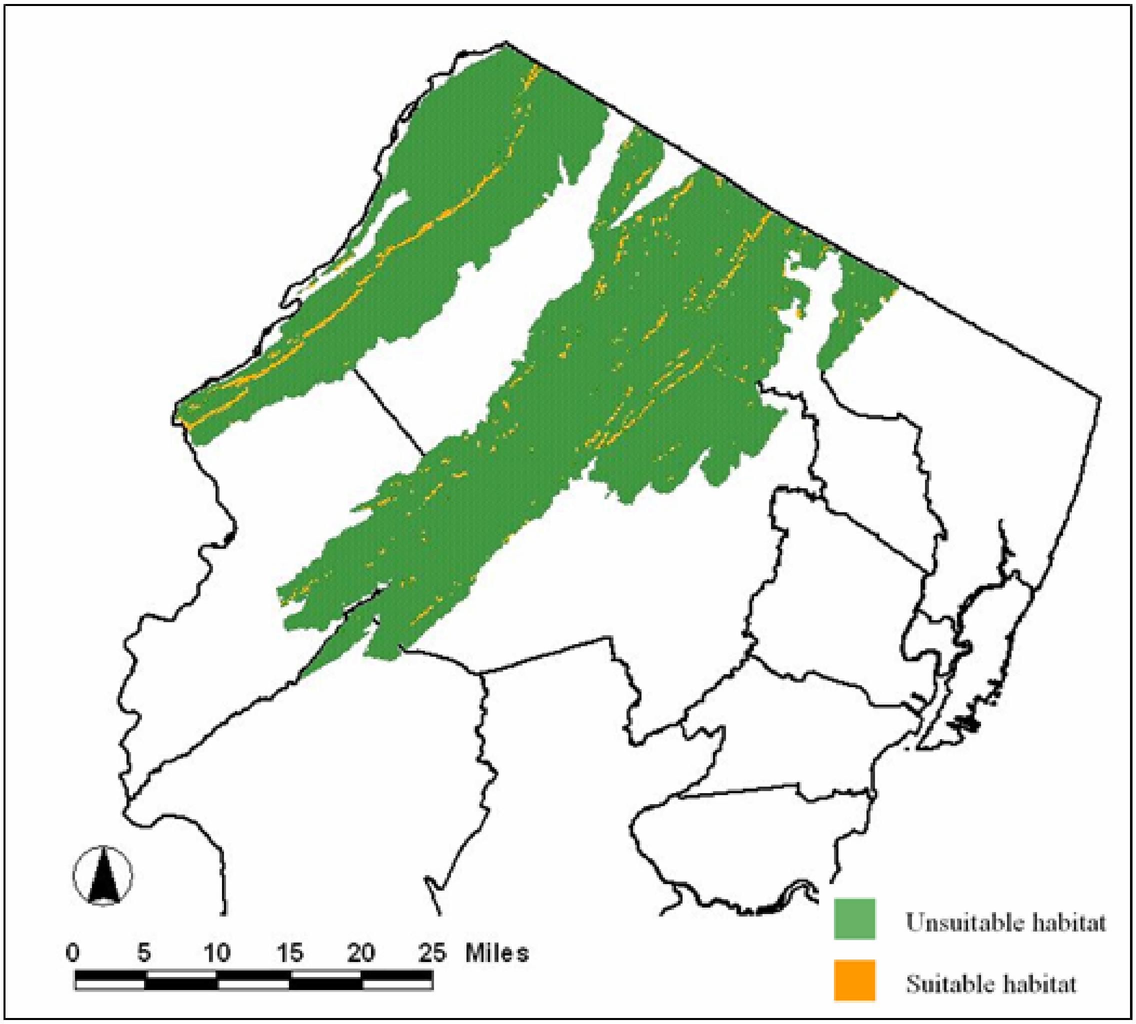


Figure 3. Map distinguishing suitable versus unsuitable habitat for hibernacula, 2004.

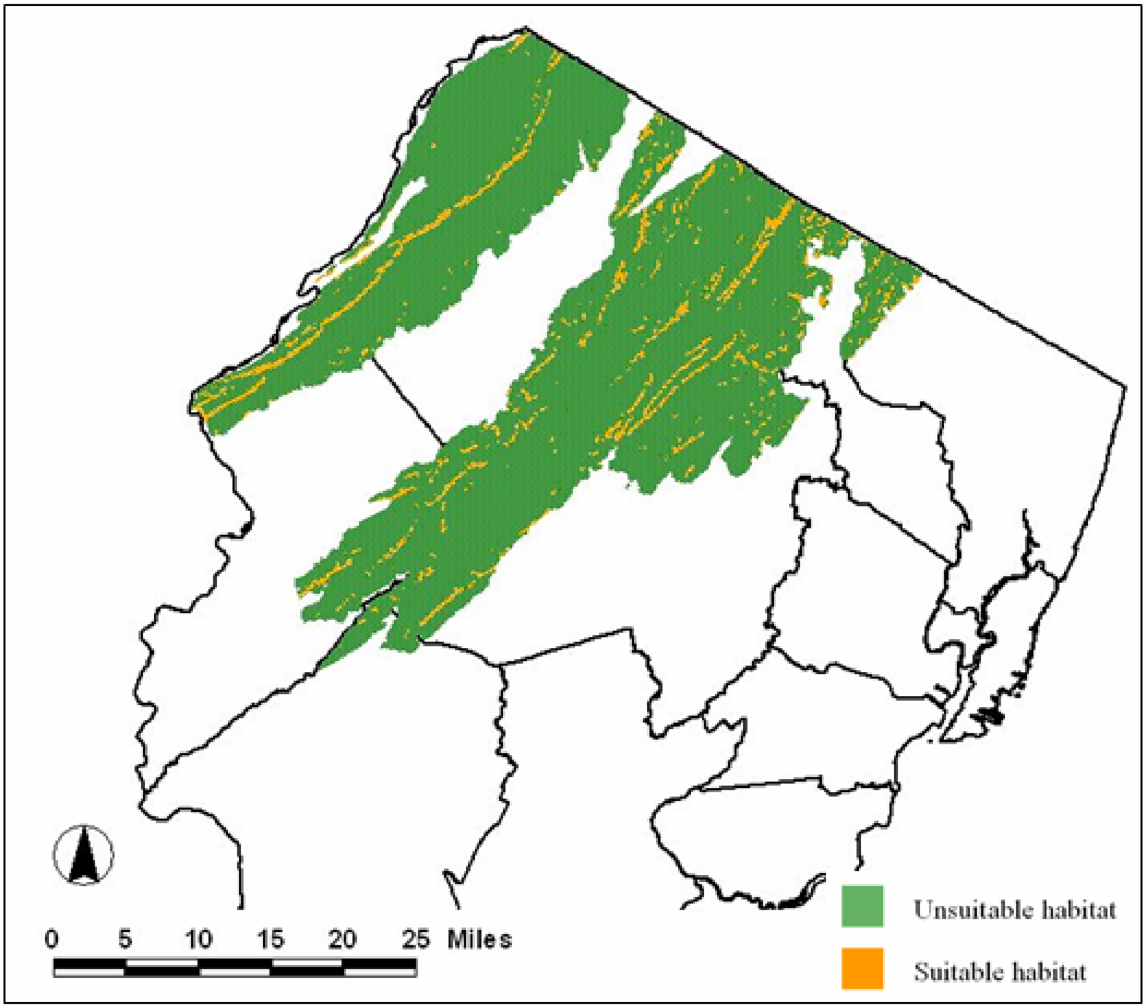


Figure 4. Map distinguishing suitable versus unsuitable habitat for hibernacula, 2009.

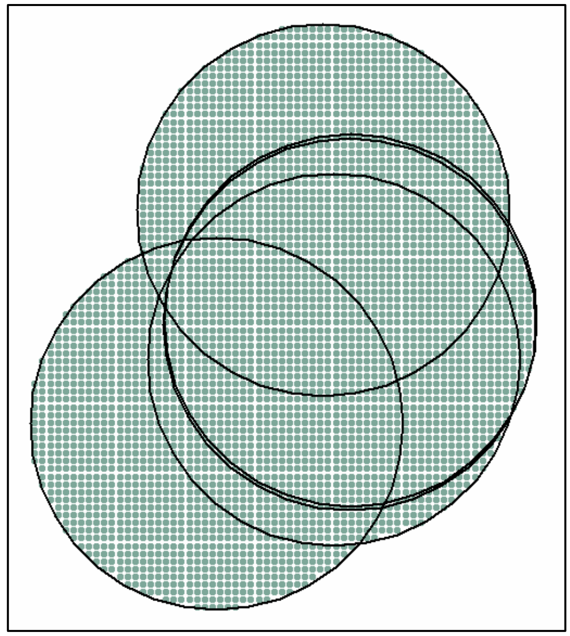


Figure 5. Example of random points generated by overlaying five hibernacula buffers with a 100m x 100m grid overlay; points were generated consistently throughout combined area, ignoring hibernacula buffer overlap.

APPENDICES

Appendix 1. Transmitter package and snake capture, implant and release details.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[a]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
Site 1: Kittatinny Ridge											
M01	Female, gravid	831	5/05/99	5/19/99	5/20/99	15	G-3	(1) Li 1018; 3.6V	12.5[b]	227	1.50
	post-partum	663	9/22/99	9/23/99	9/24/99	2	G-3	(1) Li 1018; 3.6V	12.5[b]	520	1.89
		613	8/27/00	9/02/00	9/06/00	10	SM-1	(2) Ag 357; 1.5V	12.5[b]	324	2.04
M02	Male	552	5/05/99	5/19/99	5/20/99	15	G-3	(1) Li 1025; 3.6V	12.5	277	2.26
M03	Male	1170	5/05/99	5/19/99	5/20/99	15	G-3	(1) Li 1025; 3.6V	12.5	297	1.07
		1443	9/24/99	9/27/99	10/05/99	11	G-3	(1) Li 1025; 3.6V	12.5	520	0.87
		1513	8/27/00	8/29/00	8/29/00	2	G-3	(1) Li 1025; 3.6V	12.5	no data	0.83

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) transmitters and L.L. Electronics (LS-1) transmitters.

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 1, continued.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[b]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
M04	Male, subadult (suspected)	650	5/05/99	5/27/99	5/29/99	24	G-3	(1) Li 1025; 3.6V	12.5	244	1.92
		913	9/22/99	9/23/99	9/24/99	2	G-3	(1) Li 1025; 3.6V	12.5	520	1.37
		no data	9/08/00	9/24/00	9/29/00	21	G-3	(1) Li 1025; 3.6V	12.5	no data	no data
M05	Male	1125	5/12/99	5/27/99	5/29/99	17	G-3	(1) Li 1025; 3.6V	12.5	277	1.11
		1213	9/24/99	9/27/99	10/01/99	7	G-3	(1) Li 1025; 3.6V	12.5	520	1.03
		1163	6/29/00	7/17/00	7/18/00	19	G-3	(1) Li 1025; 3.6V	12.5	462	1.07

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) and L.L. Electronics (LS-1).

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 1, continued.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[a]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
M06	Male	650	5/20/99	5/28/99	5/29-6/01/99	29-31	G-3	(1) Li 1025; 3.6V	12.5	320	1.92
		888	9/22/99	9/23/99	9/24/99	2	G-3	(1) Li 1025; 3.6V	12.5	378	1.41
		813	5/28/00	6/16/00	6/21/00	23	G-3	(1) Li 1025; 3.6V	12.5	462	1.54
M07	Male	912.5	6/28/99	7/15/99	7/18/99	20	G-3	(1) Li 1025; 3.6V	12.5	462	1.37
M08	Female	438	7/16/99	7/19/99	7/20/99	4	SM-1	(2) Ag 357; 1.5V	<11	365	2.85
		488	5/13/00	5/24/00	5/25/00	12	G-3	(1) Li 1018; 3.6V	12.5[b]	277	2.56
		463	8/29/00	9/07/00	9/08/00	10	SM-1	(2) Ag 357; 1.5V	<11	324	2.70

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) and L.L. Electronics (LS-1).

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 1, continued.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[a]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
M09	Female, nongravid	563	8/06/99	8/17/99	8/18/99	12	G-3	(1) Li 1018; 3.6V	12.5[b]	312.5	2.22
	gravid	588	5/09/00	5/18/00	5/23/00	14	G-3	(1) Li 1025; 3.6V	12.5	462	2.13
M10	Female, nongravid	313	8/02/99	8/25/99	8/26/99	24	SM-1	(2) Ag 357; 1.5V	<11	324	3.99
	gravid	338	6/23/00	7/05/00	7/07/00	15	SM-1	(2) Ag 357; 1.5V	<11	324	3.70
M11	Female-nongravid	513	8/05/99	8/25/99	8/26/99	21	SM-1	(2) Ag 357; 1.5V	<11	365	2.44
M12	Female, gravid	938	4/25/00	4/28/00	prior to 05/05/00	max. 6	G-3	(1) Li 1018; 3.6V	12.5[b]	277	1.33
M13	Female	613	4/29/00	6/06/00	6/07/00	38	G-3	(1) Li 1018; 3.6V	12.5[b]	277	2.04

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) and L.L. Electronics (LS-1).

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 1, continued.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[a]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
M14	Male, subadult	188	4/29/00	6/06/00	6/07/00	38	SM-1	(2) Ag 357; 1.5V	<11	277	6.65
M15	Male, subadult	363	5/09/00	6/16/00	n/a	n/a	G-3	(1) Li 1018; 3.6V	12.5[b]	277	3.44
M16	Female, gravid	688	6/12/00	6/26/00	6/27/00	15	G-3	(1) Li 1018; 3.6V	12.5[b]	277	1.82
M17	Male	1138	6/23/00	7/17/00	7/18/00	26	G-3	(1) Li 1025; 3.6V	12.5	462	1.10
Site 2: Highlands Region											
H01	Male, adult	1314	5/01/03	5/08/03	5/09/03	8	G-3	(1) Li 1025; 3.6V	11	346	0.84
H02	Male, subadult	614	5/07/03	5/28/03	5/29/03	22	G-3	(1) Li 1025; 3.6V	11	416	1.79

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) and L.L. Electronics (LS-1).

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 1, continued.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[a]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
H03	Male, adult	989	5/28/03	6/01/03	6/03/03	6	G-3	(1) Li 1025; 3.6V	11	378	1.11
H04	Female, gravid	**Released without transmitter**									
H05	Female, gravid	1264	6/10/03	6/13/03	6/17/03	7	G-3	(1) Li 1025; 3.6V	11	520	0.87
H06	Female, gravid	**Released without transmitter**									
H07	Female, pp	**Released without transmitter**									
H08	Female, gravid	**Released without transmitter**									
H09	Male	1014	7/02/03	7/08/03	7/09/03	7	G-3	(1) Li 1025; 3.6V	11	520	1.08

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) and L.L. Electronics (LS-1).

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 1, continued.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[a]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
H10	Male, subadult (suspected)	839	7/01/03	7/10/03	7/11/03	10	G-3	(1) Li 1025; 3.6V	11	520	1.31
H11	Female, gravid	**Released without transmitter**									
H12	Female, suspected gravid	**Released without transmitter**									
H13	U	**Released without transmitter; injured- temporarily held at rehabilitator's facility and was released 9/4/03**									
H14	Male, juvenile	**Released without transmitter**									
H15	Male	689	7/27/03	7/31/03	9/04/03	40*	G-3, 1-V	(3) Ag 357; 1.5V	11	438	1.60
H16	Male, adult	1340	7/28/03	7/31/03	8/01/03	4	G-3	(1) Li 1025; 3.6V	10	416	0.75

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) and L.L. Electronics (LS-1).

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 1, continued.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[a]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
H17	Male, adult	**Released without transmitter; digesting large prey item**									
H18	Male, adult	1389	8/12/03	8/21/03	8/22/03	10	G-3	(1) Li 1025; 3.6V	11	520	0.79
H19	Female, pp	496	6/07/04	6/11/04	6/12/04	5	G-3, 1-V	(3) Ag 357; 1.5V	11	438	2.22
H20	Male, subadult (suspected)	887	6/29/04	7/07/04	7/07/04	8	G-3	(1) Li 1025; 3.6V	11	462	1.24
H21	Male, adult	1373	7/08/04	7/14/04	7/15/04	7	G-3	(1) Li 1025; 3.6V	11	416	0.80
H22	Male, adult	1819	7/16/04	7/21/04	7/23/04	7	G-3	(1) Li 1025; 3.6V	11	426	0.60
H23	Male, adult	1829	7/17/04	7/22/04	7/23/04	6	G-3	(1) Li 1025; 3.6V	11	438	0.60

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) and L.L. Electronics (LS-1).

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 1, continued.

Snake ID	Sex/Age Class	Snake: Initial Wt. (g)	Capture Date	Trans. Implant Date	Release Date	Time in Captivity (days)	Trans. Type[a]	Battery	Trans. Wt. (g)	Trans. Life (est. days)	Transmitter Proportional Weight to Snake (%)
H24	Male, adult	1222	7/21/04	7/22/04	7/23/04	2	G-3	(1) Li 1025; 3.6V	11	438	0.90
	Female, suspected gravid	**Released without transmitter**									
H26	Male, adult	1358	8/02/04	8/05/04	8/06/04	4	LS-1	(1) Li 1025; 3.6V	11	462	0.81
		1337	7/06/05	7/07/05	7/08/05	2	LS-1	(1) Li 1025; 3.6V	11	-	0.82
H27	Male, adult	1281	8/09/04	8/13/04	8/15/04	6	LS-1	(1) Li 1025; 3.6V	11	416	0.86
H28	Male, subadult	598	8/09/04	8/13/04	8/15/04	6	LS-1	(1) Li 1025; 3.6V	11	416	1.84
H29	Female	877	8/15/04	8/17/04	8/17/04	2	LS-1	(1) Li 1025; 3.6V	11	416	1.25

[a]Transmitters manufactured by AVM Instrument, Ltd. (G-3, SM-1 and G3,1V) and L.L. Electronics (LS-1).

[b]Weights were not recorded for the transmitter package (G-3 with Li1018 battery). The larger package (G-3 with Li1025) weighed 12.5g and therefore was used as an estimated maximum weight for the smaller transmitter package.

Appendix 2. Summary of available data.

Snake ID	Sex, Age Class or Condition	Microhabitat data available	Macrohabitat data available	Complete Activity Season of Data	Partial Activity Season of Data
Site 1: Kittatinny Ridge, NJ Ridge and Valley Region					
M01	♀, PP (2000)	X	-	X	-
M02	♂, A	X	X	X	-
M03	♂, A	X	X	X	-
M04	♂, SA	X	X	X	-
M05	♂, A	X	X	X	-
M06	♂, A	X	X	X	-
M07	♂, A	X	X	Micro	Macro
M08	♀, A	X	X	Micro	Macro
M09	♀, NG	X	X	-	X
M10	♀, NG	X	X	-	X
M11	♀, NG	X	X	-	X
M12	♀, G	-	-	-	-
M13	♀, U	-	-	-	-
M14	♂, SA	-	-	-	-
M15	♂, SA	-	-	-	-
M16	♀, G	-	-	-	-
M17	♂, A	X	-	-	X

[a]Fewer than 10 observations during one or more seasonal periods.

A - Adult, reproductively mature

SA - Subadult or nearly mature

NG - Nongravid female

G - Gravid female

U - Undetermined condition or sex

Appendix 2, continued.

Snake ID	Sex, Age Class or Condition	Microhabitat data available	Macrohabitat data available	Complete Activity Season of Data	Partial Activity Season of Data
Site 2: NJ Highlands Region					
H01	♂, A	X	X	-	X
H02	♂, SA	X	X	-	X
H03	♂, A	X	X	-	X
H04	♀, G	-	-	-	-
H05	♀, G	-	-	-	-
H06	♀, G	-	-	-	-
H07	♀, PP	-	-	-	-
H08	♀, G	-	-	-	-
H09	♂, A	-	-	-	-
H10	♂, U	X	X	-	X
H11	♀, G	-	-	-	-
H12	♀, G-s	-	-	-	-
H13	U	-	-	-	-
H14	♂, J	-	-	-	-
H15	M, U	-	-	-	-

[a]Fewer than 10 observations during one or more seasonal periods.

A - Adult, reproductively mature

SA - Subadult or nearly mature

G - Gravid female

U - Undetermined condition or sex

PP - Post partum female

G-s - Suspected gravid

J - Juvenile

Appendix 2, continued.

Snake ID	Sex, Age Class or Condition	Microhabitat data available	Macrohabitat data available	Complete Activity Season of Data	Partial Activity Season of Data
H16	♂, A	X	X	-	X
H17	♂, A	-	-	-	-
H18	♂, A	X	X	-	X
H19	♀, PP	-	-	-	-
H20	♂, A	X	X	X	-
H21	♂, A	X	X	X	-
H22	♂, A	X	X	-	X
H23	♂, A	X	X	-	X
H24	♂, A	X	X	-	X
H25	♀, G-s	-	-	-	-
H26	♂, A	X	X	X	-
H27	♂, A	X	X	X	-
H28	♂, SA	X	X	X	-
H29	♀, NG	X	X	-	X

[a]Fewer than 10 observations during one or more seasonal periods.

A - Adult, reproductively mature

SA - Subadult or nearly mature

NG - Nongravid female

PP - Post partum female

G-s - Suspected gravid

Appendix 3. Microhabitat random sampling requirements, the number of completed surveys and the associated allowable error.

Den Association	No. of random sample points needed for AE=15%	No. of random sample points needed for AE=10%	No. random habitat points generated	Total No. of points surveyed	No. of inaccessible points	Percentage of inaccessible points
1	9	20	20	20	0	0
2 [a]	13	29	29	16	13	44.8%
3 [a]	25	55	55	48	7	12.7%
4	11	28	28	25	3	10.7%
5	16	36	36	36	0	0
6	3	7	7	5	2	28.5%
7 [b]	7	16	33	30	n/a	n/a
8	15	34	34	23	11	32.3%
9	31	70	70	49	21	30
TOTALS	**130**	**295**	**312**	**252** [c]	**57**	**-**

[a]Dens 2 and 3 contain two dens each, but due to the severity of overlap, they were combined to determine the number of required random sample points.

[b]Random sample points for hibernacula # 7 were generated using data from three snakes including an injured female (H19) who was later excluded from this study's analysis. As a result, more random points were generated and surveyed for this location than were necessary.

[c]An additional 14 points were surveyed at hibernacula # 7, however only 238 of the required 295 points (generated for each hibernacula buffer to meet an AE of 10%) have been surveyed.

Appendix 4a. Kittatinny Study (1999-2000) datasheet and instructions.

Habitat and Climatic Variables and Geographical Information	**Sampling Method**
Date and time snake located	Collector will note the date and time that the snake was located.
GPS sighting number/ PDOP value/ Number of Position Fixes (min. 120)	Collector will identify GPS tracking number for each sighting, note the PDOP value and the number of satellite fixes gathered.
Distance to rock	Distance (m) to nearest rock (>25 cm on shortest side)
Distance to log	Distance (m) to nearest downed woody log (≥5.0cm diameter)
Distance to overstory tree	Distance (m) to nearest tree (≥ 7.5 cm dbh)
Identification of same overstory tree	Collector will identify same overstory tree (above) by species
DBH of overstory tree	DBH of same overstory tree (above)
Distance to understory tree/ shrub	Distance to nearest understory tree or shrub (≤ 7.5 cm dbh and ≥ 2.0 m height)
Identification of same understory tree/ shrub	Identify species of same understory tree/ shrub (above).
Canopy closure	% canopy closure within a 45 deg. cone measured with a convex spherical crown densiometer
Surface temperature (C)	Collector will note surface temperature (C) within 10 cm of snake.
Surface humidity (%)	Collector will note surface humidity (%) within 10 cm of snake.
Ambient temperature (C)	Collector will note ambient temperature (C) (shaded air 1m above snake).
Ambient humidity (%)	Collector will note ambient relative humidity (%) (shaded air 1m above snake).
Soil temperature (C)	Collector will note soil temperature (C) @ 5 cm depth within 10 cm of snake.
Soil moisture (%)	Collector will note soil moisture (%) @ 5 cm depth within 10 cm of snake.
Illumination at snake (lux)	Collector will note illumination and note if there is overcast, shade or sun at point of measuring unit.
Slope at snake sighting	Slope at snake measured in percentage with a clinometer.
Percent of body visible – overhead view	Collector will estimate percent of snake's body visible from overhead view, and note any obstructions
Difficulties or comments	Collector will note if they obtained a visual observation and behavioral activity in addition to any other pertinent information.

Appendix 4b. Highlands Study (2003-2006) datasheet and instructions.

Habitat and Climatic Variables and Geographical Information	**Sampling Method**
Date and time snake located	Collector will note the date and time that the snake was located.
GPS sighting number/ Accuracy	Collector will identify GPS tracking number for each sighting and note GPS accuracy distance.
Distance to rock	Distance (m) to nearest rock (>25 cm on shortest side)
Distance to log	Distance (m) to nearest downed woody log (≥5.0cm diameter)
Distance to overstory tree	Distance (m) to nearest tree (≥ 7.5 cm dbh)
Identification of same overstory tree	Collector will identify same overstory tree (above) by species
DBH of overstory tree	DBH of same overstory tree (above)
Distance to understory tree/ shrub	Distance to nearest understory tree or shrub (≤ 7.5 cm dbh and ≥ 2.0 m height)
Identification of same understory tree/ shrub	Identify species of same understory tree/ shrub (above).
Canopy closure	% canopy closure within a 45 deg. cone measured with a convex spherical crown densiometer
Slope at snake sighting	Slope at snake measured in percentage with a clinometer
Nearest rock outcrop	Distance (m) to nearest rock outcrop within 50 m of sighting
Nearest talus slope	Distance (m) to nearest talus slope within 50 m of sighting
Habitat description	Collector will identify general habitat description at snake sighting as: 1) Forest or forested wetland 2) Open land (old field, successional fields) 3) Rock cover (talus, scree, outcrop, boulder field, other-describe) 4) Grassland 5) Seep 6) Emergent wetland (includes wetlands at edges of water bodies) 7) Floodplain
Percent of body visible – overhead view	Collector will estimate percent of snake's body visible from overhead view, and note any obstructions
Surface temperature (C)	Collector will note surface temperature (C) within 10 cm of snake.
Surface humidity (%)	Collector will note surface humidity (%) within 10 cm of snake.

Appendix 4b, continued.

Ambient temperature (C)	Collector will note ambient temperature (C) (shaded air 1m above snake).
Ambient humidity (%)	Collector will note ambient relative humidity (%) (shaded air 1m above snake).
Snake's behavioral activity at sighting	A. Collector will note activity of snake as: 1) Hunting: active ambush, passive ambush, Reinert position, scent trailing prey 2) Eating or drinking 3) Mating: copulation, courtship 4) Basking (collector will draw snake's position): alone, near/ with another snake 5) Traveling 6) Pre-shed, shedding 7) Within crevice: Partially or completely? Coiled or stretched? B. Collector will note snake's response to collector's presence 1) Silent: Still/ held ground OR moved away 2) Rattle: Rattle and hold ground OR rattle and move away 3) Enlarges body in self defense 4) Continues **activity** without apparent disruption
General description of weather conditions	Collector will note general weather conditions at time of observation and if applicable, prior to observation (i.e. a rainy am will create high humidity in pm).

Note: Size and color phase of snake will be collected when snakes are collected for transmitter implantation.

Appendix 5. Landuse/ Landcover types, as identified by NJDEP(2002), included as "human activity" areas or "within forest" parcels.

LU/LC02 Code	Label/ Description[a]
Human activity areas	
1110	RESIDENTIAL, HIGH DENSITY OR MULTIPLE DWELLING
1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY
1130	RESIDENTIAL, SINGLE UNIT, LOW DENSITY
1140	RESIDENTIAL, RURAL, SINGLE UNIT
1200	COMMERCIAL/SERVICES
1211	MILITARY INSTALLATIONS
1300	INDUSTRIAL
1400	TRANSPORTATION/COMMUNICATION/UTILITIES
1410	MAJOR ROADWAY
1419	BRIDGE OVER WATER
1440	AIRPORT FACILITIES
1462	UPLAND RIGHTS-OF-WAY DEVELOPED
1499	STORMWATER BASIN
1500	INDUSTRIAL/COMMERCIAL COMPLEXES
1600	MIXED URBAN OR BUILT-UP LAND
1700	OTHER URBAN OR BUILT-UP LAND
1710	CEMETERY
1710	CEMETERY
1711	CEMETERY ON WETLAND
1750	MANAGED WETLAND IN MAINTAINED LAWN GREENSPACE
1800	RECREATIONAL LAND
1804	ATHLETIC FIELDS (SCHOOLS)
1810	STADIUM THEATERS CULTURAL CENTERS AND ZOOS
1850	MANAGED WETLAND IN BUILT-UP MAINTAINED REC AREA
2100	CROPLAND AND PASTURELAND
2140	AGRICULTURAL WETLANDS (MODIFIED)
2150	FORMER AGRICULTURAL WETLAND (BECOMING SHRUBBY, NOT BUILT-UP)
2200	ORCHARDS/VINEYARDS/NURSERIES/HORTICULTURAL AREAS

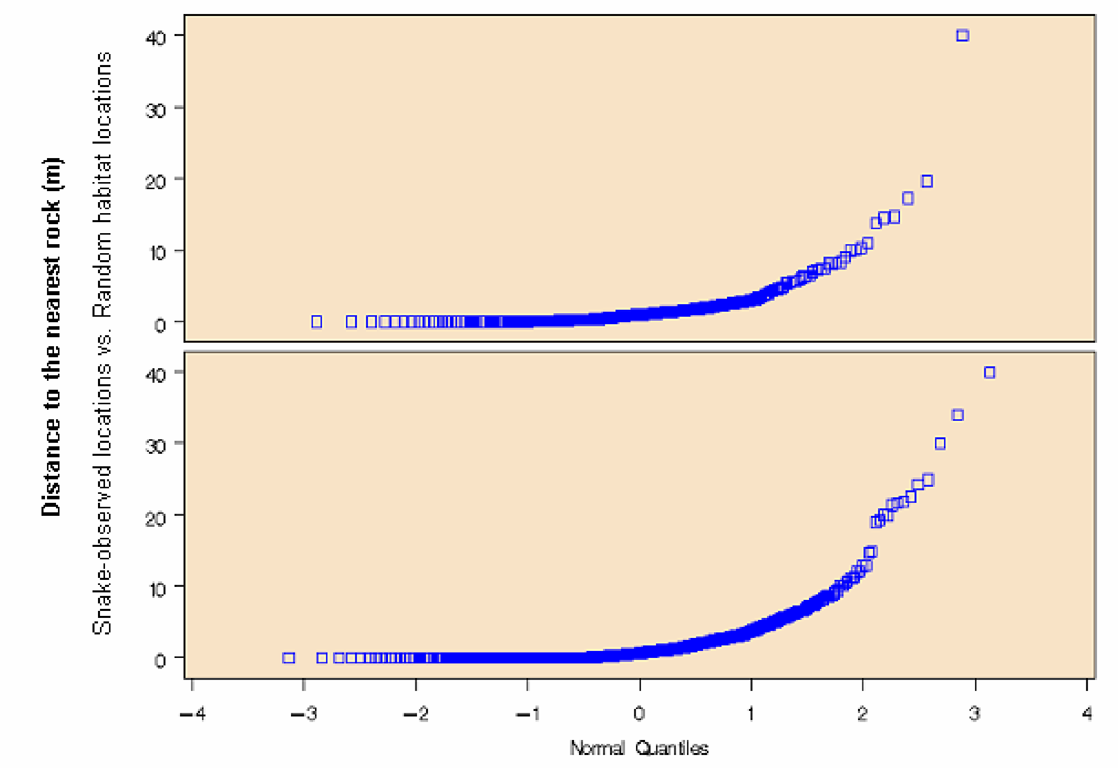
[a]For complete descriptions of habitats, see NJDEP (2002).

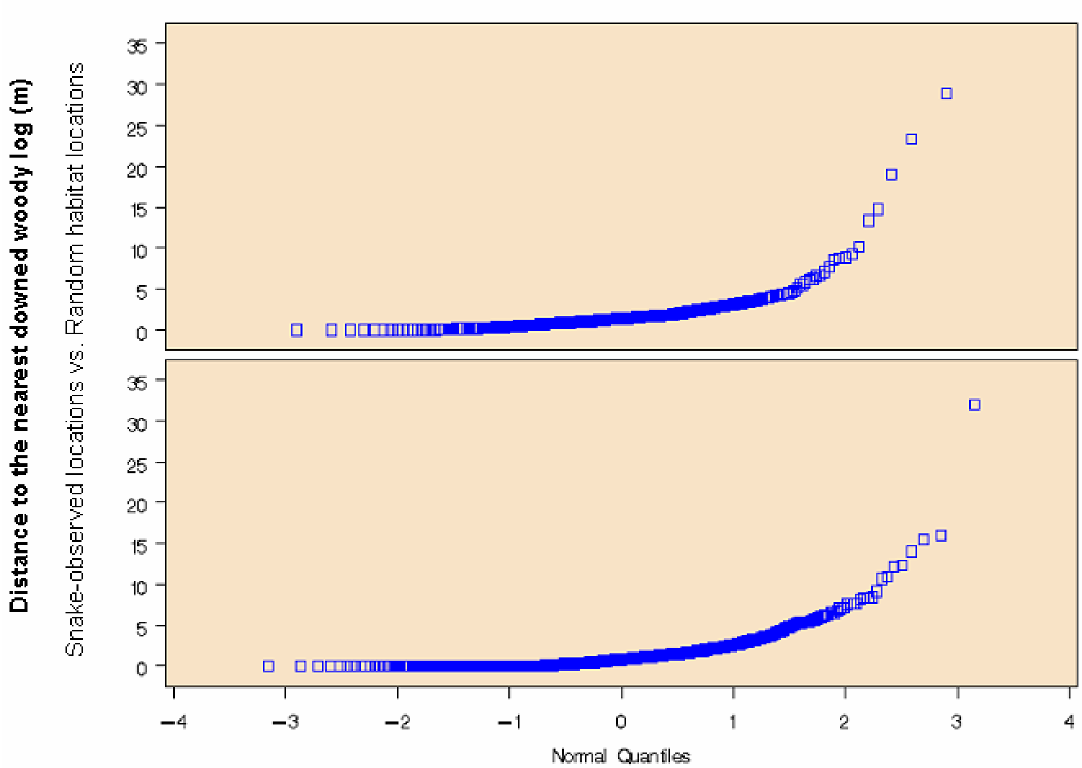
Appendix 5, continued.

LU/LC02 Code	Label/ Description[a]
2300	CONFINED FEEDING OPERATIONS
2400	OTHER AGRICULTURE
5410	TIDAL RIVERS, INLAND BAYS, AND OTHER TIDAL WATERS
5420	DREDGED LAGOON
6111	SALINE MARSH (LOW MARSH)
6112	SALINE MARSH (HIGH MARSH)
6141	PHRAGMITES DOMINATE COASTAL WETLANDS
7100	BEACHES
7300	EXTRACTIVE MINING
7400	ALTERED LANDS
7500	TRANSITIONAL AREAS
Forest habitats	
4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)
4220	CONIFEROUS FOREST (>50% CROWN CLOSURE)
4312	MIXED FOREST (>50% CONIFEROUS WITH >50% CROWN CLOSURE)
4322	MIXED FOREST (>50% DECIDUOUS WITH >50% CROWN CLOSURE)
6210	DECIDUOUS WOODED WETLANDS
6220	CONIFEROUS WOODED WETLANDS
6221	ATLANTIC WHITE CEDAR WETLANDS
6251	MIXED WOODED WETLANDS (DECIDUOUS DOM.)
6252	MIXED WOODED WETLANDS (CONIFEROUS DOM.)

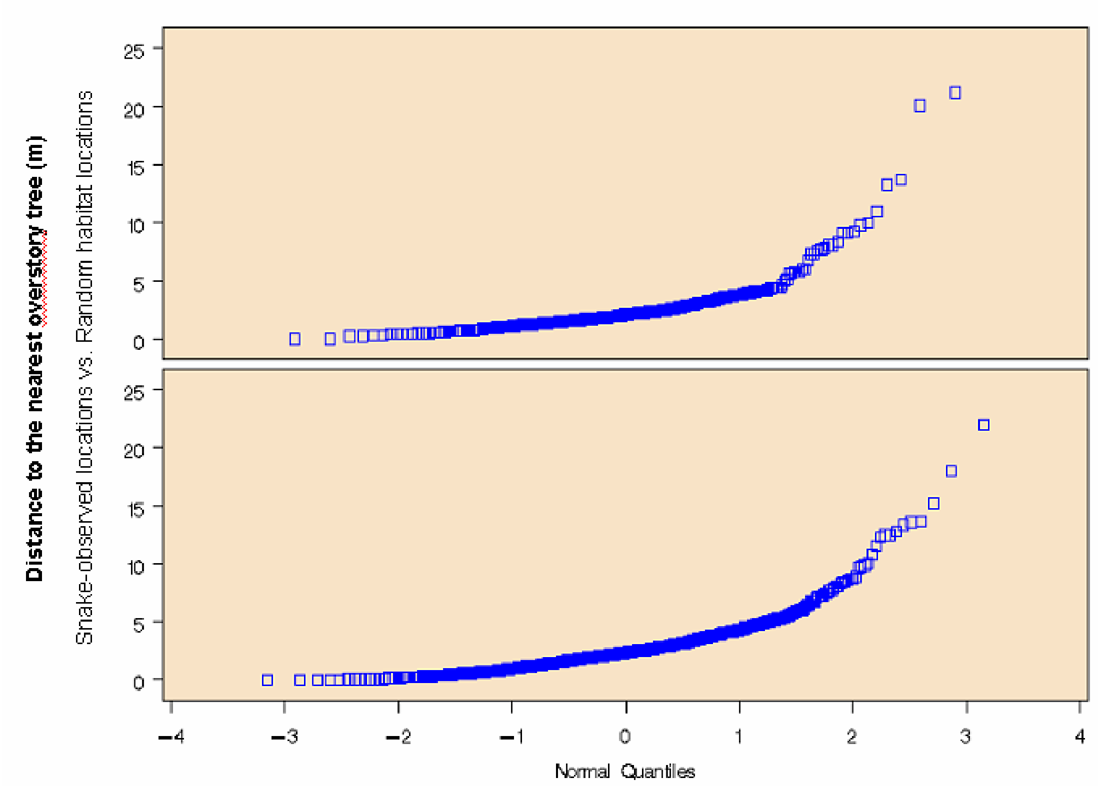
[a]For complete descriptions of habitats, see NJDEP (2002).

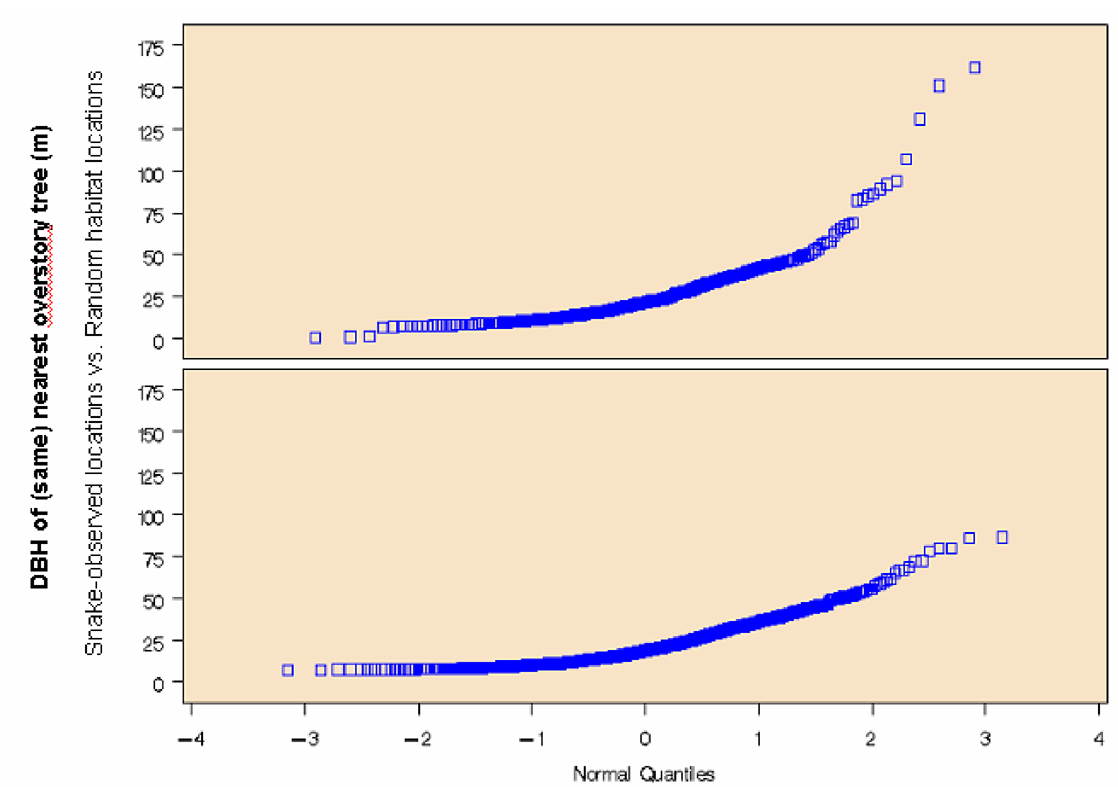
Appendix 6a. Quantile plots (Q-Q plots) of microhabitat data collected at both snake-used and random (available) locations demonstrate the data does not have a normal distribution.



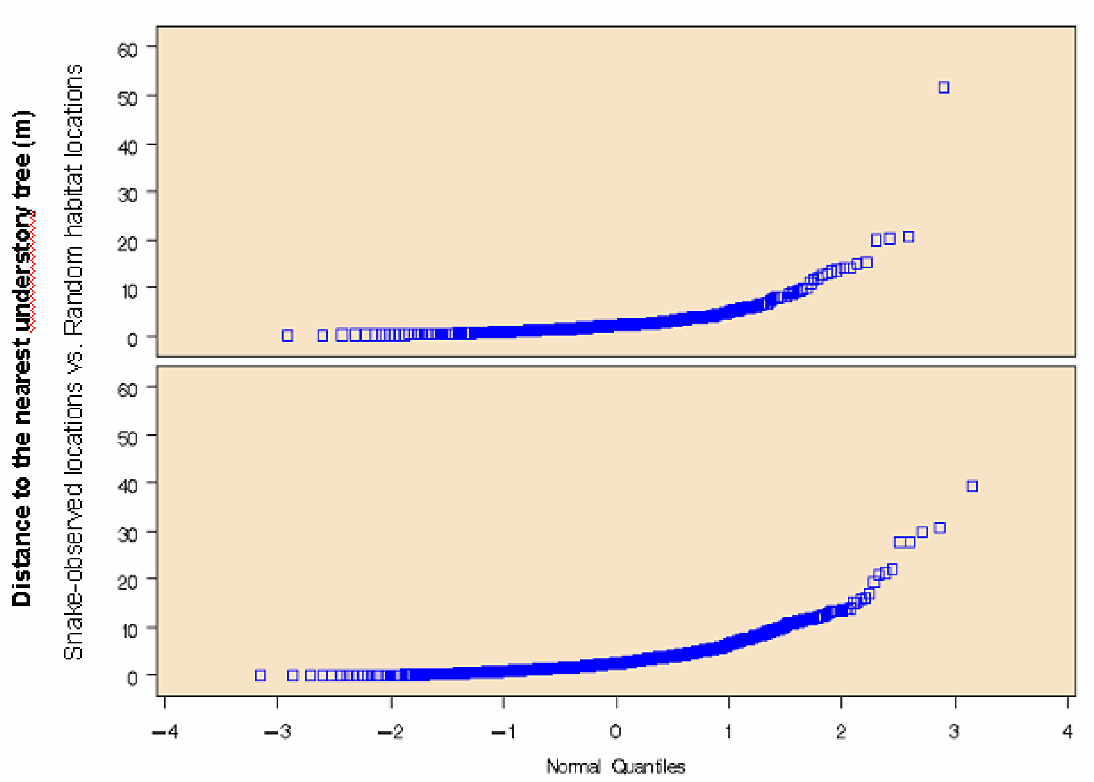


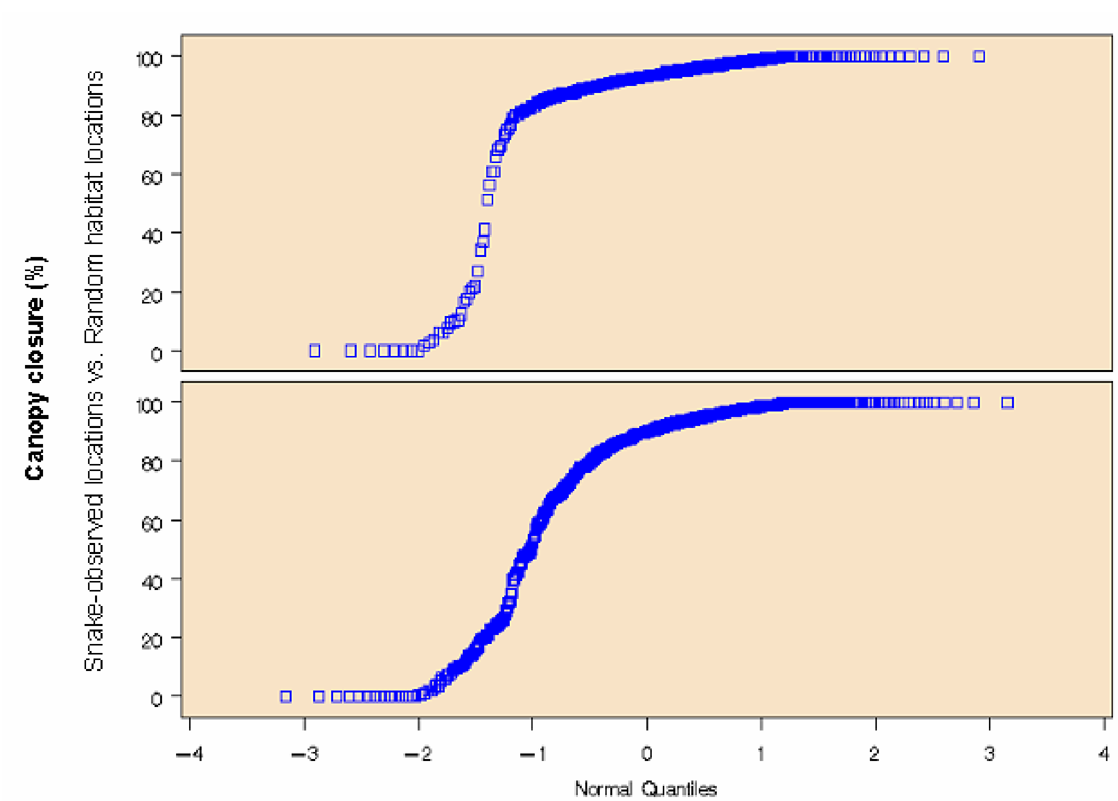
Appendix 6a, continued.



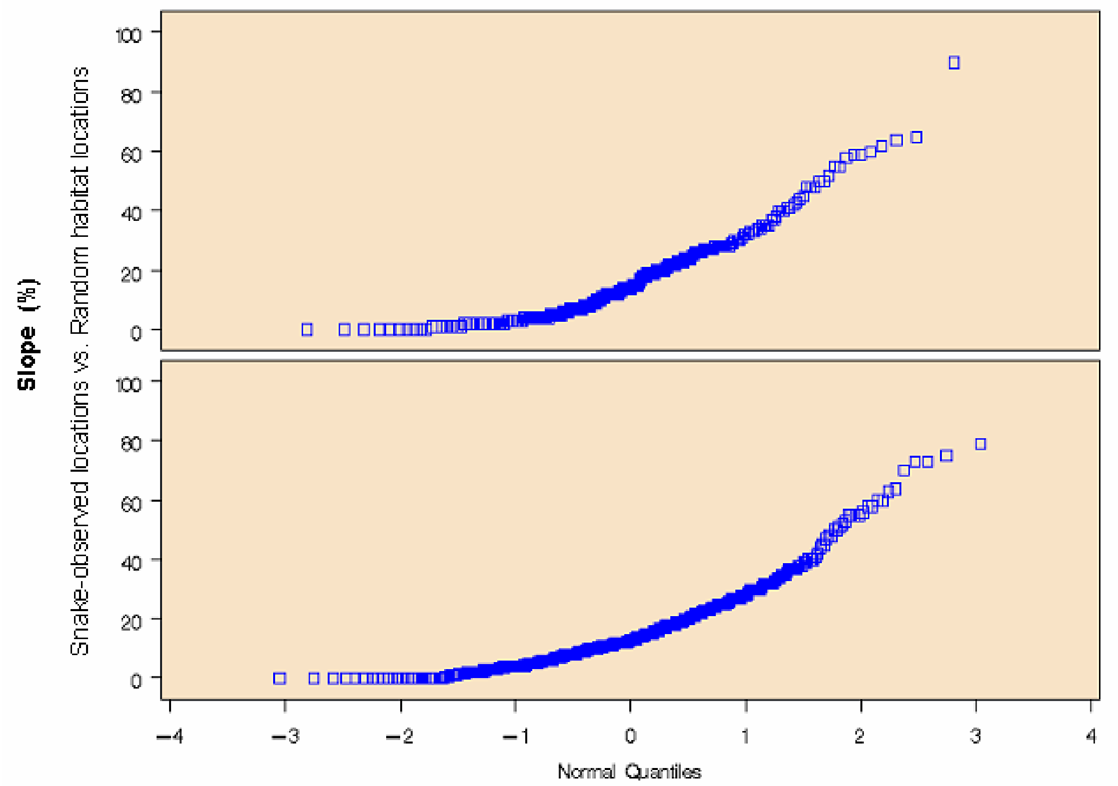


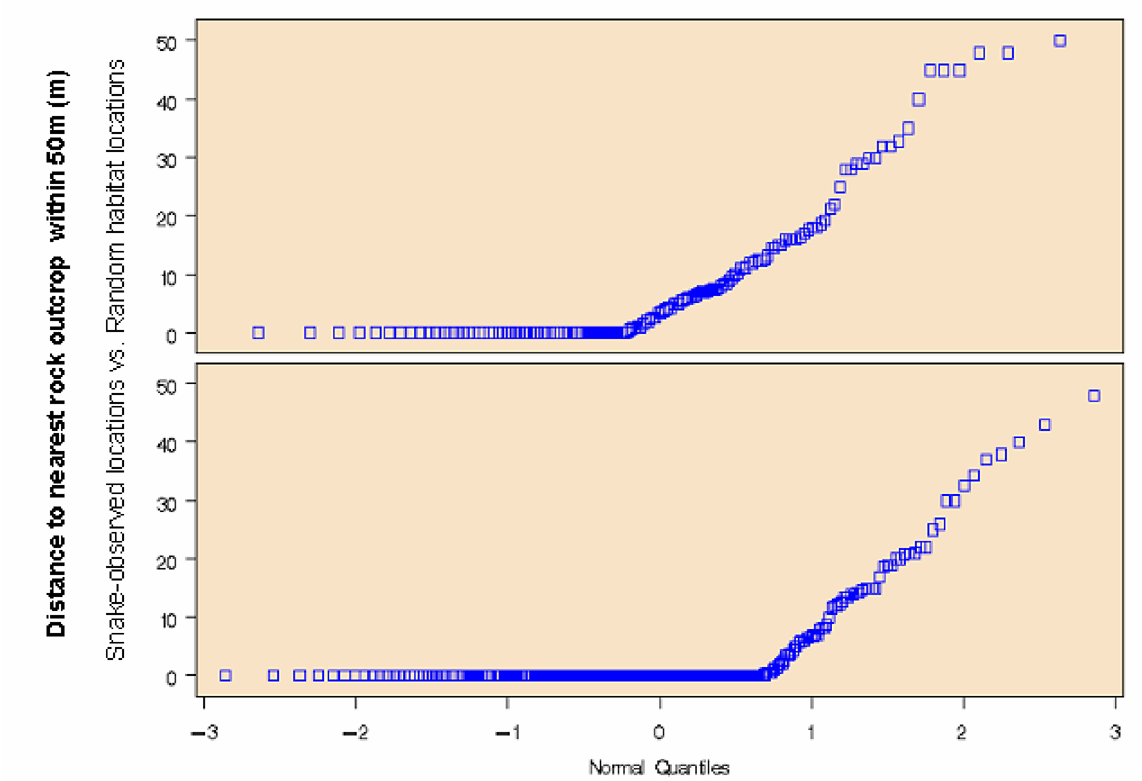
Appendix 6a, continued.



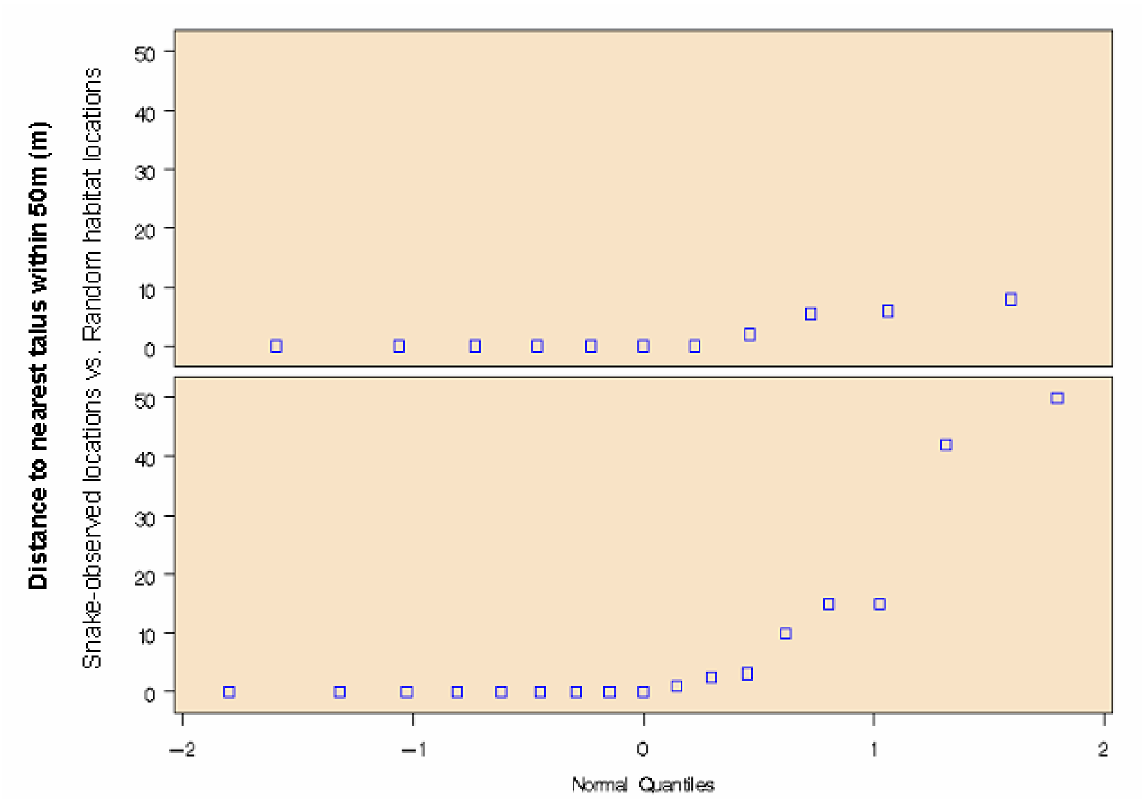


Appendix 6a, continued.

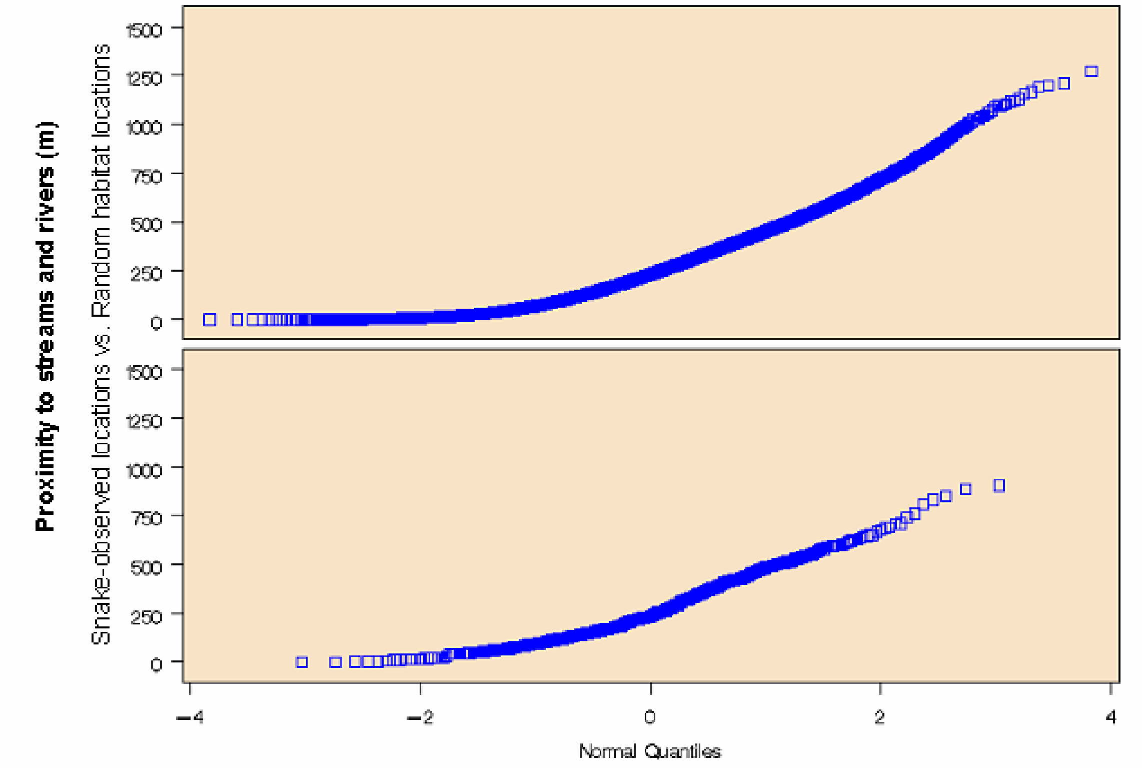


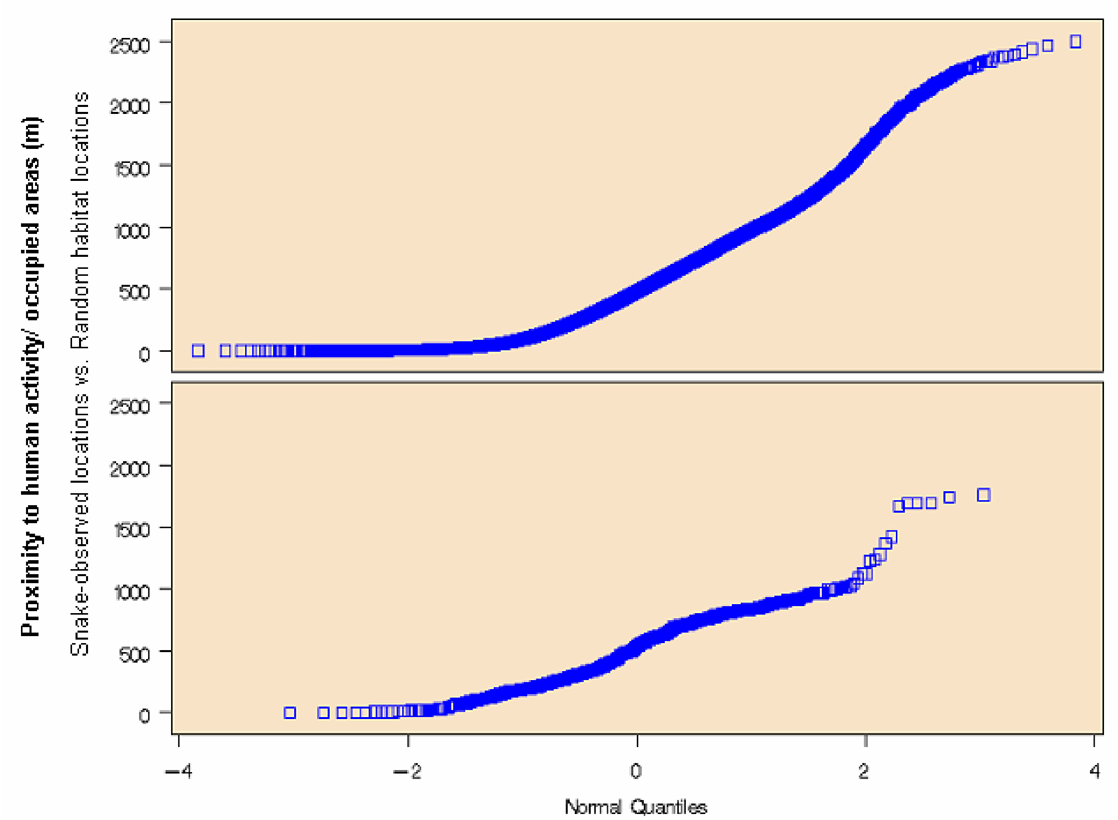


Appendix 6a, continued.

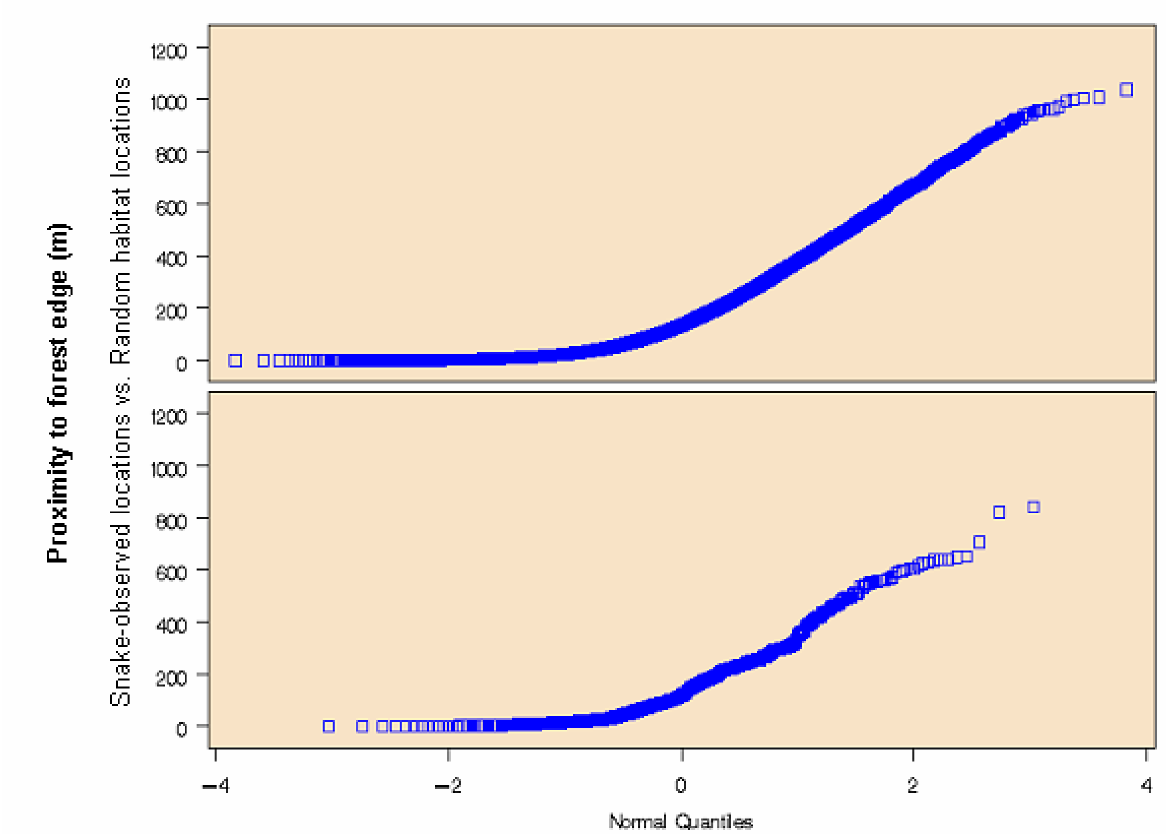


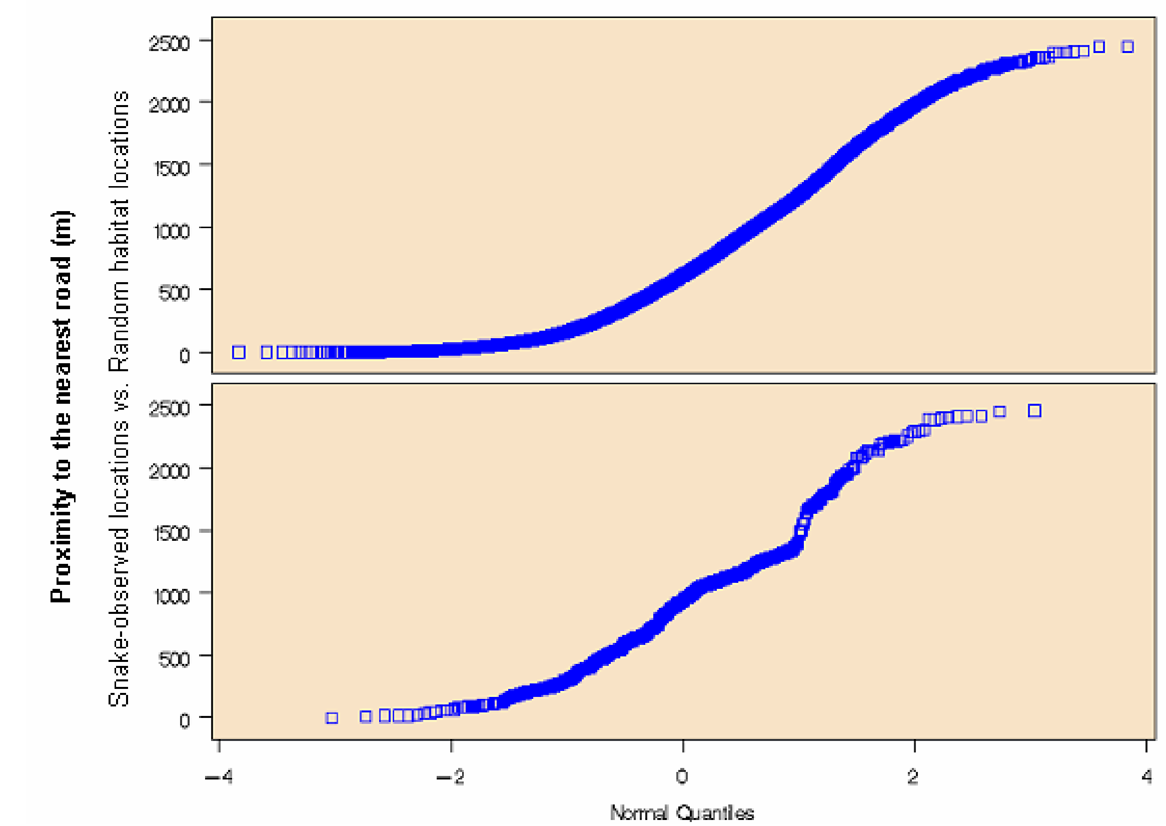
Appendix 6b. Quantile plots (Q-Q plots) of macrohabitat data collected at both snake-used and random (available) locations demonstrate the data does not have a normal distribution.





Appendix 6b, continued.





Appendix 7a. Tracking success, in total, at Site 1 (Kittatinny Ridge) and furthest distance traveled by each snake. Snakes whose data is not being used in this analysis have been omitted.

			Point Data Available		Furthest distance from hibernaculum	
Snake ID	Start Date[a]	End Date[a]	Total days located/ No. of days tracked)[b]	Success rate of locating snake (%)	mi	km
M01[c]	05/26/99	08/27/00	57/57	100.00	no data	no data
M02	05/24/99	09/19/99	48/48	100.00	0.71	1.14
M03	05/24/99	09/21/00	121/124	97.58	1.04	1.67
M04	05/30/99	10/03/00	88/88	100.00	0.65	1.05
M05	05/30/99	10/07/00	115/116	99.14	0.9	1.45
M06	06/02/99	08/05/00	71/72	98.61	1.89	3.04

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Only observations made during the year a female was nongravid are included in this table (M01, 2000 observations only; M09 and M10, 1999 observations only). However, start and end dates indicate the first and last observations made away from their dens throughout their time included in this study.

[d] These snakes did not hibernate in the "study den" but rather led to the discovery of a two new dens. The distance shown is from their dens.

Appendix 7a, continued.

			Point Data Available		Furthest distance from hibernaculum	
Snake ID	Start Date[a]	End Date[a]	Total days located/ No. of days tracked)[b]	Success rate of locating snake (%)	mi	km
M07	07/20/99	09/21/00	98/98	100.00	1.60[d]	2.57
M08	07/22/99	09/27/00	84/85	98.82	1.15	1.85
M09[c]	08/18/99	09/29/00	21/21	100.00	0.48	0.77
M10[c]	08/28/99	09/24/00	15/15	100.00	1.08	1.74
M11	08/05/99	10/11/99	19/19	100.00	no data	no data
M17	07/20/00	10/19/00	37/37	100.00	no data	no data
		TOTALS	**774/780**	**99.23**	-	-

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Only observations made during the year a female was nongravid are included in this table (M01, 2000 observations only; M09 and M10, 1999 observations only). However, start and end dates indicate the first and last observations made away from their dens throughout their time included in this study.

[d]These snakes did not hibernate in the "study den" but rather led to the discovery of a two new dens. The distance shown is from their dens.

Appendix 7b. Tracking success, by season, at Site 1 (Kittatinny Ridge). Snakes whose data is not being used in this analysis have been omitted.

			Seasonal Point Data Available					
Snake ID	**Start Date[a]**	**End Date[a]**	**Pre-breeding/ egress observations[b] (emergence - June 30)**	**Tracking success rate (%) during pre-breeding period**	**Breeding observations[b] (July 1 - August 15)**	**Tracking success rate (%) during breeding period**	**Post-breeding/ ingress observations[b] (August 15 - October 31)**	**Tracking success rate (%) during post-breeding period**
M01[c]	05/26/99	08/27/00	32/32	100.00	21/21	100.00	4/4	100.00
M02	05/24/99	09/19/99	15/15	100.00	17/17	100.00	16/16	100.00
M03	05/24/99	09/21/00	43/46	93.48	46/46	100.00	32/32	100.00
M04	05/30/99	10/03/00	23/23	100.00	37/37	100.00	28/28	100.00
M05	05/30/99	10/07/00	42/42	100.00	33/33	100.00	40/41	97.56
M06	06/02/99	08/05/00	24/25	96.00	34/34[e]	100.00	13/13	100.00

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Only observations made during the year a female was nongravid are included in this table (M01, 2000 observations only; M09 and M10, 1999 observations only). However, start and end dates indicate the first and last observations made away from their dens throughout their time included in this study.

[d](Notation used in Appendix 4a.)

[e]Of the 34 observations made during this seasonal period, 14 exceeded the 1.5mi den buffer.

Appendix 7b, continued.

Snake ID	Start Date[a]	End Date[a]	Pre-breeding/ egress observations (emergence - June 30)	Tracking success rate (%) during pre-breeding period	Breeding observations (July 1 - August 15)	Tracking success rate (%) during breeding period	Post-breeding/ ingress observations (August 15 - October 31)	Tracking success rate (%) during post-breeding period
M07	07/20/99	09/21/00	29/29	100.00	36/36	100.00	33/33	100.00
M08	07/22/99	09/27/00	21/21	100.00	33/33	100.00	30/31	96.77
M09[c]	08/18/99	09/29/00	0/0	n/a	0/0	n/a	21/21	100.00
M10[c]	08/28/99	09/24/00	0/0	n/a	0/0	n/a	15/15	100.00
M11	08/05/99	10/11/99	0/0	n/a	0/0	n/a	19/19	100.00
M17	07/20/00	10/19/00	0/0	n/a	14/14	100.00	23/23	100.00
		TOTALS	**229/233**	**98.28**	**271/271**	**100.00**	**274/276**	**99.28**

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Only observations made during the year a female was nongravid are included in this table (M01, 2000 observations only; M09 and M10, 1999 observations only). However, start and end dates indicate the first and last observations made away from their dens throughout their time included in this study.

[d](Notation used in Appendix 4a.)

[e]Of the 34 observations made during this seasonal period, 14 exceeded the 1.5mi den buffer.

Appendix 8a. Tracking success, in total, at Site 2 (Highlands Region) and furthest distance traveled by each snake. Snakes whose data is not being used in this analysis have been omitted.

			Total point data available		Furthest recorded distance from hibernaculum	
Snake ID	Start Date[a]	End Date[a]	Total days located/ No. of days tracked)[b]	Success rate of locating snake (%)	mi	km
H01	06/10/03	10/04/03	28/29	96.55	1.24	2.00
H02	06/10/03	06/15/04	42/47	89.36	1.71	2.75
H03	06/06/03	10/04/03	32/32	100.00	0.97	1.56
H10	07/13/03	08/13/03	12/12	100.00	0.68	1.09
H16[c]	07/28/03	06/04/04	26/26	100.00	0.91	1.46
H18	10/22/03	08/12/04	41/42	97.62	0.74	1.19
H20	07/09/04	07/24/05	73/75	97.33	0.86	1.38
H21	07/17/04	07/30/05	83/86	96.51	2.13	3.43
H22	07/25/04	08/07/05	58/62	93.55	1.66	2.67
H23	07/17/04	05/31/05	10/13	76.92	0.79	1.27

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Snake H16 was incorporated into study in late July 2003 and tracked until mid-August but then not tracked again until the denning period in late October. H16 was tracked into early July but then removed from study due to anticipated transmitter failure.

Appendix 8a, continued.

			Total point data available		Furthest recorded distance from hibernaculum	
Snake ID	Start Date[a]	End Date[a]	Total days located/ No. of days tracked)[b]	Success rate of locating snake (%)	mi	km
H24	07/21/04	06/04/05	16/16	100.00	0.71	1.14
H26	08/07/04	10/06/05	71/74	95.95	1.85	2.98
H27	08/18/04	08/03/05	67/67	100.00	1.77	2.85
H28	08/26/04	08/01/05	62/62	100.00	2.28	3.67
H29	08/15/04	05/15/05	31/31	100.00	0.75	1.21
		TOTALS	**652/674**	**96.74**		

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Snake H16 was incorporated into study in late July 2003 and tracked until mid-August but then not tracked again until the denning period in late October. H16 was tracked into early July but then removed from study due to anticipated transmitter failure.

Appendix 8b. Tracking success, by season, at Site 2 (Highlands Region). Snakes whose data is not being used in this analysis have been omitted.

			Seasonal point data available					
Snake ID	Start Date[a]	End Date[a]	Pre-breeding observations (May - June 30)	Tracking success rate (%) during pre-breeding period	Breeding observations (July 1 - August 15)	Tracking success rate (%) during breeding period	Post-breeding/ Ingress observations (August 15 - October 31)	Tracking success rate (%) during post-breeding period
H01	06/10/03	10/04/03	5/6	83.33	21/21	100.00	2/2	100.00
H02	06/10/03	06/15/04	25/27[d]	92.59	17/20[d]	85.00	0/0	0.00
H03	06/06/03	10/04/03	6/6	100.00	23/23	100.00	3/3[e]	100.00
H10	07/13/03	08/13/03	0/0	n/a	12/12	100.00	0/0	n/a
H16[c]	07/28/03	06/04/04	17/17	100.00	7/7	100.00	2/2	100.00

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Snake H16 was incorporated into study in late July 2003 and tracked until mid-August but then not tracked again until the denning period in late October. H16 was tracked into early July but then removed from study due to anticipated transmitter failure.

[d]Some observations were outside of the snake's 1.5mi den buffer.

[e]Transmitters had unscheduled failures. H03's transmitter failed during hibernation and H23 and H29's transmitters failed early in the 2005 season and were not recovered.

Appendix 8b, continued.

Snake ID	Start Date[a]	End Date[a]	Pre-breeding observations (May - June 30)	Tracking success rate (%) during pre-breeding period	Breeding observations (July 1 - August 15)	Tracking success rate (%) during breeding period	Post-breeding/ Ingress observations (August 15 - October 31)	Tracking success rate (%) during post-breeding period
H18	10/22/03	08/12/04	28/28	100.00	12/13	92.31	1/1	100.00
H20	07/09/04	07/24/05	26/26	100.00	28/30	93.33	19/19	100.00
H21	07/17/04	07/30/05	28/28	100.00	28/31	90.32	27/27	100.00
H22	07/25/04	08/07/05	29/29	100.00	21/25[d]	84.00	8/8	100.00
H23	07/17/04	05/31/05	7/10[e]	70.00	1/1	100.00	2/2	100.00
H24	07/21/04	06/04/05	15/15	100.00	1/1	100.00	0/0	n/a

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Snake H16 was incorporated into study in late July 2003 and tracked until mid-August but then not tracked again until the denning period in late October. H16 was tracked into early July but then removed from study due to anticipated transmitter failure.

[d]Some observations were outside of the snake's 1.5mi den buffer.

[e]Transmitters had unscheduled failures. H03's transmitter failed during hibernation and H23 and H29's transmitters failed early in the 2005 season and were not recovered.

Appendix 8b, continued.

Snake ID	Start Date[a]	End Date[a]	Pre-breeding observations (May - June 30)	Tracking success rate (%) during pre-breeding period	Breeding observations (July 1 - August 15)	Tracking success rate (%) during breeding period	Post-breeding/ Ingress observations (August 15 - October 31)	Tracking success rate (%) during post-breeding period
H26	08/07/04	10/06/05	25/28	89.29	21/21[d]	100.00	25/25	100.00
H27	08/18/04	08/03/05	25/25	100.00	16/16	100.00	26/26	100.00
H28	08/26/04	08/01/05	27/27	100.00	15/15	100.00	20/20[d]	100.00
H29	08/15/04	05/15/05	6/6[e]	100.00	1/1	100.00	24/24	100.00
		TOTALS	**269/278**	**96.76**	**224/237**	**94.51**	**159/159**	**100.00**

[a]Start and end dates refer to the first observation made away from the den after surgical implantation of transmitter and the last documented observation away from the den.

[b]All den observations have been excluded from this table.

[c]Snake H16 was incorporated into study in late July 2003 and tracked until mid-August but then not tracked again until the denning period in late October. H16 was tracked into early July but then removed from study due to anticipated transmitter failure.

[d]Some observations were outside of the snake's 1.5mi den buffer.

[e]Transmitters had unscheduled failures. H03's transmitter failed during hibernation and H23 and H29's transmitters failed early in the 2005 season and were not recovered.

Appendix 9a. Sample sizes per study site and microhabitat variable collected at random habitats and snakes' stationary observations (males and females), excluding observations at repeated locations and dens.

		Distance to rock	Distance to log	Distance to overstory tree	DBH of overstory tree	Distance to understory tree/shrub	Canopy	Slope	Distance to rock outcrop (w/i 50m)	Distance to talus (w/i 50m)
Site 1 (Kittatinny)	**Snakes; n =**	429	433	430	430	432	431	224	n/a	n/a
Site 1 (Kittatinny)	**Random; n =**	94	94	94	94	94	93	1	n/a	n/a
Site 2 (Highlands)	**Snakes; n =**	370	368	370	362	369	369	321	321	322
Site 2 (Highlands)	**Random; n =**	251	251	251	251	251	246	249	249	250
TOTALS	**Snakes; n =**	**799**	**801**	**800**	**792**	**801**	**800**	**545**	**321**	**322**
	Random; n =	**345**	**345**	**345**	**345**	**345**	**339**	**250**	**249**	**250**

Appendix 9b. Sample sizes per study site and macrohabitat variable collected at random habitats and snakes' stationary observations (males and females), excluding observations at repeated locations and dens.

		Proximity to streams/rivers	Proximity to human activity	Proximity to forest edge	Proximity to roads
Site 1 (Kittatinny)	**Snakes; n =**	191	191	191	191
Site 1 (Kittatinny)	**Random; n =**	1,793	1,793	1,793	1,793
Site 2 (Highlands)	**Snakes; n =**	358	358	358	358
Site 2 (Highlands)	**Random; n =**	10,799	10,799	10,799	10,799
TOTALS	**Snakes; n =**	**549**	**549**	**549**	**549**
	Random; n =	**12,592**	**12,592**	**12,592**	**12,592**

Appendix 10. Proportional comparison of expected and actual use of the available habitat as identified by NJDEP, LU/LC02 (2002) by transmitter-implanted timber rattlesnakes. LU/LC02 types are in order of snake use.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4120	DECIDUOUS FOREST (>50% CROWN CLOSURE)	2435.03	H01, H02	0.740	33.31	40
		2212.52	H23	0.492	4.92	6
		2295.65	H24	0.510	7.65	14
		3736.05	H16	0.830	13.28	18
		3734.25	H03	0.830	24.06	21
		3667.49	H21, H27	0.815	109.19	120
		3904.73	H22, H28	0.868	84.15	79
		3491.25	H26	0.776	45.76	47
		1220.36	H20 (♂) H29 (♀)	0.271	25.22	40
		1629.86	H18	0.362	14.85	23
		1430.87	H10	0.318	3.81	10
		2696.86	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.599	118.64	133
TOTALS		**32454.92**		**7.41**	**484.84**	**551**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4110	DECIDUOUS FOREST (10-50% CROWN CLOSURE)	26.37	H01, H02	0.008	0.36	0
		103.64	H23	0.023	0.23	0
		133.11	H24	0.030	0.44	0
		161.08	H16	0.036	0.57	0
		161.01	H03	0.036	1.04	0
		159.15	H21, H27	0.035	4.74	8
		99.76	H22, H28	0.022	2.15	2
		152.29	H26	0.034	2.00	0
		287.24	H20 (♂) H29 (♀)	0.064	5.93	41
		53.22	H18	0.012	0.48	0
		293.36	H10	0.065	0.78	1
		210.51	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.047	9.26	39
TOTALS		**1840.73**		**0.41**	**27.99**	**91**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
6210	DECIDUOUS WOODED WETLANDS	132.83	H01, H02	0.040	1.82	5
		281.36	H23	0.063	0.63	1
		261.15	H24	0.058	0.87	0
		273.09	H16	0.061	0.97	0
		272.35	H03	0.061	1.75	0
		260.65	H21, H27	0.058	7.76	5
		274.54	H22, H28	0.061	5.92	6
		174.23	H26	0.039	2.28	0
		231.54	H20 (♂) H29 (♀)	0.051	4.78	0
		140.62	H18	0.031	1.28	16
		217.35	H10	0.048	0.58	0
		162.52	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.036	7.15	2
TOTALS		**2682.23**		**0.61**	**35.79**	**35**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4312	MIXED FOREST (>50% CONIFEROUS WITH >50% CROWN CLOSURE)	116.99	H01, H02	0.036	1.60	0
		200.01	H23	0.044	0.44	1
		212.63	H24	0.047	0.71	0
		5.47	H16	0.001	0.02	0
		5.47	H03	0.001	0.04	0
		5.47	H21, H27	0.001	0.16	0
		11.11	H22, H28	0.002	0.24	0
		7.51	H26	0.002	0.10	0
		404.52	H20 (♂) H29 (♀)	0.090	8.36	6
		119.60	H18	0.027	1.09	1
		370.60	H10	0.082	0.99	0
		190.18	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.042	8.37	9
TOTALS		**1649.55**		**0.38**	**22.11**	**17**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4440	MIXED DECIDUOUS/ CONIFEROUS BRUSH/ SHRUBLAND	1.34	H01, H02	0.000	0.02	0
		17.68	H20 (♂) H29 (♀)	0.004	0.37	0
		60.52	H18	0.013	0.55	0
		13.23	H10	0.003	0.04	0
		37.05	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.008	1.63	10
TOTALS		**129.81**		**0.03**	**2.60**	**10**
4420	DECIDUOUS BRUSH/ SHRUBLAND	4.33	H01, H02	0.001	0.06	0
		1.05	H23	0.000	0.00	0
		1.05	H24	0.000	0.00	0
		2.01	H16	0.000	0.01	0
		0.86	H03	0.000	0.01	0
		5.77	H22, H28	0.001	0.12	10
		0.11	H26	0.000	0.00	0
		16.12	H20 (♂) H29 (♀)	0.004	0.33	0
		28.22	H18	0.006	0.26	0
		9.81	H10	0.002	0.03	0
		18.36	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.004	0.81	0
TOTALS		**87.70**		**0.02**	**1.63**	**10**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4322	MIXED FOREST (>50% DECIDUOUS WITH >50% CROWN CLOSURE)	186.66	H01, H02	0.057	2.55	1
		208.94	H23	0.046	0.46	2
		229.74	H24	0.051	0.77	0
		7.89	H16	0.002	0.03	0
		7.89	H03	0.002	0.05	0
		12.78	H21, H27	0.003	0.38	0
		2.51	H22, H28	0.001	0.05	0
		4.89	H26	0.001	0.06	0
		402.10	H20 (♂) H29 (♀)	0.089	8.31	3
		293.51	H18	0.065	2.67	1
		358.50	H10	0.080	0.96	1
		149.35	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.033	6.57	1
TOTALS		**1864.77**		**0.43**	**22.87**	**9**
1120	RESIDENTIAL, SINGLE UNIT, MEDIUM DENSITY	1.34	H16	0.000	0.00	0
		2.23	H03	0.000	0.01	0
		11.61	H21, H27	0.003	0.35	1
		13.01	H22, H28	0.003	0.28	0
		223.84	H26	0.050	2.93	7
		411.81	H20 (♂) H29 (♀)	0.091	8.51	0
		227.35	H18	0.051	2.07	0
		384.63	H10	0.085	1.03	0
TOTALS		**1870.17**		**0.42**	**16.84**	**8**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
6240	HERBACEOUS WETLANDS	18.13	H01, H02	0.006	0.25	0
		5.40	H23	0.001	0.01	0
		4.75	H24	0.001	0.02	0
		6.87	H16	0.002	0.02	0
		6.81	H03	0.002	0.04	8
		4.03	H21, H27	0.001	0.12	0
		3.51	H22, H28	0.001	0.08	0
		1.35	H26	0.000	0.02	0
		6.99	H20 (♂) H29 (♀)	0.002	0.14	0
		66.15	H18	0.015	0.60	0
		6.27	H10	0.001	0.02	0
		38.11	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.008	1.68	0
TOTALS		**168.36**		**0.04**	**3.00**	**8**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
1463	UPLAND RIGHTS-OF-WAY UNDEVELOPED	19.21	H23	0.004	0.04	0
		27.64	H24	0.006	0.09	0
		31.89	H16	0.007	0.11	1
		31.98	H03	0.007	0.21	0
		32.60	H21, H27	0.007	0.97	0
		25.40	H22, H28	0.006	0.55	0
		35.34	H26	0.008	0.46	5
		18.88	H20 (♂) H29 (♀)	0.004	0.39	0
		26.87	H18	0.006	0.24	0
		21.18	H10	0.005	0.06	0
		37.28	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.008	1.64	0
TOTALS		**308.26**		**0.07**	**4.77**	**6**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4220	CONIFEROUS FOREST (>50% CROWN CLOSURE)	224.05	H01, H02	0.068	3.07	0
		70.29	H23	0.016	0.16	0
		71.22	H24	0.016	0.24	0
		2.39	H21, H27	0.001	0.07	0
		11.67	H22, H28	0.003	0.25	0
		3.13	H26	0.001	0.04	0
		311.83	H20 (♂) H29 (♀)	0.069	6.44	1
		186.69	H18	0.041	1.70	0
		302.38	H10	0.067	0.81	0
		86.96	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.019	3.83	2
TOTALS		**1270.60**		**0.30**	**16.60**	**3**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
1130	RESIDENTIAL, SINGLE UNIT, LOW DENSITY	251.84	H23	0.056	0.56	0
		202.49	H24	0.045	0.67	1
		0.48	H16	0.000	0.00	0
		1.73	H03	0.000	0.01	0
		16.05	H21, H27	0.004	0.48	0
		2.22	H22, H28	0.000	0.05	0
		201.29	H26	0.045	2.64	0
		128.15	H20 (♂) H29 (♀)	0.028	2.65	1
		73.07	H18	0.016	0.67	0
		126.71	H10	0.028	0.34	0
		35.06	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.008	1.54	0
TOTALS		**1039.08**		**0.23**	**9.60**	**2**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
5200	NATURAL LAKES	73.24	H16	0.016	0.26	2
		73.33	H03	0.016	0.47	0
		67.63	H21, H27	0.015	2.01	0
		52.01	H22, H28	0.012	1.12	0
		71.95	H26	0.016	1.55	0
		170.88	H20 (♂) H29 (♀)	0.038	3.53	0
		2.93	H18	0.001	0.03	0
		70.01	H10	0.016	0.19	0
		0.55	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.000	0.02	0
TOTALS		**582.50**		**0.13**	**9.19**	**2**
4210	CONIFEROUS FOREST (10-50% CROWN CLOSURE)	12.88	H20 (♂) H29 (♀)	0.003	0.27	1
		17.19	H18	0.004	0.16	0
		11.48	H10	0.003	0.03	0
		12.25	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.003	0.54	0
TOTALS		**53.79**		**0.01**	**0.99**	**1**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
6231	DECIDUOUS SCRUB/SHRUB WETLANDS	2.07	H01, H02	0.001	0.03	0
		110.95	H23	0.025	0.25	0
		119.37	H24	0.027	0.40	0
		6.90	H16	0.002	0.02	0
		5.84	H03	0.001	0.04	0
		3.26	H21, H27	0.001	0.10	0
		22.63	H22, H28	0.005	0.49	0
		3.11	H26	0.001	0.04	0
		45.58	H20 (♂) H29 (♀)	0.010	0.94	0
		41.18	H18	0.009	0.38	0
		48.26	H10	0.011	0.13	0
		22.34	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.005	0.98	1
TOTALS		**431.48**		**0.10**	**3.79**	**1**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4321	MIXED FOREST (>50% DECIDUOUS WITH 10-50% CROWN CLOSURE)	19.89	H01, H02	0.006	0.27	0
		26.44	H23	0.006	0.06	0
		31.50	H24	0.007	0.10	0
		92.81	H20 (♂) H29 (♀)	0.021	1.92	0
		8.28	H18	0.002	0.08	0
		65.49	H10	0.015	0.17	0
		45.16	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.010	1.99	1
TOTALS		**289.58**		**0.07**	**4.59**	**1**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
1700	OTHER URBAN OR BUILT-UP LAND	13.04	H01, H02	0.004	0.18	1
		8.36	H23	0.002	0.02	0
		4.23	H24	0.001	0.01	0
		8.49	H16	0.002	0.03	0
		8.49	H03	0.002	0.05	0
		8.74	H21, H27	0.002	0.26	0
		1.09	H22, H28	0.000	0.02	0
		3.05	H26	0.001	0.04	0
		18.70	H20 (♂) H29 (♀)	0.004	0.39	0
		19.37	H18	0.004	0.18	0
		17.86	H10	0.004	0.05	0
		11.40	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.008	1.63	0
TOTALS		**122.81**		**0.03**	**2.86**	**1**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
5300	ARTIFICIAL LAKES[c]	53.65	H01, H02	0.016	0.73	0
		255.27	H23	0.057	0.57	0
		246.76	H24	0.055	0.82	0
		19.59	H16	0.004	0.07	0
		19.59	H03	0.004	0.13	0
		16.04	H21, H27	0.004	0.48	0
		23.92	H22, H28	0.005	0.52	0
		5.10	H26	0.001	0.07	0
		165.15	H20 (♂) H29 (♀)	0.037	3.41	0
		66.71	H18	0.015	0.61	0
		217.04	H10	0.048	0.58	0
		43.72	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.010	1.92	0
TOTALS		**1132.52**		**0.26**	**9.90**	**0**
1804	ATHLETIC FIELDS (SCHOOLS)	13.05	H23	0.003	0.03	0
		3.11	H24	0.001	0.01	0
		5.80	H22, H28	0.001	0.12	0
TOTALS		**21.96**	**0.00**	**0.00**	**0.16**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

[c]At the time of observation, a drought had caused ~30-40m edge of marsh-like habitat around the lake.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
2100	CROPLAND AND PASTURELAND	12.39	H23	0.003	0.03	0
		3.84	H24	0.001	0.01	0
		29.80	H16	0.007	0.11	0
		30.02	H03	0.007	0.19	0
		35.17	H21, H27	0.008	1.05	0
		3.51	H22, H28	0.001	0.08	0
		15.69	H26	0.003	0.21	0
		40.38	H20 (♂) H29 (♀)	0.009	0.83	0
		574.85	H18	0.128	5.24	0
		36.99	H10	0.008	0.10	0
		294.66	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.065	12.96	0
TOTALS		**1077.29**		**0.24**	**20.80**	**0**
2150	FORMER AGRICULTURAL WETLAND (BECOMING SHRUBBY, NOT BUILT-UP)	55.98	H18	0.012	0.51	0
TOTALS		**55.98**		**0.01**	**0.51**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4311	MIXED FOREST (>50% CONIFEROUS WITH 10-50% CROWN CLOSURE)	1.75	H01, H02	0.001	0.02	0
		18.37	H23	0.004	0.04	0
		19.31	H24	0.004	0.06	0
		3.24	H16	0.001	0.01	0
		4.33	H03	0.001	0.03	0
		13.98	H21, H27	0.003	0.42	0
		1.17	H22, H28	0.000	0.03	0
		30.63	H20 (♂) H29 (♀)	0.007	0.63	0
		9.36	H18	0.002	0.09	0
		25.83	H10	0.006	0.07	0
		35.90	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.008	1.58	0
TOTALS		**163.86**		**0.04**	**2.98**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4430	CONIFEROUS BRUSH/ SHRUBLAND	2.00	H01, H02	0.001	0.03	0
		1.19	H22, H28	0.000	0.03	0
		10.70	H20 (♂) H29 (♀)	0.002	0.22	0
		88.51	H18	0.020	0.81	0
		10.70	H10	0.002	0.03	0
		41.18	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.009	1.81	0
TOTALS		**154.28**		**0.03**	**2.92**	**0**
1800	RECREATIONAL LAND	0.80	H01, H02	0.000	0.01	0
		61.99	H23	0.014	0.14	0
		49.16	H24	0.011	0.16	0
		17.43	H16	0.004	0.06	0
		17.43	H03	0.004	0.11	0
		18.90	H21, H27	0.004	0.56	0
		17.43	H22, H28	0.004	0.38	0
		37.50	H26	0.008	0.49	0
		41.48	H20 (♂) H29 (♀)	0.009	0.86	0
		37.39	H10	0.008	0.10	0
		9.50	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.002	0.42	0
TOTALS		**309.00**		**0.07**	**3.29**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
7500	TRANSITIONAL AREAS	136.60	H23	0.030	0.30	0
		125.30	H24	0.028	0.42	0
		5.23	H20 (♂) H29 (♀)	0.001	0.11	0
		1.93	H18	0.000	0.02	0
		5.23	H10	0.001	0.01	0
		6.67	M02, M03, M04, M05, M06 (♂) M09 (♀)	0.001	0.29	0
TOTALS		**280.94**		**0.06**	**1.15**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
Below are additional LU/LC02 types located within the den buffers. No observations were made within these habitats; totals are provided as a reference of available habitats throughout the combined den buffers.						
1140	RESIDENTIAL, RURAL, SINGLE UNIT	**715.45**		**0.014**	**10.23**	**0**
2140	AGRICULTURAL WETLANDS (MODIFIED)	**494.73**		**0.009**	**7.07**	**0**
1200	COMMERCIAL/ SERVICES	**275.98**		**0.005**	**3.95**	**0**
5100	STREAMS AND CANALS	**243.35**		**0.005**	**3.48**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
4410	OLD FIELD (< 25% BRUSH COVERED)	**240.50**		**0.005**	**3.44**	**0**
6251	MIXED WOODED WETLANDS (DECIDUOUS DOM.)	**150.34**		**0.003**	**2.15**	**0**
6220	CONIFEROUS WOODED WETLANDS	**120.85**		**0.002**	**1.73**	**0**
6252	MIXED WOODED WETLANDS (CONIFEROUS DOM.)	**108.98**		**0.002**	**1.56**	**0**
7200	BARE EXPOSED ROCK, ROCK SLIDES, ETC.	**62.69**		**0.001**	**0.90**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
6233	MIXED SCRUB/SHRUB WETLANDS (DECIDUOUS DOM.)	**56.12**		**0.001**	**0.80**	**0**
2400	OTHER AGRICULTURE	**51.04**		**0.001**	**0.73**	**0**
4230	PLANTATION	**50.30**		**0.001**	**0.72**	**0**
1300	INDUSTRIAL	**30.98**		**0.001**	**0.44**	**0**
2200	ORCHARDS/ VINEYARDS/ NURSERIES/ HORTICULTURAL AREAS	**27.76**		**0.001**	**0.40**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
1461	WETLAND RIGHTS-OF-WAY	**23.69**		**0.000**	**0.34**	**0**
1850	MANAGED WETLAND IN BUILT-UP MAINTAINED REC AREA	**17.93**		**0.000**	**0.26**	**0**
7430	DISTURBED WETLANDS (MODIFIED)	**16.18**		**0.000**	**0.23**	**0**
7300	EXTRACTIVE MINING	**14.87**		**0.000**	**0.21**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
1400	TRANSPORTATION/ COMMUNICATION/ UTILITIES	**14.14**		**0.000**	**0.20**	**0**
6232	CONIFEROUS SCRUB/SHRUB WETLANDS	**6.28**		**0.000**	**0.09**	**0**
1499	STORMWATER BASIN	**6.00**		**0.000**	**0.09**	**0**
6241	PHRAGMITES DOMINATE INTERIOR WETLANDS	**5.64**		**0.000**	**0.08**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 10, continued.

LU/LC02 ID and Label[a]		Acres of LULC within den buffer[b]	Snake(s) associated with the den	Relative acreage per den buffer	Expected # of obs.	All stationary obs.
1750	MANAGED WETLAND IN MAINTAINED LAWN GREENSPACE	**5.08**		**0.000**	**0.07**	**0**
7600	UNDIFFERENTIATED BARREN LANDS	**4.02**		**0.000**	**0.06**	**0**
1110	RESIDENTIAL, HIGH DENSITY OR MULTIPLE DWELLING	**3.69**		**0.000**	**0.05**	**0**
6234	MIXED SCRUB/SHRUB WETLANDS (CONIFEROUS DOM.)	**2.11**		**0.000**	**0.03**	**0**
1419	BRIDGE OVER WATER	**1.06**		**0.000**	**0.02**	**0**

[a]LULC02 code and Label are identified and described in further detail by NJDEP, 2002.

[b]Acreages were summed per LU/LC02 within each den buffer regardless of overlap. NOTE: Two dens are based on four den buffers.

Appendix 11. Land use cover types containing snake observations not captured by *The Landscape Project, Version 3.0 Highlands.*

Habitat type (per LU/LC02[a])	# of Observations
Herbaceous wetlands	4
Natural lake[b]	1
Cropland/pastureland	1
Residential, single unit	22
Other urban or built up	2
Athletic fields/schools	1
Transportation/communication	5

[a]LU/LC02 (Land Use Land Cover 2002) per NJ Department of Environmental Protection (2002; modified descriptions of Anderson 1976).

[b]Observation was made during a dry year; snake was foraging at the lake edge in marsh-like habitat.

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