Status Assessment of the Northern Pine Snake (*Pituophis m. melanoleucus*) in New Jersey: An Evaluation of Trends and Threats

The New Jersey Department of Environmental Protection
Division of Fish and Wildlife
Endangered and Nongame Species Program
December 17, 2009

Prepared by: David M. Golden, Peter Winkler, Patrick Woerner, Gretchen Fowles, William Pitts, and Dave Jenkins

Suggested Reference: Golden, D.M., P. Winkler, P. Woerner, G. Fowles, W. Pitts, and D. Jenkins. 2009. Status Assessment of the Northern Pine Snake (*Pituophis m. melanoleucus*) in New Jersey: An Evaluation of Trends and Threats. New Jersey Department of Environmental Protection, Trenton, NJ. 53pp.

Taxonomy and Life History

The northern pine snake (*Pituophis m. melanoleucus*) is a large-bodied snake in the subfamily Colubrinae. The genus *Pituophis* is represented by three species; pine snakes (*P. melanoleucus*), bull and gopher snakes (*P. catenifer*), and the Louisiana pine snake (*P. ruthveni*). Pine snakes (*P. melanoleucus*) are further divided into three subspecies: the Florida pine snake (*P. m. mugitus*; Barbour, 1921), the black pine snake (*P. m. lodingi*; Blanchard, 1924), and the northern pine snake (*P. m. melanoleucus*; Daudin, 1803). All three subspecies of pine snakes have distributions limited to the eastern United States and are considered to be rare throughout their range (Tennant and Bartlett, 2000). The northern pine snake is the only representative of this genus found within New Jersey and, therefore, for the purposes of this document any references made to "pine snakes" in New Jersey will be referring to the subspecies *P. m. melanoleucus* the northern pine snake.

Like all members of the genus *Pituophis*, northern pine snakes are large, nonvenomous snakes that are adept at burrowing. Adult northern pine snakes can grow to 2m and have a distinct white or light gray base color with varying amounts of black or brown blotching (Conant and Collins, 1998; Schwartz and Golden, 2002). In New Jersey, pine snakes are typically active (above ground) from mid-April to mid-October and spend the remaining part of the year in underground hibernacula ("dens") with other pine snakes and in some cases with other snake species (Burger et al., 1988; D.

Golden personal observation, 2007). Females are oviparous (egg-layers) and typically produce clutches of 4-16 eggs that are laid in underground burrows (Tennant and Barlett, 2000). The eggs are large (4.5 – 6.7 cm) and give rise to large hatchling snakes (Wright and Wright, 1957), which have been documented to live for up to 23 years in the wild (Burger personal communication, 2009).

The ability of pine snakes to burrow aids in their pursuit of subterranean prey (such as moles, voles, and shrews) and also plays an essential role in nest excavation. Northern pine snakes have fairly narrow habitat requirements, and, as their name suggests, prefer well-drained, sandy, upland pine and pine-oak forests throughout their range (Burger and Zappalorti, 1988; Woodward and Barthalmus, 1996; Smith and Bien, 2005; Zappalorti et al., 2008; Zappalorti et al., 2009). These sandy habitats make the burrowing behavior of this oviparous species possible, and pine snake nests are found almost exclusively in open areas with loose sandy soils and little vegetation (Burger and Zappalorti 1986). In New Jersey, the ability for a snake to excavate its own deep burrows is unique to the pine snake, and a great deal of research on this species' burrowing behavior has taken place in the state (Tennant and Bartlett 2000). Joanna Burger and Robert Zappalorti have pioneered much of this research and have published extensively on the subject of pine snake nesting (Burger and Zappalorti 1986, Burger and Zappalorti 1991, Burger and Zappalorti 1992). Their combined work has led to a solid understanding of the habits, habitat preferences, and phenology of nesting northern pine snakes in New Jersey. It is now well understood that pine snakes mate in mid-May and that female snakes excavate nests and lay eggs in those nests between mid-June and early July of each year (Burger and Zappalorti 1992). Burger and Zappalorti (1992) found that female pine snakes often use the same nest during consecutive years, with 95% of the female snakes in their study using the same nest for at least two consecutive years and one nest being used for 11 consecutive years. Such high nest site fidelity suggests the availability of suitable nesting locations may be limited and that maintaining or protecting existing suitable nesting habitat is an essential component of protection and management for this species.

Northern pine snakes overwinter in underground hibernacula to escape the cold temperature of winter. Pine snakes will typically enter their winter hibernacula in early to mid-October, but will occasionally come back above ground to bask on warm days (Zappalorti et al., 2008; Zappalorti et al., 2009). Research on the characteristics of pine snake hibernacula by Burger et al. (1988) shows that hibernacula typically have small (narrow) entrances that extend into the B soil horizon at a 30^{o} slope; average tunnel length exceeds 6 m, with a mean of eight side chambers. Hibernacula are usually located in vegetated areas with fallen logs and high leaf cover around entrances (Burger et al., 1988). Pine snakes do exhibit fidelity to hibernacula, and will use the same hibernacula in successive years. However, human activity and disturbance (such as off-road vehicle [ORV] activity) has been shown to reduce pine snake use and abundance at hibernacula (Burger et al., 2007). Like nest sites, hibernacula serve a critical function in the pine snake's life history. Proper protection and management of hibernacula sites is therefore a key element in sustaining pine snake populations in New Jersey.

Distribution

North American Distribution:

The historic range of the northern pine snake is limited to the eastern portion of the United States (U.S.). That is to say, this species (*Pituophis m. melanoleucus*) is found nowhere else in the world but along a narrow fringe of pinelands habitat that occurs within the eastern U.S. (Figure 1). In their 1991 field guide, Conant and Collins list the northern pine snake as having a small, limited distribution in the following states: New Jersey, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Kentucky, Tennessee, and Alabama.

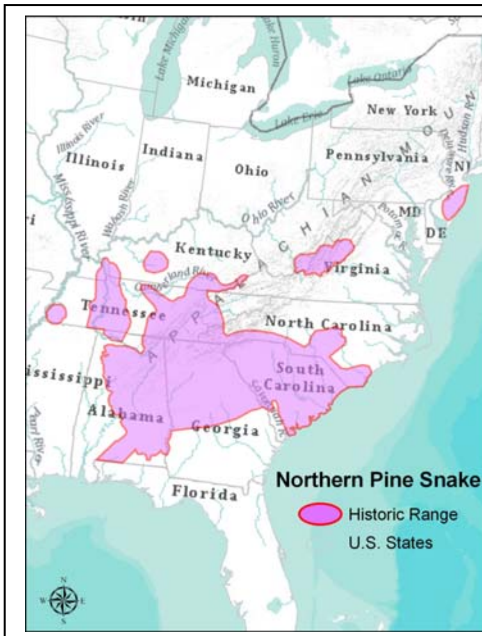


Figure 1. A historic range map for the northern pine snake (*P. m. melanoleucus)* showing the U.S. distribution for this species (adapted from Conant 1975, Conant and Collins 1991, 1998; NatureServe 2009).

As part of this assessment, we contacted state biologists from each of the states in the historic range of the northern pine snake (as described in Conant and Collins, 1991) and asked them to respond to a questionnaire about the current status and distribution of pine snakes within their state. The same questions were asked of state biologists from Maryland and Delaware, since there have also been documented sightings of pine snakes in these states within the past 20 years (even though these states are not listed in Conant [1975] and Conant and Collins [1991 and 1998] as being part of the northern pine snake range). The findings from these "interviews" are summarized in Table 1 and a sample of the questionnaire that was used can be found in Appendix I.

We received responses from nine of the ten states that were sent questionnaires. Tennessee was the only state for which we relied entirely on information obtained from the Internet to complete Table 1. Delaware and Maryland reported having documented recent pine snake sightings in their states,

Table 1. Summary of responses provided by state biologists regarding the status of pine snake in their states.

State	Present in State?	Current Status	Date of Last Status Review	Does the Status Provide Species w/ Special Protections?	Estimated Population Size	Does Active Management Take Place for This Species?	Range	Source
AL	Yes	"Priority 2" - Imperiled	2002	No	Not Available	Any beneficial mgmt is coincidental as part of forest mgmt initiatives	Estimated to exist in eastern part of State	Questionnaire
SC	Yes	Special Concern	2004	No	Not Available	Coincidental	Present in sand hill habitats throughout state	Phone Interview
NC	Yes	Special Concern	Recently	Individual/no habitat	Not Available	Prescribe Burning	Limited - 10 counties	Questionnaire
GA	Yes	No State Status; S2-NatureServe	No Formal Review Completed	No	Not Available	No	Restricted to northern part of the state	Questionnaire
TN	Yes	Threatened	?	?	?	?	Widespread distribution in portions of state	Internet
KY	Yes	Nearly Extirpated	2005	No	< 500 snakes	Coincidental	Ext. limited - 5 counties	Questionnaire
History of Sightings								
VA	Unknown	One documented occurrence from the 1940's, which was a dead-on-road sighting. Despite intensive sampling, no new specimens have been found.					NA	Questionnaire
WV	Unknown	Listed as "Special Concern", but only one documented record in the state from 1940.					Ext. limited - 1 county	Phone Interview
MD	No	Yes, dating back to 1924, but none have been accepted by scientific community. More recent sightings (1970, 2006) are believed to be escaped pets.					NA	Questionnaire
DE	No	Yes, one confirmed sighting in 1997 that was believed to be an escaped pet.					NA	Questionnaire

but in both cases these sighting were believed to be escaped pets. The discussion of whether the historic range of pine snakes ever extended into these states is ongoing (Grogan and Heckscher, 2001), especially in Maryland where there are several historic records. The most recent sighting of a northern pine snake in Virginia was made in the mid-1990s. This specimen was found dead on the road in Craig County, and the long time period (15-years) without a live sighting of this species in Virginia places doubt as to whether or not it still exists in that state. Similarly, West Virginia has only one documented pine snake record that was a dead-on-road specimen found in the 1940’s. Despite recent (and intensive) surveys in West Virginia, no other pine snakes have been found and it appears unlikely that pine snakes are still extant in West Virginia.

Northern pine snakes have very limited distributions in North Carolina and Kentucky, but are generally widespread in Tennessee, Alabama, and South Carolina. Georgia has a moderate distribution of this species, which is now restricted to the northern portion of the state. Our findings suggest that northern pine snakes have experienced a range reduction in every state in which they historically existed (Figure 2). South Carolina is the possible exception to this statement. They still appear to have a range that extends throughout SC, being absent only in the very southwestern tip (Figure 2). However, they are still listed as “special concern” in South Carolina, which suggests that the South Carolina Department of Natural Resources has concerns about existing threats to this species; we are unaware of what those concerns are since this question was not part of our questionnaire. Georgia, Virginia, Kentucky, and North Carolina show the largest range reduction for this species. In Kentucky, no pine snakes have been documented in the southeast portion of the state (the portion of the range that extends up from Tennessee; Figure 2) since 1984. Similarly, the Tennessee herpetological atlas has failed to find pine snakes in northeast Tennessee

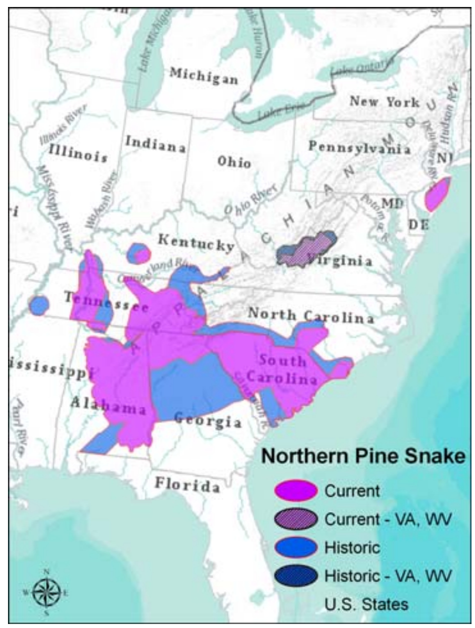


Figure 2. Revised US range of northern pine snakes adapted from responses to questionnaires (and two phone interviews) that were given to state biologist from states within the pine snake’s historic range. Distributions within TN and WV were interpreted from information found on the Internet.

since 1998 (Scott and Redmond, 2009). The extant nature of the population in the southwest corner of Tennessee is also questionable (Figure 2). Therefore, even though the U.S. range of the northern pine snake has always been limited, the results of our queries to state biologists find that the range of this species has become even more reduced in the past 20-25 years. This distribution pattern and the resultant isolation of the New Jersey population present a significant concern for its long-term viability.

New Jersey Distribution:

As described previously, typical habitat for northern pine snakes consists of pine forests with loose, sandy, upland soils. These habitats are often referred to as pine barrens habitats and, in New Jersey, occur in a region referred to as the Pinelands. The boundary of the New Jersey Pinelands has been defined differently by various sources (Forman, 1979; Boyd, 1991; New Jersey Pinelands Commission, 2009), but by all accounts extends through Ocean, Burlington, Camden, Gloucester, and Atlantic counties. The northern pine snake is one of the iconic species of the New Jersey Pinelands, it is found only in the Pinelands Region, and is totally isolated from all other pine snake populations throughout the country (Figure 1). The disjunct nature of the New Jersey pine snake population adds to its importance and vulnerability since natural immigration or recolonization from surrounding populations is not possible.

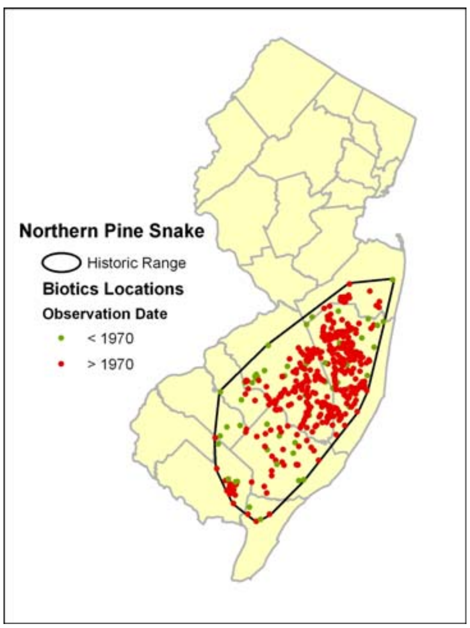
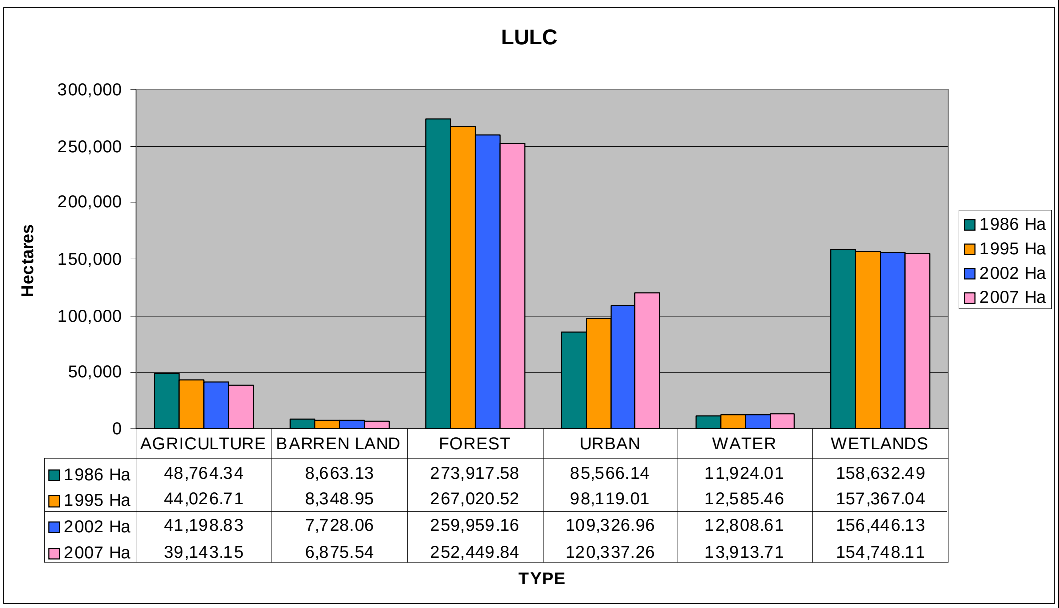


Figure 3. The estimated historic range of northern pine snakes in New Jersey calculated using occurrence data from 1901 to 2009.

We estimated the historic range of pine snakes in New Jersey using occurrence data from the Department's Biotics database (referred to as "Biotics"). Biotics is the name of a biodiversity data management software that is used by the Endangered and Nongame Species Program (ENSP) to track rare species occurrences and to store relevant information on these occurrences. Species occurrence records are entered into the database after ENSP staff has verified a record according to its verification process (Appendix II). Each pine snake occurrence from Biotics was buffered by 500 m - to approximate the activity range of a pine snake (Smith and

Bien, 2005; Golden, 2007; Zappalorti et al., 2008; Zappalorti et al., 2009) - and the overall extent of occurrences was then bounded by the outermost occurrences using a minimum convex-polygon methodology (Beyer, 2004). Figure 3 illustrates the result of this analysis and provides an estimation of the historic range for northern pine snakes in New Jersey using data from 1901 to 2009. The total area captured within the estimated historic range is 587,074 ha (1,450,691 acres).

The Department's aerial-photo-based Land Use / Land Cover (LULC) data (Appendix III) divides habitat within the state into six broad land cover classes (level-one, based on a modified Anderson Classification system [Anderson et al., 1976]). The Department's LULC data set becomes available periodically and can be used for landscape-level analysis of land-use land-cover change over time.



	AGRICULTURE	BARREN LAND	FOREST	URBAN	WATER	WETLANDS
1986 Ha	48,764.34	8,663.13	273,917.58	85,566.14	11,924.01	158,632.49
1995 Ha	44,026.71	8,348.95	267,020.52	98,119.01	12,585.46	157,367.04
2002 Ha	41,198.83	7,728.06	259,959.16	109,326.96	12,808.61	156,446.13
2007 Ha	39,143.15	6,875.54	252,449.84	120,337.26	13,913.71	154,748.11

Figure 4 depicts the general composition of the land use land cover within the historic range of pine snakes for 1986, 1995, 2002, and 2007 (Draft Data). Over this time period, forest (this category contains only upland forest) was the dominant habitat type, but steadily decreased and experienced a total reduction of 21,468 ha (53,026 ac), or 7.8%, from 1986 to 2007. Smaller decreases were seen in agriculture, wetlands (which include forested wetlands), and barren land (Figure 4). Urban was the only land cover type that exhibited an increase each year, with a total increase of 34,771 ha (85,844 ac), or 40.6%, between 1986 and 2007. This suggests that since 1986 urban development has been replacing other LULC types within the historic range of northern pine snakes at a rate of roughly 1,655 ha (4,086 ac) per year, reducing potential habitat each year.

Current Status Across the U.S. Range

As described in the U.S. range analysis, northern pine snakes are still considered to be extant in Alabama, Georgia, North Carolina, Kentucky, South Carolina, Tennessee, and New Jersey; although in each of these states the species has some elevated status of "concern." We suspect that this species has been extirpated from West Virginia and Virginia and could be on its way to extirpation in Kentucky. In Kentucky they are considered "nearly extirpated," with an estimated population size of less than 500 snakes (Table 1). The responses we received from our questionnaire and phone interview indicate that only North Carolina has special regulations to protect individuals of this species, but even in North Carolina, no regulations to protect its habitat are in place. The elevated conservation status assigned to this species in every state throughout it range, along with the documented range retractions described previously, suggest that pine snakes are struggling throughout their entire U.S. range.

The northern pine snake is currently assigned the status of "threatened" in New Jersey. By definition a threatened species is "a species that may become endangered if conditions surrounding the species begin or continue to deteriorate" (N.J.A.C. 7:25-4.1 and 4.17). Pine snakes were originally assigned this status in 1979 by the New Jersey Department of Environmental Protection (NJDEP) and since that time, the list of nongame species (and their statuses) has been readopted seven times through the State's administrative procedures for rule adoption and amendment (1984, 1985, 1987, 1991, 1999, 2002 and 2003). In 2001, a thorough review of the pine snake's status was completed using a process referred to as the Delphi method (Clark et al., 2006). At that time, the status of the northern pine snake was reviewed along with those of 17 other reptiles and 19 amphibians. A group of 16 panelists participated in the 2001 review, each with expertise in reptiles and/or amphibians, including seven panelists with specific experience and expertise with the northern pine snake. Panelists evaluated the existing threats to northern pine snakes and, from this, generated an informed opinion on the appropriate status of this species in New Jersey; the panelists reached "consensus" (15 out of 16 agreed) that this species continued to meet the definition of "threatened" in New Jersey.

Like all other states where this species exists (except Kentucky), New Jersey does not currently have a population estimate of the number of pine snakes that exist in the state (Table 1). The secretive nature of this species makes surveying for it difficult and, therefore, calculating accurate estimates of total abundance is time consuming and complex even on a localized scale. Generating a statewide population estimate for this semi-fossorial species would require a level of sampling that would most likely be impractical and prohibitively expensive for any state agency to undertake. This likely explains why, like New Jersey, no other state with a moderate distribution of pine snakes has an estimate of population size for this species. Instead, several states take an approach that is similar to New Jersey and rely on predictive mapping of suitable habitat as a surrogate for population size estimates.

Threats

In conducting a status assessment for the northern pine snake (or any species) it is necessary to evaluate the level and severity of threats facing the species. Like most reptiles, pine snakes face a myriad of threats in New Jersey. In this document we explore what are thought to be the six greatest threats to the long term viability of the pine snake population in the state. These threats include: 1) habitat loss and fragmentation (Dobson, 1996; Golden and Jenkins, 2003; NJDEP, 2003); 2) poaching and illegal collection (Burger et al, 1992); 3) predation from both natural and subsidized predators (Burger et a., 1992; Zappalorti et al., 2008); 4) mortality along roads (NJDEP, 2003); 5) fire suppression and habitat change (Golden and Jenkins, 2003); and 6) ORV use (Burger et al., 2007).

- **Habitat Loss and Fragmentation**

The loss of natural habitats and the fragmenting effect that results from habitat loss are among the greatest threats to wildlife (Saunders et al., 1991; Andrén, 1994). New Jersey is the most densely populated state in the U.S. and has experienced habitat loss (to urban development) over the past 20 years at a rate of nearly 6,130ha (15,141 ac) per year (Hasse and Lathrop, 2008). This translates to roughly a 0.27% annual loss of habitat (1,656 ha or 4,090 ac/yr) to urban development statewide versus a slightly larger decrease of 0.29% annual habitat loss within the pine snake's estimated historic range (Figure 5). This rate of habitat loss to urban development is influenced by multiple factors, but two that stand out as relevant to protecting pine snake habitat include: 1) the strong land use regulations that exist within much of the pine snake's range and that include specific and strong provisions for the protection of Endangered and Threatened species habitat, and 2) large areas of open space preservation within the historic range.

The New Jersey Pinelands Commission regulates land use within the Pinelands National Reserve through a set of regulations known as the Comprehensive Management Plan (CMP – *N.J.A.C. 7:50-1.1 et seq*.). These regulations apply within a large portion (72%) of the pine snake's historic range. In addition, the NJDEP's Coastal Zone Management Rules (CZM; *N.J.A.C. 7:7*) apply to an additional 7% of the pine snakes historic range. This leaves 21% of the northern pine snake's historic range lacking any regulatory protection for pine snake habitat (Figure 5).

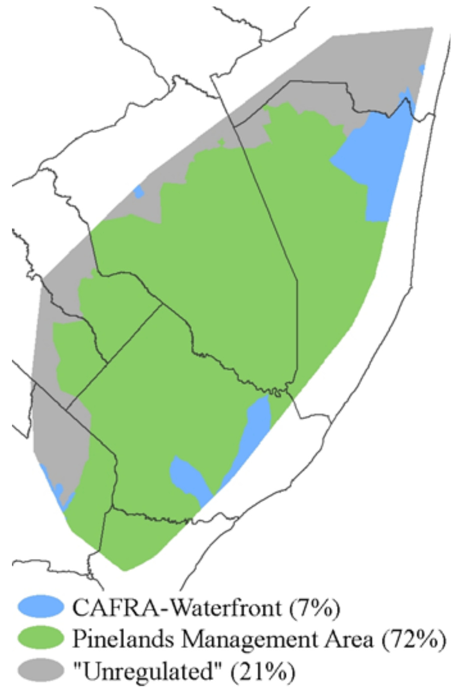


Figure 5. Map of the historic range of pine snake in New Jersey showing the areas that currently have regulations to protect the habitat for this threatened species (GRN=CMP, BLUE=CZM)

In the "unregulated" region (not CMP or CZM), pine snake habitat could potentially be developed for any use without consideration of the implications to pine snakes. Therefore, pine snake habitat within this region is considered to be the most vulnerable to development. Most of the pine snake habitat that is not protected through state regulations exists on the western and northern periphery of the range (Figure 5). In addition, because the CZM regulations (with limited exceptions) do not typically apply to residential developments of fewer than 25 units or to commercial and industrial developments that require fewer than 50 parking spaces, the protection of pine snake habitats in the region that is under the sole jurisdiction of the CZM rules is much less far-reaching. Therefore, although the pine snake carries the status of "threatened" there are areas and situations where this status does not guarantee that its habitat will not be developed (see Zampella, 1986).

In order to calculate how suitable habitat for this species has changed over time we modeled pine snake habitat within its historic range and calculated the total suitable habitat available in 1986, 1995, 2002, and 2007. These years were selected due to the availability of NJDEP LULC data (note: the 2007 LULC is currently available in draft form only). Two different GIS modeling methods were utilized for this analysis. The “Species-based Patch” methodology (“SBP” method) used NJDEP LULC data to model pine snake habitat. Appropriate LULC level three classes were chosen and dissolved/combined into species-specific patches of habitat. These habitat patches were then mapped within the historic range for pine snakes. A similar methodology was used in the creation of the Landscape Project (*v. 3.0*) to map endangered and threatened species habitat in the Highlands (Winkler et al., 2008). A more statistically-based model was also used to model pine snake habitat within the historic range. This model (“STAT_MOD” method) is a resource selection function model that was estimated using presence/absence data and incorporated both LULC and soil data (SSURGO) to create a predictive map of pine snake habitat. The key predictive variables for this model were: 1) extremely well drained soils, 2) pine-dominated forest, and 3) shrub habitat. Both the SBP and STAT_MOD models were created using a subset of the occurrence data (75% of the data between 1998 and 2006) from the NJDEP’s Biotics database. The remaining 25% of the Biotics data were then used to validate these models. Additional details on the creation and validation of these models can be found in Appendix IV. The general objective of this modeling was to evaluate the severity of the threat posed by habitat loss and fragmentation. Estimating the quantity of suitable pine snake habitat that once existed within the historic range and then analyzing how this habitat has changed over the past 20 years provides an indication of the extent to which pine snake habitat has been lost. From this, inferences can be made about the overall trend in the pine snake habitat and, by implication, in the pine snake population.

Range-wide Landscape Change:

There was high consistency between our two models in the amount of estimated pine snake habitat that existed in 1986. The SBP model estimated that New Jersey contained 229,837 ha (567,697 ac) of pine snake habitat in 1986, while the STAT_MOD model estimated that 228,685 ha existed in that year. Therefore, both models predict that nearly 40% of the habitat within the pine snakes historic range was suitable for this species in 1986.

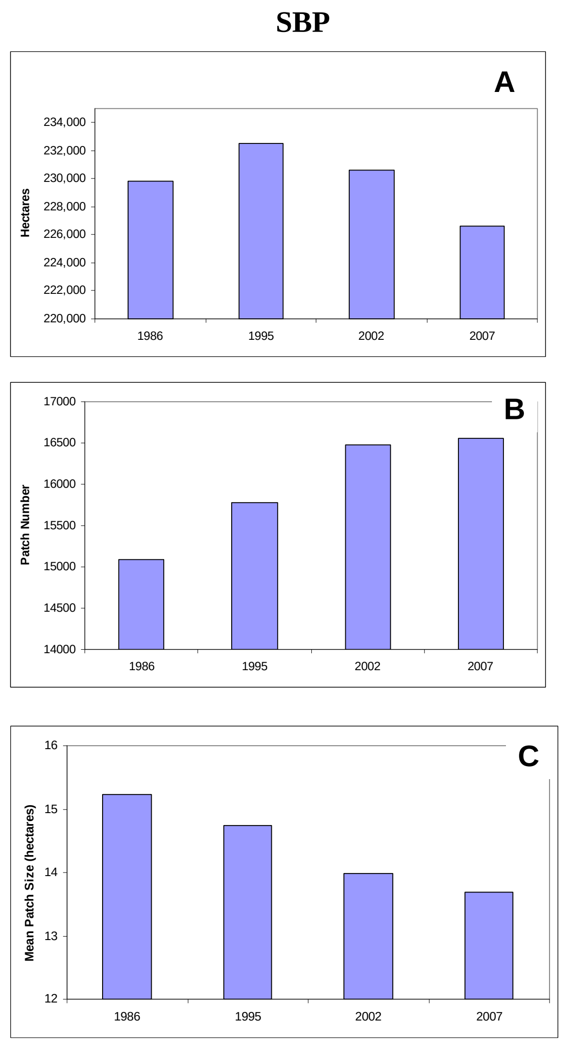


Figure 6. Changes in pine snake habitat total area (A), patch number (B), and mean patch size (C) between 1986 and 2007. Estimates of pine snake habitat were calculated using a Species-based Patch methodology that relied on level 3 LULC classes to identify suitable habitat patches for this species.

Results of the SBP model show a continual decrease in the amount of suitable pine snake habitat within the historic range from 1995 to 2007, with an overall decrease of 5,875 ha (14,511 ac; Figure 6A). This analysis takes into account both additions to pine snake habitat (as a result of natural succession and habitat becoming increasingly suitable for this species over time) as well as losses in habitat that might be attributed to urbanization, natural succession, fire, or disturbances. In addition to an overall loss of habitat, the SBP modeling results also show patterns in patch size and patch number that are consistent with a trend of increasing habitat fragmentation (Wiens et al., 1993). That is, in the period from 1986 to 2007 the number of suitable pine snake habitat patches steadily increased, while the mean size of these patches steadily decreased (Figure 6B and 6C). This pattern of habitat change illustrates how landscapes become more fragmented over time. As total area decreases, mean patch size also decreases, but patches become more numerous. The overall result is a landscape with smaller, more isolated patches that have a higher edge to area ratio (Fahrig and

Merriam, 1994; Golden and Crist, 2000), which can change patch microclimates, increase access for predators and humans, isolate populations, and increase competition for remaining suitable habitat (Saunders, 1991; Andrén, 1994). For a species like the pine snake, an increasingly fragmented landscape poses a serious threat to individuals and the population as exposure to roads, subsidized predators, human interactions, and unsuitable habitat types likely increase under this scenario (Sauders et al., 1991; Byers and Mitchell, 2005; Mitchell et al., 2006). Furthermore, Mitchell et al. (2006) suggest that small land holdings are simply not of sufficient size to maintain viable populations of pine snakes due to this species' large home range requirements.

STAT_MOD

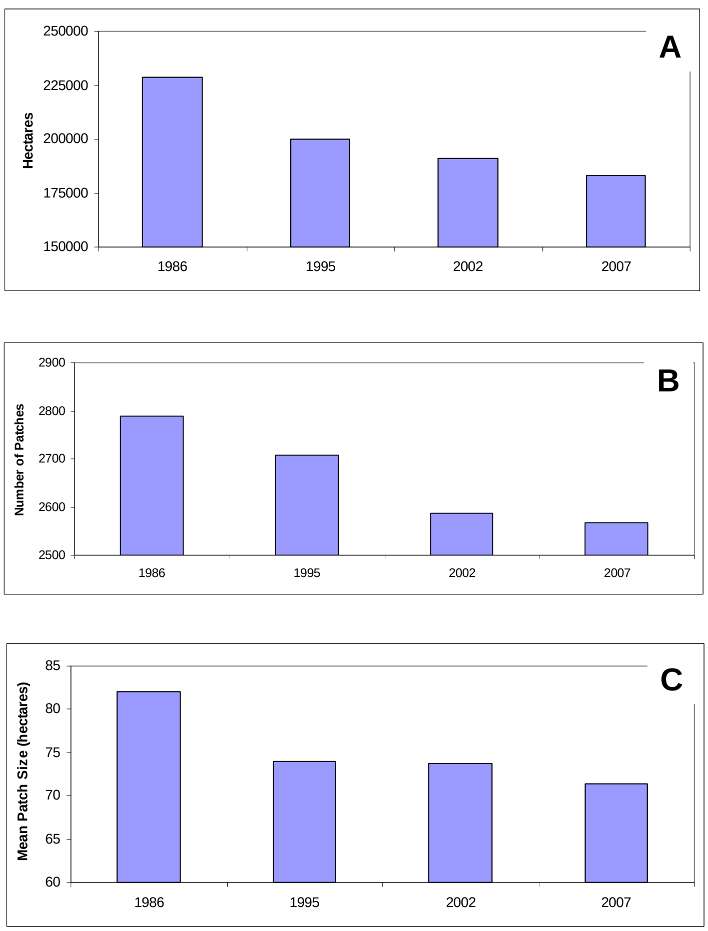


Figure 7. Changes in pine snake habitat total area (A), patch number (B), and mean patch size (C) between 1986 and 2007. Estimates of pine snake habitat were calculated using a Statistically-based model that used shrub habitat, coniferous forest, and extremely well drained soils as the predictive variables.

Pine snakes nest in open areas with loose sandy soils and outside of the nesting season they seem to exhibit a clear association with coniferous dominant forests, shrub habitats, and extremely well drained soils (NJDEP STAT_MOD). This type of habitat specialization makes pine snakes more susceptible than other species to the threats of habitat loss that are illustrated by the SBP and STAT_MOD models. Species that are habitat generalists are pliable in their use of habitats and if, for example, development takes away one habitat type they can be equally successful in another. However, a species like the pine snake, with specific habitat needs, is less flexible in its ability to use various habitat types. Small losses of nesting habitat, for example, can have a disproportionate impact on a local population if suitable alternatives are not available within the home range of pine snakes in the area.

The STAT_MOD analysis resulted in trends similar to those of the SBP analysis, but the STAT_MOD results show a much greater loss of overall pine snake habitat between 1986 and 2007 and a decrease in overall patch number through time (Figure 7). Pine snake habitat decreased a total 45,530 ha (112,459 acres) from 1986 to 2007 in the STAT_MOD analysis. As with the SBP results, this decrease is likely attributed to multiple factors including urbanization and natural succession (i.e., where habitats might become less suitable as they succeed into different seral stages).

Range-wide Habitat Loss Resulting from Urban Development:

State regulations can act to help protect habitat for a species, if regulated activities are either excluded or modified when they are proposed in habitats suitable for that species. The estimates of habitat change described above do not isolate the amount of pine snake habitat that has been lost as a result of urban development. Instead, the habitat changes illustrated in Figures 6 and 7 are most likely the result of multiple factors acting simultaneously to increase and decrease pine snake habitat, with an overall net reduction observed.

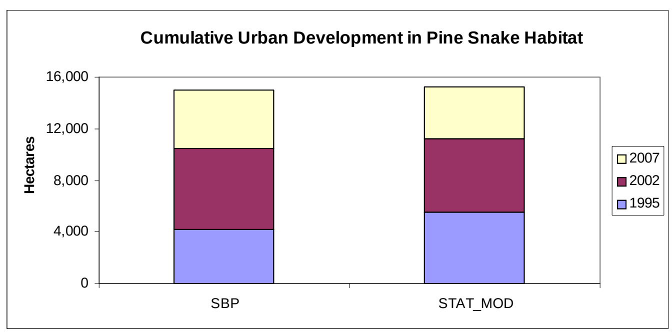


Figure 8. Graph depicting the cumulative amount of urban development (from 1995 to 2007) that directly replaced habitat modeled as suitable for northern pine snakes using a Species-based Patch model (SBP) and a Statistically-based model (STAT_MOD).

To calculate the amount of pine snake habitat lost specifically to development, we used the 1986 estimates of pine snake habitat from the SBP and STAT_MOD models and systematically calculated the amount of urban LULC (Appendix III) that replaced this pine snake habitat (1986) in 1995, 2002, and 2007. Both models show a consistent trend of increasing urban development within pine snake habitat and both were similar in the amount of habitat loss attributed to urban developments (Figure 8). The SBP model estimated that 14,979 ha (36,998 ac) of pine snake habitat was lost directly to development between 1986 and 2007, the STAT_MOD model estimated that 15,235 ha (37,631 acres) was lost during this timeframe. This results in an estimated overall loss of pine snake habitat due to development ranging from 6.5% to 7.0% between 1986 and 2007, depending on which model is used. When compared with other rates of habitat loss in other portions of the state this amount of habitat loss may not seem substantial, but it is likely that the protected status of the northern pine snake partially accounts for this somewhat less dramatic rate of loss over time. Because state regulations are in place that are designed to protect habitat for this species (and others) by prohibiting growth in sensitive areas, the development of pine snake habitat may have occurred at a rate slower than other non-regulated areas over the last 20 years. In fact, this may illustrate that the existing state regulations help to reduce habitat loss for this species. Nonetheless both models show that, despite the existing regulations that are currently in place, development poses a continuing threat to this species and its habitat.

Regional Analysis of Habitat Loss Resulting from Urban Development:

We further explored how the existence of regulations may have influenced changes in northern pine snake habitat over the past 20 years by analyzing habitat change in the three different regulatory regions that occur within the northern pine snake's historic range. For the purposes of this report we will refer to these regions as the following: 1) PMA – this is the region under the regulatory authority of the Pineland Commission and the CMP; 2) CAFRA – this is the region under the regulatory authority of the NJDEP and the CZM rules; 3) NO_REG – this region lacks regulatory protection* for northern pine snake habitat *(*Note – this region has other state regulations in place, but none that require consideration of northern pine snake habitat*). If the regulations that prohibit development in northern pine snake habitat are working, we would expect that there would be less conversion of pine snake habitat to urban LULC in areas with stronger regulations. Therefore, with its strong regulations under the CMP, the PMA region would be expected to have the smallest percentage of pine snake habitat lost to development, while the NO_REG region would be expected to have the greatest.

We modeled habitat loss directly attributable to urban for each region using the same method described above for the range-wide analysis. As expected, our results did find that PMA has the smallest percentage of overall decrease of pine snake habitat for both models (SBP = 1.9% and STAT_MOD = 1.8%). However, it was actually the CAFRA region that we found to have the highest percentage of pine snake habitat converted to urban from 1986-2007 (Figure 9). The actual amount of habitat loss for the CAFRA and NO_REG regions were quite similar (SBP Model: CAFRA = 3,517 ha *vs.* NO_REG = 3,393 ha; and STAT_MOD: CAFRA 3,197 ha vs. NO_REG = 4,312 ha), but when calculated on percentage basis (hectares lost in region/total hectares in region) the CAFRA region far exceeds that of the NO_REG region for both models (Figure 9), with nearly 9% of the pine snake habitat converted to urban LULC in this region between 1986 and 2007.

We believe that "sub-CAFRA" development (i.e., development below the statutory threshold for requiring a CAFRA permit) is the primary reason for explaining the high percentage of pine snake habitat that has been lost to development within the CAFRA region. The regulations that are in place to protect pine snake habitat in this region do not apply to activities that are referred to as "sub-CAFRA". This would include things like housing developments of fewer than 25 units and businesses with fewer than 50 parking spaces. This CAFRA "loop hole" has been exploited by those wanting to develop within the CAFRA region and it is common to see developments built to 24 units in order to avoid the CAFRA regulations. Another factor that may help to explain the higher percentage of habitat loss in the CAFRA zone is the relatively small area protected as public open space in this region.

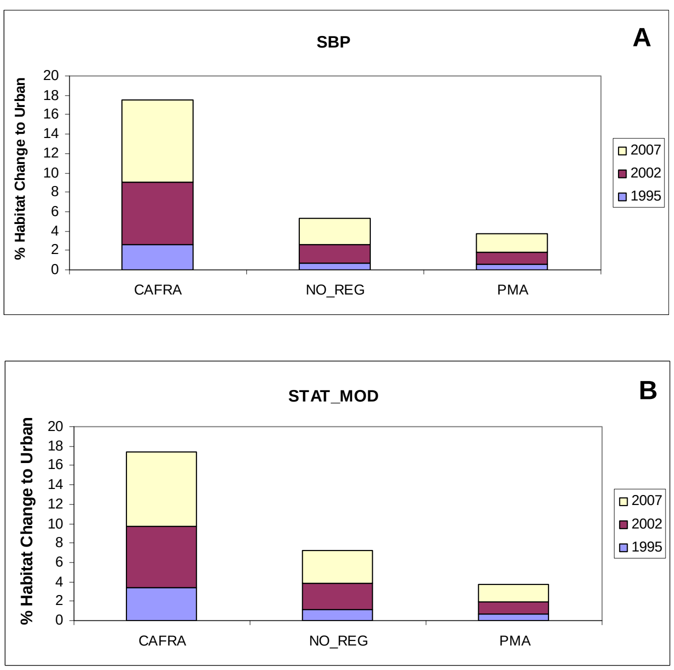


Figure 9. Estimated changes in pine snake habitat directly attributed to urban development (based on 1986 mapping) for different regions within the pine snake's historic range. Habitat modeling was conducted using A. Species-based patch model (SBP) and B. Statistically-based modeling (STAT_MOD) approaches.

Regional open space patterns are discussed in more detail in a subsequent section of this document.

Individual Occurrences and Range Reduction:

As previously discussed, rare species occurrence information is tracked by NJDEP using the Biotics Database, and currently there are 536 documented occurrences of northern pine snakes contained within this database. Many land-use decisions are based on information gained or extrapolated (e.g., Landscape Project by Niles et al., 2008) from these occurrences. The first step in using occurrence data for land-use purposes is to estimate the area around each occurrence and approximate the amount of habitat or land area that an individual snake is likely using. Because snakes exhibit daily and annual movement patterns it seems inappropriate to rely on point data to represent an individual snake's habitat needs. Instead, to better represent each snake's area requirements, the NJDEP assigns "Species Occurrence Areas" (SOAs) to each point location. For northern pine snakes, the SOA is derived by placing a 500-m buffer around each species occurrence point (Golden 2007). This buffer is meant to approximate the typical activity range of northern pine snakes (Burger and Zappalorti, 1988; Smith and Bien, 2005; Gerald et al., 2006; Zappalorti et al., 2008).

Using our current SOA database for pine snakes (536 SOAs from 1975 – 2008), we calculated the number of SOAs that have been "impacted" by development. An SOA was considered to be impacted if any portion of the SOA (500-m buffer) contained urban LULC (2007 LULC). Urban LULCs are described in Appendix III. The intent behind this analysis was to determine what number, or percentage, of documented pine snakes are currently exposed to any level of development within their estimated activity range. This analysis assumes that all pine snakes have circular activity ranges measuring 1000-m in diameter (78.5 ha or 194 ac) and that the occurrence information recorded by the NJDEP represents the centrum of an individual snake's activity range. While these assumptions are likely not being met for most of the 536 SOAs, knowing the percentage of SOAs "impacted" by development still contributes to our understanding of the level of habitat fragmentation that northern pine snakes are experiencing within their historic range. Along with this, the analysis also provides some indication of the exposure pine snakes have to development and other human influences (roads, pets, off-road vehicles, etc.). A total of 419 out of 536 SOAs (78%) were found to be impacted by urban development, suggesting that some level of development falls within the estimated activity range of the majority of pine snake SOAs that NJDEP has on record. The urban LULC accounted for a wide range of area within the impacted SOAs, comprising from 92.7% to less than 1% of the total SOA area (mean = 15.5% $\pm$ 16.93). Of those SOAs that were not impacted, only eight fell outside of permanently preserved open space. The remaining 109 SOAs were at least 95% contained within open space. While this is an indication that the diligent efforts of the Green Acres Program (the State's open space acquisition agency) and other land acquisition efforts are helping to protect pine snake habitat, it also suggests that most pine snakes are still exposed to some level development within their activity range.

In a preceding section of this document the methodology for estimating the historic range of northern pine snake in New Jersey, using data from 1901 to 2009, was described. We believe that the northern pine snake has experienced a considerable range reduction over the last 100 years and that the map presented in Figure 3 does not represent the current range for this species. To assess this, we compared the historic range calculation for pine snakes to a more contemporary calculation that used data from 1986 to 2009. The same method of buffering occurrences and using minimum convex polygon was applied to this dataset. As expected, the historic range of pine snakes was much greater than what we estimate to be the current range for pine snakes in the state (Figure 10). Major contractions are obvious in the western and northeastern portion of the range, and the total area of the range decreased from 587,074 ha to 488,515 ha, a decrease of 98,559 ha (17%). This pattern is similar to what has been seen throughout the US range for this species, where, in nearly every state supporting populations of this species, reductions in their range have occurred (Table 1, Figure 2).

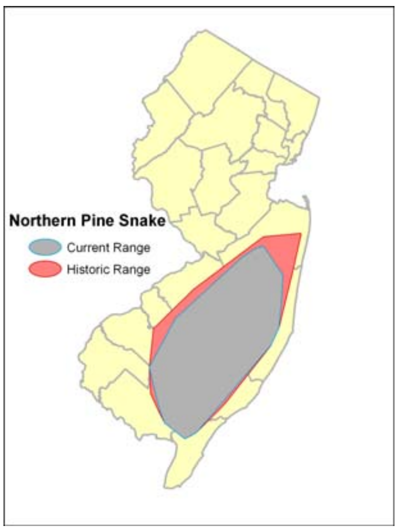


Figure 10. Map showing the estimated range reduction experienced by pine snakes in New Jersey. Historic range estimate (red shading) based on all pine snake data available in Biotics, current range (gray shading) based on data from 1986-2009.

The reductions that have taken place in the pine snake's range in New Jersey (Figure 10) and throughout the United States (Figure 2) highlight the overall, and increasing, isolation of New

Jersey's pine snake population. This extreme level of regional isolation is not something that is seen for many other New Jersey species. Based on our surveys with biologists in other states, it appears that the next closest extant population of northern pine snakes is located in southern North Carolina (straight-line distance roughly 645 km [400 miles] from the New Jersey Pinelands). Clearly the New Jersey pine snake population is disjunct and totally isolated from all other populations of this species. Range size and degree of isolation have been identified as two major factors that need to be considered when evaluating the level of extinction risk for a species (Gaston, 1994). Pine snakes in New Jersey have a limited range and are highly isolated from other populations; two characteristics that place them in a high-risk category (Gaston, 1994). As it relates to the northern pine snake, population isolation can be considered at multiple scales: local (within New Jersey) and regional (within its U.S. range). Regional isolation, coupled with a restricted local distribution, can put populations at great risk of extinction. Populations with these characteristics become more susceptible to demographic, genetic, and environmental stochastic events because they lack the immigration flow that adjacent populations (or meta-populations) might otherwise provide (Wiens, 1997; Drechsler and Wissel, 1998). Therefore, if the New Jersey population of pine snakes were to dip below a minimum viable population size, there would be no chance for it to naturally recover or be reestablished through immigration from surrounding populations. Furthermore, the extreme regional isolation of this population increases the likelihood that pine snakes in New Jersey might someday dip below a minimum viable population size because they lack the regular (or irregular) influx of individuals from other populations (Gotelli, 1995).

Open Space Analysis:

One possible means of addressing the threat of habitat loss and fragmentation is through open space preservation. New Jersey has one of the most successful land preservation programs in the country with nearly $100 million dollars of state money spent on open space acquisition annually (John Flynn, personal communication 2009). Throughout the pine snake's historic range in New Jersey, a total of 215,538 ha (532,379 ac) are currently preserved as "open space." This includes State, Federal, County, Municipal, and "non-profit" lands and accounts for roughly 37% of this species' historic range (Figure 11). Open space within the PMA region accounts for 90% (194,514 ha) of this estimate.

In order for open space to be valuable to pine snakes it must encompass habitat that is considered to be important for this species. We estimated the amount of pine snake habitat that has been protected through open space preservation using the habitat predictions generated by our SBP and STAT_MOD models. These results are displayed for the entire range and for each region in Figure 12, and are based on 2007 habitat estimates for each model type and the most recent state open space GIS coverage. Once again, both models show the same overall pattern and estimate that slightly more than half of the pine snake habitat in New Jersey currently exists as permanently preserved land. The total amount of pine snake habitat contained within open space is 122,306 ha (302,096 ac) or 54% of the SBP predicted habitat, and 111,928 ha (276,463 ac) or 61% of the STAT_MOD predicted habitat. However, a portion of this estimate of open space includes pine snake habitat entirely contained on military bases (10.5% and 11.6% of the total open space estimates for the SBP and STAT_MOD habitat, respectively). Currently this habitat is intact, but it cannot be considered as permanently preserved since national security takes complete precedence over rare species habitat and base activities could negatively impact this habitat in the future. The CAFRA region has the smallest percentage of pine snake habitat protected by open space and the PMA region the greatest. This may partially explain why the CAFRA region lost the highest percentage of pine snake habitat to urban development over the past 20 years (Figure 9). Because a smaller percentage of habitat for this species is protected by open space in the CAFRA region, more

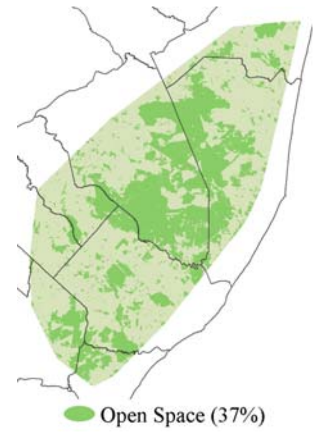


Figure 11. Open space (green) within the historic range of the northern pine snake (gray).

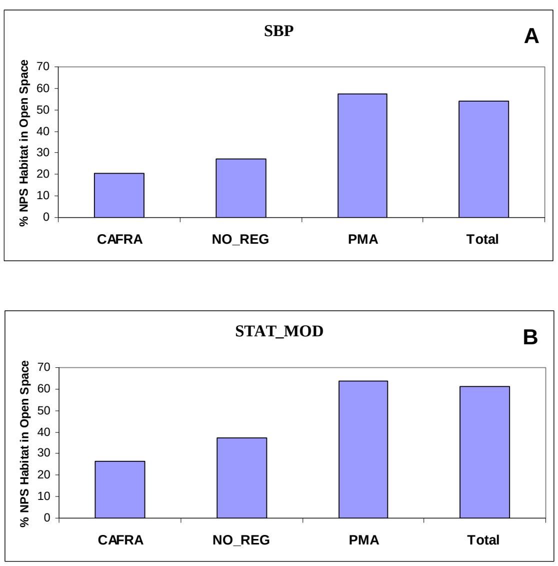


Figure 12. Percentage of modeled pine snake habitat within open space for each region. Pine snake habitat was modeled using a Species-based Patch (A) and Statistically-based Modeling (B) approach.

of it is vulnerable to development pressures. This, in addition to the sub-CAFRA loophole discussed previously, likely explains the pattern of habitat loss observed for this region.

- **Killing, Poaching, and Illegal Collecting**

Snakes have been vilified throughout history and many people report having a natural fear of snakes. This fear often results in the needless killing of snakes when they are encountered by humans. Even nonvenomous species are killed in this manner simply because many humans are fearful that they might be harmed by these species and do not fully understand them. Biologists within the New Jersey Division of Fish and Wildlife receive numerous calls every spring and fall from residents that are troubled by the presence of a snake around their home or on their property (personal observation, 2009; Kris Schanz, personal communication, 2009). Often times these calls seem to serve the sole purpose of allowing the caller to report on how the encounter ended with them killing the snake. In New Jersey, all snakes are protected from direct "take" (i.e., killing) under the Endangered and Nongame Species Act (N.J.S.A. 23:2A *et seq.*), and yet, open testimonials from residents about killing snakes are regularly received. These calls reflect ignorance of state regulations and of the fact that nonvenomous snake species pose no real threat to humans. By itself, purposeful killing of pine snakes in the Pinelands does not pose a major threat to the long-term viability of this species. This needless killing does occur, however, and when combined with other threats, it contributes to the stresses placed on the New Jersey pine snake population.

Of greater concern to the pine snake is a more nefarious and common type of "take." This is the *take* associated with the poaching and illegal collection of pine snakes for commercial gain or personal gratification. Simply put, these activities involve individuals traveling into known, or suspected, pine snake habitats with the specific intent of capturing and removing pine snakes or their eggs. References to this type of activity date back to the early 1900's (Kauffeld, 1957) and continue to this day even though the act of collecting and removing pine snakes from their natural habitat is illegal (N.J.S.A. 23:2A *et seq.*). A quick search of the Internet easily reveals classified ads advertising "wild caught pine snakes from the New Jersey Pinelands" for sale. Those that are "wild caught" seem to list for a higher price than captive bred individuals (D. Golden, personal observation, November, 2009). The excerpt below was taken directly from the website “www.faunalclassifieds.com” and provides some insight into the financial motivation that might feed into the illegal collection of northern pine snakes:

> *“For Sale – Adult Female NJ Pine [Snake]*
>
> *5 foot female. Burlington Co., NJ locale. Feeds on f/t medium or large rats. Tame and handleable. Puffs a little but doesn't even hiss. Really great, impressive pine. I just don't have the time right now to clean up after her. I guess I tried to distract myself from what a handful colubrids are. I've gotten used to just having to take care of my pythons and copperheads. Asking $200 shipped. I'd expect shipping to be around $60-$65. Contact me if you're interested. Thanks a lot. Ryan.”*

This is just one of many ads that were easily found on the classified pages of websites like “kingsnake.com,” “repticzone.com,” “faunalclassifieds.com,” and “turtleforum.com” during the drafting of this document. With individual snakes fetching a price of $200 it seems obvious that northern pine snakes are facing real pressure from illegal collection.

In spring of 2009, the conclusion of an undercover investigation know as “Operation Shellshocked” made the public and law enforcement agencies aware of just how widespread the illegal collection and trade of snakes and other reptiles are in the northeastern U.S. Launched by the New York State Department of Environmental Conservation, this undercover investigation lasted 2.5 years, documented more than 2,000 separate violations, led to 28 individual arrests (including at least one New Jersey resident), and brought a great deal of attention to the severity of the black-market trade of reptiles (Thomas, 2009). Some researchers have even suggested that for certain species of snakes, illegal collection is the primary threat leading to their decline (Filippi and Luiselli, 2000). The snake species that are believed to be most susceptible to illegal collection and trade are those with patchy distributions, synchronized mating, and reduced range (Filippi and Luiselli, 2000); pine snakes exhibit all of these characteristics.

Suspicions about prevalence of illegal collecting of pine snakes in New Jersey have existed for some time. In a 1992 study, Burger and Zappalorti reported that humans illegally removed the eggs from 23 out of 80 pine snake nests (29%) over a three year period. The authors also point out that nesting season is an opportune time for human poachers to also take gravid female snakes. Pine snakes nest in very characteristic locations and their nest entrances and dump piles (pile of soil left behind during excavation) are easily identified. Finding nest sites therefore poses only a minimal challenge to those who know what to look for, even though this species occurs in low numbers in the Pinelands. Added to this is the fact that female pine snakes often use the same nest location year after year (Burger and Zappalorti, 1992). Therefore, a person intent on poaching nests could easily revisit known nesting locations annually and poach eggs from the same snake population and quite possibly the same individual snake. Removing eggs from a snake population can negatively affect the long-term stability of a local population, and the levels of poaching reported are alarming (Burger and Zappalorti, 1992).

The Division of Fish and Wildlife's Bureau of Law Enforcement reports that during the course of routine patrols in the area of the Pine Barrens, their Conservation Officers have noticed a decline in the number of pine snakes present in the wild in areas in which they were previously observed (T. Cussen, personal communication, 2009). They attribute a portion of this decline to unlawful collection and are currently investigating several reports of unlawful commercialization of pine snakes that were unlawfully collected from the wild. The Bureau of Law Enforcement intends to continue these investigations through covert methods and to prosecute those individuals apprehended as a result (T. Cussen, personal communication, 2009).

Compared to other species in New Jersey, pine snakes are also at an elevated risk of being poached or illegally collected. Along with bog turtles (federally endangered) and corn snakes (state endangered) pine snake are among the species most likely to be sought by illegal collectors in the state. Part of this collection pressure is probably explained by the striking appearance of New Jersey pine snakes, with their creamy white base color and discrete black blotching. Oddly enough, their rarity throughout the United States and their elevated conservation status in each state also makes them a target for some collectors, who find personal or financial gratification in having a species that is difficult to obtain. Despite their low abundance, however, their nesting habits and characteristic nesting habitats may make them a relatively easy target for collectors. Northern pine snakes have a relatively low reproductive rate which further amplifies the damage that illegal collection, predation, or destruction of nest sites has on the local population.

We believe that the illegal collection of pine snakes poses a serious threat to this species throughout its New Jersey range. Moreover, unlike the loss of habitat that results from development, this threat is not abated by land preservation and may actually become amplified as more open space is purchased and made accessible to the public. The very limited number of law enforcement agents responsible for enforcing wildlife laws results in one or two officers covering tens of thousands of acres, and with reductions in staff they already struggle to patrol the 215,538 ha (532,379 ac) of open space that exists within the pine snakes' historic range. So, while increases in open space help slow the rate at which pine snake habitat is lost to development, it may put increasing strain on law enforcement's ability to find and prosecute poachers in the field.

- **Natural and Subsidized Predators**

Like all other organisms, snakes face a number of potential mortality factors. Natural predation is a mortality factor that acts on all life stages of northern pine snakes (adult, hatchling, and egg). The following animals have been documented to prey upon some life stage of pine snakes or other species within the genus *Pituophis*: coyote, red fox, striped skunk, raccoon, opossum, short-tailed shrew, white-footed mouse, other snake species, great blue heron, red-tailed hawk, and broad-winged hawk (Fitch, 1999; Burger and Zappalorti, 1992; Zappalorti et al., 2008). During their active season healthy adult pine snakes are relatively safe from small predators, but can be depredated by natural predators such as red-tailed hawk, coyote, and larger birds of prey or mammals (Zappalorti et al., 2008). During hibernation, however, adult pine snakes are lethargic due to a lower body temperature, and may be vulnerable to smaller mammalian predators such as striped skunks and possibly even short-tailed shrews (Burger and Zappalorti, 1992).

Hatchling pine snakes and pine snake nests/eggs are susceptible to a wider range of predators due to either their small size or immobility (eggs). In their 15-year study on subterranean predation on pine snakes, Burger and Zappalorti (1992) found that 42 of the 201 nests (21%) in their study were depredated by foxes. Seven nests were depredated by striped skunks, and a scarlet snake was observed eating eggs from one nest. Interestingly, the rate of predation on pine snake nests from natural predators was actually slightly less than that of human poaching, 25% vs. 29%.

Placing large pieces of chain fence over pine snake nests may be a practical, small-scale solution to reduce the rate of nest predation by natural predators. This technique prevents large and medium-sized predators from being able to dig up the nest and depredate the eggs. However, this method has the potential to unintentionally increase the incidence of poaching by visually drawing attention to the location of nests. Researchers at the Lakehurst Air Force Base (Lakehurst, NJ) have been using this method for the past several years and have found that it prevents natural predators from excavating pine snake nests (Farrell, personal communication 2009). The effectiveness of this technique in areas without restricted access (like military bases) is questionable due to poaching and therefore reducing nest predation on a broad scale throughout the Pinelands using this method seems unlikely.

Hatchling snakes are vulnerable to predation both above ground and during hibernation. Short-tailed shrews have been documented eating hatchling pine snakes within their hibernacula by Burger and Zappalorti (1992). Because of their small size, hatchling pine snakes may also be susceptible to subsidized predators such as free-roaming cats. While we have seen no published literature documenting that free-roaming cats depredate hatchling pine snakes, cats have been documented to kill garter snakes, northern rough green snakes, northern brown snakes, eastern worm snakes, black rat snakes, and other reptiles (Bonnaud et al., 2007; Dewey, 2009; NEPARC, 2009). Hatchling pine snakes are smaller than these snake species so it seems quite probable that cats are capable of killing a hatchling, or even a juvenile, pine snake.

Among the predators known to prey on northern pine snakes, several are species that biologists have recognized can become “subsidized” predators. Subsidized predators are predatory animals whose survival and reproduction are enhanced by the intentional or inadvertent provisioning of food by people (Boarman, 1997). As a result, many subsidized predators (e.g., coyotes, red foxes, opossums, striped skunks, raccoons and feral cats) appear to adjust to suburban, and in some cases urban, development (DeStafano and Johnson, 2005) and species like cats have been shown to increase in number in areas adjacent to development (Hansen et al., 2005). We believe that the predation pressures that pine snakes are experiencing from subsidized predators is likely increasing over time as development increases in the Pinelands. However, further investigation is needed to assess which predators increase in these urban fringe areas and whether, as a result, predation pressure on northern pine snakes is increasing significantly.

- **Effects of Roads**

Roads often negatively impact wildlife through both direct and indirect effects. When suitable wildlife habitat is replaced with asphalt during the construction of a paved roadway, direct impacts have occurred in the form of habitat loss. Simply put, road construction removes suitable habitat and replaces it with an impervious surface that is unsuitable for wildlife. Usually, however, the actual amount of habitat that is lost during the construction of a road is less damaging to wildlife than the roadside mortality and numerous secondary impacts that result following construction (Sherwood et al., 2002). The secondary impacts created by roads include: population isolation, changes in temperature gradients, increased sedimentation, increased human access, chemical pollution, and vehicle disturbance (Forman et al., 2003). Within the core pinelands many of the roads are not paved (sand roads) and most are only lightly traveled, although a few do have moderate traffic levels. Many sand roads may occasionally be part of the route for "enduro" motorcycle events. This could result in 500 or more motorbikes legally traveling sand roads that are part of an approved enduro course in a single afternoon. However, these events are relatively infrequent and typically last 1-2 days. The impacts that enduro events have on plants and wildlife in the Pinelands have not yet been evaluated, but all sand roads, despite their traffic densities, affect wildlife in both direct and indirect ways.

Direct mortality:

Pine snakes are subject to road mortality in New Jersey. This is evident from reviewing the Biotics database and from other incidental reports of "Dead-on-Road" (DOR) pine snakes. Of the 536 pine snakes occurrences in the Biotics database, 120 records (23%) submitted were from DOR snake sightings. Caution should be used when interpreting this number, however, because DOR snakes may be more likely to be observed and reported to the NJDEP than snakes occurring in the middle of a large forest patch (for example); DOR snakes can be easily observed by passing motorists.

Potential sampling biases aside, these data do show that snakes are being killed along roadways and highlight the level of threat that roads might present to pine snakes.

Our data show that even when land preservation has eliminated the threat of development in a particular area, roadside mortality still takes a toll on a local population of pine snakes. For example, County Route 539 bisects the New Jersey Pinelands heading northwest from Tuckerton, NJ to Allentown, NJ. A considerable amount of permanently preserved open space exists along this road. One particular 6.5-mi stretch of this road is bound on both sides by the state-owned Greenwood Wildlife Management Area. Between 1990 and 2006, a total of 12 DOR pine snakes were recorded along this 6.5-mi stretch of road.

Additional incidental DOR data has been collected and made available to NJDEP by Robert Zappalorti (Zappalorti, unpublished data 2006). In his travels throughout the Pinelands between 1977 and 2006, Zappalorti has been recording DOR sightings of snakes. He reported a total of 49 DOR pine snakes, 30 DOR corn snakes, and 38 DOR timber rattlesnakes. All of these snakes are listed species in the state and Zappalorti's data supports our finding that road mortality is a factor that must be included in any discussion about threats to the long-term viability of these species.

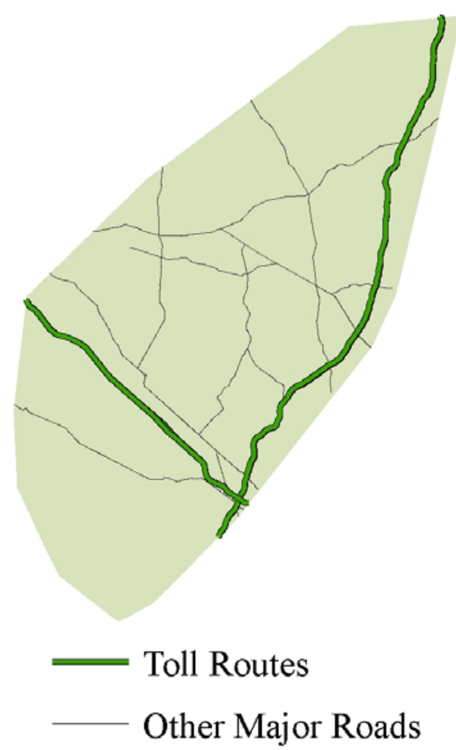


Figure 13. Map of the pine snake's historic range showing distribution of major roads. Toll roads (green) likely create complete barriers to snake movement.

Isolating effects of roads:

Roads can also serve to isolate populations, especially for small or slow moving animals (Forman et al., 2003). Isolation from roads can result in decreased genetic flow, decreased resource availability, difficulty in finding mates or reproducing (e.g., finding suitable nest sites) and increase the potential for local "extinction" at the patch level (Gotelli, 1995; Forman et al., 2003). Andrews and Gibbons (2005) tested the avoidance of roads exhibited by snakes and estimated the probability of mortality along roads for three snake species at varying traffic levels. They found that smaller snake species were more likely to avoid roads entirely, compared to large snake species. However, larger snakes were still either deterred from crossing or did not attempt to cross roads in 35% - 75% of their trials (*Coluber constrictor* 35%, *Crotalus horridus* 75%). Even though the northern pine snake was not included as part of this study, we believe that it would likely fall within this range based on its similarity in size (Schwartz and Golden, 2002). The Andrews and Gibbons study also estimated the probability of mortality for large snakes attempting to cross roads at different traffic densities. At a traffic density of 2,000 vehicles/day (1.4 vehicles/min) the probability of mortality ranged from ~ 30% to 80%. As traffic density increased so did the probability of mortality. At densities of 15,000 vehicles/per day (10.4 vehicles/min) estimated mortality rates were 100% for two species (*Crotalus horridus* and *Elaphe obsoleta*) and ~ 82% for *Coluber constrictor* (Andrews and Gibbons, 2005). The Garden State Parkway and Atlantic City Expressway are two toll roads within the pine snakes' range in New Jersey that far exceed a traffic density of 15,000 vehicles/day (Figure 13, Table 2). These are heavily traveled roads with at least two lanes running in each direction. Therefore, any snake attempting to cross would have to navigate a minimum of four lanes of high volume traffic. We believe these roads create a complete barrier to pine snake movement and functionally divide the New Jersey pine snake population into at least three discrete populations (Figure 13). Further division of the pine snake population is likely when data available from New Jersey Department of Transportation (reported as Average Annual Daily Traffic estimates) is considered on Route 30, Route 322, and Route 72 (NJDOT, 2009; Table 2). Along these roads, traffic volumes also exceed the 15,000 vehicles per day threshold reported by Andrews and Gibbons (2005). We think that County Routes 539, 563, 679 and 532, and State Routes 70, 49, and 40 have a similar, but less adverse, isolating effect; traffic data for some of these roads is also presented in Table 2.

NJDOT data also show that traffic volumes have increased along many roads in the Pinelands over the past ten years (NJDOT, 2009). This finding supports our general observation about traffic densities increasing in the Pinelands over time, especially during the summer months, as more and more people cross through the Pinelands on their way to and from New Jersey's Atlantic Coast. Patterns of increasing traffic are an important consideration for pine snakes because as traffic volume increases so does the isolating effect that roads have on pine snakes and other snake species (Andrews and Gibbons, 2005).

Pine snakes (and snakes in general) are more susceptible to mortality along roads and the isolating effects of roads than species with greater dispersal abilities (such as birds and large mammals). Unlike endothermic mammals and birds, pine snakes will often bask on the warm asphalt of roads on cool mornings in an effort to increase their body temperatures. This can be a deadly behavior as it makes them very vulnerable to being killed by vehicular traffic, even on roads with low traffic

Table 2. Traffic Volumes expressed as Average Annual Daily Traffic (AADT) for various roads and for various sampling periods within the northern pine snakes historic range in New Jersey.

					Past Data			Most Recent Data		
Road	**Location**	**County**	**Municipality**	**DOT Station ID**	**Year**	**Sample Period**	**AADT**	**Year**	**Sample Period**	**AADT**
AC Expressway	Btwn 8th ST OVERPASS & NJ 54	Atlantic	Hamilton	9-4-309				2007	May	40,847
AC Expressway	Btwn CO 670 (INT. 14W) AND NJ 50	Atlantic	Hamilton	9-4-308				2007	May	39,895
GS Parkway	At BARNEGAT TOLL PLAZA	Ocean	Barnegat	9-2-104				2000	Full year	29,854
GS Parkway	At NEW GRETNA TOLL PLAZA	Burlington	Bass River	9-2-103				2000	Full year	20,358
Route 30	Btwn LAKEVIEW RD & RT 561	Atlantic	Mullica	8-5-058	2004	Oct	13,589	2007	Aug	18,290
Route 322	About 0.3 MILE WEST OF BIG DITCH	Atlantic	Hamilton	8-4-214				2005	Nov	17,249
Route 322	Btwn Luther St & Battle RD, WIM	Gloucester	Monroe	7-1-33	1997	Full year	14,864	2000	Full year	17,032
Route 72	Approx 1.7 MILE NW OF GSP	Ocean	Stafford	6-6-017				2007	Aug	16,627
Route 55	Btwn NJ 47 & SCHOONER LANDING RD	Cumberland	Maurice River	8-4-309				2005	Sep	13,858
New York Rd	Btwn Green Bush Rd & Jacobs Creek	Burlington	Bass River	8-1-29	1999		10,374	2000		13,197
Route 70	Btwn RT 539 & HILLTOP RD	Ocean	Manchester	6-4-322	2000	Sep	10,916	2006	Mar	11,504
Route 70	Btwn Vincetown-South Park & MILL RDS	Burlington	Southampton	7-4-318	1999	Sep	10,395	2008	Feb	11,089
Route 539	Btwn NJ 70 & CO 14, Horizon Ave	Ocean	Manchester	6-4-454	2005	Apr	9,107	2008	Aug	10,672
Route 49	Just East of Hesstown	Cumberland	Maurice River	8t5c004				2000	Jul	10,244
Route 72	Btwn Four Mile Rd & Pakim Pond Road	Burlington	Woodland	7-1-29	1997	Full year	6,476	2000	Full year	9,401
Nugenttown Rd	Btwn GIFFORDTOWN & BRIDGE RDS	Ocean	Little Egg Harbor	6-4-678	1999	Apr	2,553	2005	Apr	3,648

volume. On highly used roads, pine snakes can be physically unable to successfully cross a road due to high traffic volumes (pauses in traffic are not long enough for snakes to make it across the road without being run over). In these situations, a road creates a complete and impassable barrier to snakes. The same road would not present a complete (and possibly not even a minor) barrier to movement of birds since individuals of this animal group are capable of simply flying over the traffic that impedes a snake's movement.

- **Fire Suppression and Habitat Change**

The New Jersey Pinelands have a long history of fire that has played a major role in shaping this ecosystem (Little, 1979; Boyd, 1991). In 1906, when the New Jersey Fire Service was established, its main responsibility was to control and contain wildfires, thereby lowering the risk of wildfires causing harm to human health or property (New Jersey Forest Fire Service, 2009). This history of fire suppression continues to this day, but different techniques of "control" and suppression are used. Since 1948, the New Jersey Forest Fire Service has been using prescribed, or controlled, burning in the Pinelands to reduce fuel loads (New Jersey Forest Fire Service, 2009). Prescribed burning most often take place on state and federal lands in this region; fewer acres of private lands are burned for hazard control (New Jersey Forest Fire Service, 2009). Fuel reduction and hazard control are the primary reasons for much, if not all, of the prescribed burning that takes place in the Pinelands. Most burning activities occur around dirt and paved roads in an effort to create larger "fuel breaks" that would help to contain wildfires should they occur. Core (or interior) areas of forest are not only excluded from prescribed burns, but prescribed burning in adjacent areas reduces the natural incidence of fire in core forests. Therefore, most areas of core forest are left to develop through successional stages in the absence of fire, which leads to changes in the structure and species composition of these areas.

The question of fire suppression and its effects on habitat suitability for pine snakes is one that deserves additional study. At the Warren Grove Air National Guard Base (Warren Grove, NJ) very large blocks of forest are regularly burned to reduce the likelihood of wildfires moving off the base from routine base activities (Warren Grove INRMP 2008). This regularity of burning may closely mimic the historic frequency of burning for this region as described by Little (1979). Pine snake research has been ongoing at the Warren Grove base for the past six years under the direction of

Walter Bien, PhD, of Drexel University. While Bien's research group has found a fairly high density of pine snakes in these regularly burned areas, no direct tie to the frequency of burning and snake density has been made (Bien, personal communication 2009).

The size and frequency of natural fires in the Pinelands has decreased over the past several decades (Forman and Borner, 1981) and this altered natural fire regime has resulted in a general decline in open-canopy / bare mineral soils habitats, reducing habitat (Windisch, 1999). This pattern is tied to a general concern over how fire suppression may threaten pine snake habitat over time. Unburned, pinelands plant communities tend to change in a way that benefits oak (*Quercus*) over pine (*Pinus*) and develop into closed canopy forests with a smaller shrub component (Little 1979). These patterns reduce the suitability of the habitat for pine snakes based on field observation of habitat use (Zappalorti et al., 1983; Burger and Zappalorti, 1986; Smith and Bien, 2005) and predictive models (Appendix IV).

In our statistically-based habitat model (STAT_MOD) described in Appendix IV, two of the key elements that best predicted pine snake presence were the presence of coniferous-dominated forest and shrub communities. Furthermore, much of the decrease in pine snake habitat modeled from 1986 to 2007 (Figure 7A) was determined to be the result of LULC changing from either shrub communities to deciduous forests, or from coniferous-dominated forests to deciduous-dominated forests. One conclusion that can be drawn from this pattern is that, in the absence of habitat management (either natural or anthropogenic), key pine snake habitats may be lost even on permanently preserved lands (Bailey et al., 2006).

- **Off-road Vehicle Use**

Although illegal on public lands, the use of off-road vehicles (ORVs) on state and federal lands in the Pinelands is, nonetheless, widespread. Large stretches of sand roads and an extensive network of firebreak trails contribute to the access that ORVs have into core portions of forests and sensitive areas. In 2002, the NJDEP reported that illegal ORV activities accounted for approximately 343,000 acres of habitat damages to state park, forest and wilderness land in New Jersey (NJDEP, 2002). Research has shown that ORV use is often damaging to both plant and animal communities (Taylor, unpublished data, 2009). Physical disturbance to habitats, underground burrows, nests, and the disturbance created from ORV noise are the primary impacts (Bondello, 1979; Luckenbach and Bury, 1983).

ORV activity in the Pinelands adversely affects the use of hibernacula and can reduce pine snake hatchling success. In a study conducted by Burger et al. (2007), it was demonstrated that fewer pine snakes used hibernacula during years when ORV activity occurred in the area. A similar pattern existed for pine snake hatchling success (percentage of young in nests); hatchling success was higher in years without ORV activity than those in which ORV activity occurred. The authors reported on "squashed" hatchling pine snakes in ORV tracks and suggest that ORVs could have the following effects on pine snake reproductive success: 1) females could be run over and killed while they are excavating nests in open sandy areas, 2) eggs could be crushed, or hatchlings could be killed if females continue to nest in open areas in spite of the ORV use, 3) females might abandon optimal nesting sites due to ORV activity and settle for nesting along the forest edge; this could lower hatchling success due to decreased sun exposure and lower nesting temperatures (Burger, 1989), 4) hatchlings may be more susceptible to predation as they move across an opening that has been denuded of vegetation from ORV use (Burger et al., 2007).

The sandy soils and open canopy characteristics of pine snake nesting habitats provide favored conditions for ORV riders, who enjoy the bare loose sand and open, treeless landscape these areas provide. One of the first principles in managing for a species, whether it is common or rare, is to protect its breeding areas and breeding individuals. We see examples of this through the State's structured hunting and fishing seasons (with open seasons being set outside of breeding periods), the State's vernal pool regulations (which are in place to protect amphibian breeding ponds), the Federal Migratory Bird Treaty Act (which makes it unlawful to disturb the nest of *any* bird species), and New Jersey protections of salt marsh and estuarine areas (which serve to maintain fish "nurseries"). As with other species, protecting the nests and nesting habitats of pine snake are a paramount component in its management. However, the "high and dry" characteristics of the pine snake's nesting habitat make this species uniquely vulnerable to ORV activity since, in many cases, nesting habitats are actually targeted by these threats.

In their 2009 Recreation Vehicle Assessment for the Northeast and Midwest, the East Coast Four Wheel Drive Association, Inc. states that participation and memberships in four-wheel drive clubs has steadily increased in the Northeast since the 1960's (East Coast Four Wheel Drive Association, Inc., 2009). From a table contained within their report, we calculated that there has actually been an increase of 1,700% in memberships to these clubs since the pine snake was listed as threatened in New Jersey. Similarly, the U.S. Forest Service reports that ORV riding is one of the fastest growing recreational activities, with an estimated 19% increase in participants, and a 56% increase in the total number of days used annually from 2000 to 2007 (Cordell et al., 2009). If this is any indication of the trend of ORV "use" in New Jersey, then the threat of ORVs on pine snakes has likely increased since the time this species was given its threatened status. The threats that ORV activity in the Pinelands pose to pine snakes are similar to the threats of illegal collecting, in that land preservation does not abate them. In fact, similar to illegal collecting, land preservation may indirectly increase this activity as ORV users feel that they have the right of access to state and federally owned lands despite the illegal nature of ORV use on these properties.

Summary

Our assessment and review of northern pine snakes reveals that pine snakes and their habitats are facing numerous threats in New Jersey and in the remainder their U.S. range. The New Jersey population of pine snakes is extremely isolated from all other populations of this species, with roughly 645 km (400 mi) separating it from the next closest population in southern North Carolina. As noted, populations with this type of distribution are inherently at greater risk than populations with more continuous distributions. This distribution also makes it virtually impossible that New Jersey habitats would be re-colonized naturally if our portion of the U.S. population was extirpated. Results from our investigation suggest that the regional isolation of New Jersey's pine snake population has increased from historic levels (even within the past 25 years), as range reductions (and likely extirpations; WV and VA) have occurred within nearly all states in which this species historically occurred (with North Carolina a possible exception).

Northern pine snakes have life-history characteristics that make them inherently more vulnerable than other species to most, if not all, of the threats that we have been described in this assessment. Pine snakes are long-lived, large-bodied snakes that have slow development and delayed reproduction. These factors, along with their limited dispersal ability and nest-site habitat specialization, make pine snakes very susceptible to the threats of habitat loss (both natural and anthropogenic), human-induced mortality (e.g., mortality along roads, subsidized predators, and illegal collecting), and habitat disturbance (e.g., ORV use). Our analysis shows that within New Jersey a wide range of threats exist, and that many of these threats are increasing. Traffic densities along existing roads show increasing numbers over time and the isolating effects that roads have on populations are increasing along with traffic densities. The data we were able to obtain on ORV use/interest suggests that this threat is also increasing. Threats of illegal collection, loss of suitable habitat to development or natural succession (partially as a result of fire suppression), and natural predation continue to exist for pine snakes in New Jersey, and pressures from subsidized predators are likely increasing as development continues in the Pinelands region.

Open space protection efforts have successfully preserved nearly 37% of the habitat within the pine snake's historic New Jersey range and anywhere from 54% to 60% of pine snake habitat modeled using 2007 LULC data. Despite this high level of land preservation, most of the threats described in this document exist independent of land preservation, and some threats may actually be more prevalent on preserved lands. Poaching and ORV activities are believed to be widespread on state and federal lands due to unlimited public access, and adversely affect nesting success of pine snake and remove adults from the population. Road mortality and the isolating effects that roads have on snake populations also operate independently of land preservation. From our summary of daily traffic data, we suggest that at least four major roads (Garden State Parkway, Atlantic City Expressway, Route 30, and Route 322) create complete barriers to pine snake movement and divide pine snakes in New Jersey into five discrete populations that do not intermix; as traffic volumes increase with time more roads may also become complete barriers to movement. Natural and subsidized predation may also take place independent of land preservation, although there is likely a relationship between development and subsidized predator abundance. Finally, fire suppression efforts, widespread on public lands, are likely changing the vegetative community in a way that is unfavorable to pine snakes. Therefore, while land preservation efforts have protected a portion of pine snake habitat from the threat of development, these efforts have not, and by themselves cannot, remove many of the continuing threats to this species' survival.

Taken collectively, the patterns and documented threats that we have reported strongly justify the pine snake's existing legal status of "threatened" in New Jersey. The definition of a threatened species in New Jersey is, "a species that may become endangered if conditions surrounding the species begin or continue to deteriorate" (N.J.A.C. 7:25-4.1). Clearly, the conditions surrounding the pine snake population in New Jersey have already begun to deteriorate as a result of the threats outlined in this assessment (habitat loss, poaching, natural and subsidized predation, roads, fire suppression, and ORV activity). The maps in Figures 1 and 2 illustrate the isolation of the New Jersey pine snake population from other populations throughout the US. Given the level of existing threats to this species in the state, elevated protection and active management are required for its long-term persistence. If this species were lost from New Jersey it could not re-colonize the state without human intervention. Therefore, the New Jersey Division of Fish and Wildlife recommends that appropriate measures be taken to maintain the existing regulatory protection for pine snakes and to increase efforts to manage its habitat and, where possible, reduce threats to its long-term viability in New Jersey.

Appendix I

Northern Pine Snake Questionnaire

We are seeking responses from the following states: AL, GA, KY, MD, DE, NC, SC, TN, VA, and WV

1. Is the Northern Pine Snakes (*Pituophis m. melanoleucus*) thought or known to currently exist in your state?

"No" to Question #1

> a) What is the estimated date (year) of the last known siting?
> b) What is the current status of Northern Pine Snakes in your state?
> b) What factor(s) resulted in this species' extirpation from your state?
> c) Does your state have plans to survey for this species in the future?
> d) Do historic distribution maps for this species exist from your state? If yes, please provide if possible.

"YES" to Question #1

2) What is the current status of Northern Pine Snakes in your state?

3) Does the current status provide any special protection for this species? If so, Please describe.

4) When was the last time the status for this species was reviewed in your state?

5) Do you have a population estimate for this species in your state?

6) Are distributions maps available for Northern Pine Snakes in your state? If so, can you provide copies?

7) Do you actively manage for this species in your state? If so, please describe recent management activities.

8) Are publications on this species available from your state?

Completed by:

Title and Affiliation:

State:

Date:

Appendix II

Protocol for Accepting or Rejecting Species Sighting Reports.

1. When a sighting report arrives at the ENSP office it is logged in and tracked in a database, regardless of acceptability.
2. If no additional information is needed, the sighting report is sent to the appropriate ENSP biologist for review.
3. If additional information is needed, an attempt is made to obtain the required information. This can include sending a map to the observer to mark the location of the sighting, a telephone interview to clarify information, etc. After all of the required information is obtained the report is sent to the appropriate ENSP
biologist for review.
4. ENSP biologist receives the sighting report and reviews it for acceptability/reliability. A species sighting is accepted or rejected based on the following criteria:

- Did the sighting occur within the known range of the species?
- Did the sighting occur in the known/recognized habitat for the species?
- Is the species easily identified, or is it often confused with another?
- Did anyone else confirm the sighting, or can someone else vouch for the observer's identification skills?
- Do we have first-hand knowledge of the observer's identification skills?
- Did the observer include a photograph?
- Is the species listed as endangered, threatened or special concern for the season in which it was reported? (Some species can have a separate status for breeding season and non-breeding season.)
- If uncertainty remains about the validity of the sighting, the observer is interviewed by the ENSP biologist.

a. If sufficient information accompanies the sighting report the record is either accepted or rejected by an ENSP biologist.
b. If accepted, the reviewing biologist assigns the sighting a feature label and determines whether the sighting should be used in the Landscape Project. For some species, only occurrences assigned specific feature labels are included in the Landscape Project. For example, for many of the raptors a sighting of a migrating bird may be considered valid, but not for inclusion in the Landscape Project. The report is then returned to ENSP's GIS staff and advances to step 5 if accepted.
c. The reviewing biologist may determine that it is necessary to gather additional information (e.g., ascertain observer experience, ask if there have been additional sightings, ask for photos, ask for verifications by second observer, etc.) before the record can be accepted. If the record is accepted, advance to step 5.
d. If the reviewing biologist determines that the sighting must be field checked, it is initially rejected until fieldwork can be scheduled to verify the sighting.
5. ENSP GIS staff digitizes the sighting location and prepares the data in a standardized format to enter into the Biotics database.
6. ENSP staff perform a quality check of the documentation, mapping and data entry before the record is complete and filed.

Appendix III

NJDEP 2002 Land-use/Land Cover Descriptions

(For complete details on New Jersey 2002 LU/LC data consult the DEP's website: http://www.nj.gov/dep/gis/lulc02shp.html)

LU02	*TYPE02*	*LABEL02*
1110	URBAN	RESIDENTIAL, HIGH DENSITY OR MULTIPLE DWELLING
1130	URBAN	RESIDENTIAL, SINGLE UNIT, LOW DENSITY
1140	URBAN	RESIDENTIAL, RURAL, SINGLE UNIT
1150	URBAN	MIXED RESIDENTIAL
1200	URBAN	COMMERCIAL/SERVICES
1211	URBAN	MILITARY INSTALLATIONS
1214	URBAN	FORMER MILITARY, INDETERMINATE USE
1300	URBAN	INDUSTRIAL
1400	URBAN	TRANSPORTATION/COMMUNICATION/UTILITIES
1410	URBAN	MAJOR ROADWAY
1419	WATER	BRIDGE OVER WATER
1440	URBAN	AIRPORT FACILITIES
1461	WETLANDS	WETLAND RIGHTS-OF-WAY
1462	URBAN	UPLAND RIGHTS-OF-WAY DEVELOPED
1463	URBAN	UPLAND RIGHTS-OF-WAY UNDEVELOPED
1499	URBAN	STORMWATER BASIN
1500	URBAN	INDUSTRIAL/COMMERCIAL COMPLEXES
1600	URBAN	MIXED URBAN OR BUILT-UP LAND
1700	URBAN	OTHER URBAN OR BUILT-UP LAND
1710	URBAN	CEMETERY
1711	WETLANDS	CEMETERY ON WETLAND
1741	URBAN	PHRAGMITES DOMINATE URBAN AREA
1750	WETLANDS	MANAGED WETLAND IN MAINTAINED LAWN GREENSPACE
1800	URBAN	RECREATIONAL LAND
1804	URBAN	ATHLETIC FIELDS (SCHOOLS)
1810	URBAN	STADIUM THEATERS CULTURAL CENTERS AND ZOOS
1850	WETLANDS	MANAGED WETLAND IN BUILT-UP MAINTAINED REC AREA
2100	AGRICULTURE	CROPLAND AND PASTURELAND
2140	WETLANDS	AGRICULTURAL WETLANDS (MODIFIED)
2150	WETLANDS	FORMER AGRICULTURAL WETLAND (BECOMING SHRUBBY, NOT BUILT-UP)
2200	AGRICULTURE	ORCHARDS/VINEYARDS/NURSERIES/HORTICULTURAL AREAS
2300	AGRICULTURE	CONFINED FEEDING OPERATIONS
2400	AGRICULTURE	OTHER AGRICULTURE
4110	FOREST	DECIDUOUS FOREST (10-50% CROWN CLOSURE)
4120	FOREST	DECIDUOUS FOREST (>50% CROWN CLOSURE)
4210	FOREST	CONIFEROUS FOREST (10-50% CROWN CLOSURE)
4220	FOREST	CONIFEROUS FOREST (>50% CROWN CLOSURE)
4230	FOREST	PLANTATION
4311	FOREST	MIXED FOREST (>50% CONIFEROUS WITH 10-50% CROWN CLOSURE)
4312	FOREST	MIXED FOREST (>50% CONIFEROUS WITH >50% CROWN CLOSURE)

LU02	TYPE02	LABEL02
4321	FOREST	MIXED FOREST (>50% DECIDUOUS WITH 10-50% CROWN CLOSURE)
4322	FOREST	MIXED FOREST (>50% DECIDUOUS WITH >50% CROWN CLOSURE)
4410	FOREST	OLD FIELD (< 25% BRUSH COVERED)
4411	FOREST	PHRAGMITES DOMINATE OLD FIELD
4420	FOREST	DECIDUOUS BRUSH/SHRUBLAND
4430	FOREST	CONIFEROUS BRUSH/SHRUBLAND
4440	FOREST	MIXED DECIDUOUS/CONIFEROUS BRUSH/SHRUBLAND
4500	FOREST	SEVERE BURNED UPLAND VEGETATION
5100	WATER	STREAMS AND CANALS
5200	WATER	NATURAL LAKES
5300	WATER	ARTIFICIAL LAKES
5410	WATER	TIDAL RIVERS, INLAND BAYS, AND OTHER TIDAL WATERS
5411	WATER	OPEN TIDAL BAYS
5420	WATER	DREDGED LAGOON
5430	WATER	ATLANTIC OCEAN
6111	WETLANDS	SALINE MARSH (LOW MARSH)
6112	WETLANDS	SALINE MARSH (HIGH MARSH)
6120	WETLANDS	FRESHWATER TIDAL MARSHES
6130	WETLANDS	VEGETATED DUNE COMMUNITIES
6141	WETLANDS	PHRAGMITES DOMINATE COASTAL WETLANDS
6210	WETLANDS	DECIDUOUS WOODED WETLANDS
6220	WETLANDS	CONIFEROUS WOODED WETLANDS
6221	WETLANDS	ATLANTIC WHITE CEDAR WETLANDS
6231	WETLANDS	DECIDUOUS SCRUB/SHRUB WETLANDS
6232	WETLANDS	CONIFEROUS SCRUB/SHRUB WETLANDS
6233	WETLANDS	MIXED SCRUB/SHRUB WETLANDS (DECIDUOUS DOM.)
6234	WETLANDS	MIXED SCRUB/SHRUB WETLANDS (CONIFEROUS DOM.)
6240	WETLANDS	HERBACEOUS WETLANDS
6241	WETLANDS	PHRAGMITES DOMINATE INTERIOR WETLANDS
6251	WETLANDS	MIXED WOODED WETLANDS (DECIDUOUS DOM.)
6252	WETLANDS	MIXED WOODED WETLANDS (CONIFEROUS DOM.)
6500	WETLANDS	SEVERE BURNED WETLANDS
7100	BARREN LAND	BEACHES
7200	BARREN LAND	BARE EXPOSED ROCK, ROCK SLIDES, ETC.
7300	BARREN LAND	EXTRACTIVE MINING
7400	BARREN LAND	ALTERED LANDS
7430	WETLANDS	DISTURBED WETLANDS (MODIFIED)
7500	BARREN LAND	TRANSITIONAL AREAS
7600	BARREN LAND	UNDIFFERENTIATED BARREN LANDS

Appendix IV

Model Methodologies

I. STAT_MOD

We selected pine snake occurrences (N = 122) with precise location information that were observed between 1998 and 2006 to include in the model building. We built a minimum convex polygon around these used points using the Hawths Analysis Tools for ArcGIS (Beyer, 2004) to define the study area. We used the Hawths Analysis Tools to randomly generate a set of 122 points within the study area for comparison with the 122 used locations. These randomly generated sites were created a minimum of 1000-m away from the nearest used location to act as a surrogate for unused locations. We constructed 500-m radius buffers, centered on the used and unused locations.

We created habitat data files for vegetative and soil composition. The vegetation data sets were derived from the 2002 Land Use Land Cover layer (2002 LULC) (NJDEP GIS), and the soil composition data sets were derived from SSURGO soil layers (2008 NJDEP/NRCS). We extracted vegetation and soil categories and converted each into raster datasets with 10-m pixels to ease computation time. All Urban classes (2002 LULC) were removed from the soil data sets. We then quantified the habitat attributes within each of the used and unused buffered sites using GIS.

We explored relationships of habitat parameters and eliminated variables that were multicollinear or invariant. We also calculated point biserial correlations for each variable in relation to whether it was associated with a used or unused location to get an idea of which variables alone were most correlated with presence/absence. We built models using logistic regression in SPSS 10.0 (SPSS Inc., Chicago, Illinois), with the binary response variable of presence or absence and the habitat variables for every combination of the variables. We split the data set randomly using 3/4N (N = 91) to build the models and 1/4N (N = 31) to test the models.

We selected the best model based on classification success of used and unused locations by comparing the predicted values from the logistic regression models with a probability cut-off value, which distinguished suitable from unsuitable habitat. We calculated classification error rates by comparing the output of the logistic regression models, or the probability of presence values of each of the used and unused locations, with a probability cut-off value that distinguishes suitable vs. unsuitable habitat. We estimated the optimal probability cut-off value as the value for which most used locations are correctly classified while minimizing the number of unused locations that are incorrectly classified (Pereira and Itami, 1991). We erred slightly on the side of false positives when determining the cut-off value. We used GIS to predict relative probability of selection by pine snakes for every possible buffer in the historic northern pine snake range in New Jersey, based on the final habitat models, classifying the predicted probability of presence, (w(x)), into suitable and unsuitable habitat based on the optimal cut-off value.

A subset of roads defined by ENSP as “major roadways” (Interstate Highways, U.S. Routes, NJ State Highways, Toll Authority Routes and 500 and 600 Series County Routes) were erased out of the final STAT_MOD habitat maps. The NJ Department of Transportation (DOT) Major Roadways (2008) are stored as a GIS line file representing the centerline of the roadways. These line files were buffered, creating a polygon. Roadway lines classified as 500 and 600 Series County Routes were buffered by 25 feet, while lines classified as Interstate Highways, U.S. Routes, NJ State Highways and Toll Authority Routes were buffered by 37.5 feet. These road widths were determined by randomly selecting roads and averaging measured widths using the 2002 aerial imagery.

STAT_MOD RESULTS

The best model based on classification success of the validation data set (1/4N), correctly classified 77% (24/31) used locations and 65% (20/31) of unused locations. The model correctly classified 97% (30/31) of buffered used locations and 45% (14/31) of buffered unused locations. The final model (Table 1) predicts that pine snakes select habitat with pine-dominated forest cover and with extremely well-drained soils (Table 2) covering at least 10% of the area.

Appendix IV; Table 1. Final pine snake habitat selection model. Model coefficient (B) and standard error of the coefficient (SE), and probability value (P) are shown for each variable that remained in the model.

Variable	B	SE	P
Shrub Habitat	0.051	0.016	0.001
Pine-Dominated Forest	0.027	0.007	0.000
Extremely Well Drained Soils >10%	1.014	0.347	0.003
Constant	-1.685	0.350	0.000

II. Species Based Patches (SBP)

We selected the same set of pine snake occurrences (N = 122) observed between 1998 and 2006 for the SBP model building as we did for the STATS_MOD. We constructed 500 m radius buffers (SOAs) centered on these occurrences and selected out 3/4N (N = 91) for the model building. The remaining 1/4N (N = 31) was used to validate the model when complete in conjunction with unused locations (N = 31) generated for the STATS_MOD model building/validation. The model building SOAs were dissolved together generating SOA clumps that served as the sampling units. We clipped the 2002 NJDEP LULC by the SOA clumps and summarized the LULC by the percentage of LU02 within the clumps to serve as the used habitat. Using the Historic Range (HR) of the northern pine snake we clipped the 2002 NJDEP LULC and summarized the LULC by the percentage of LU02 within the HR to serve as the available habitat. Next we compared the percentage of LULC within the HR of the pine snake compared (available habitat) to the percentage LULC within the SOA clumps (used habitat). Using these data and knowledge of habitat requirements we selected certain LULC types (Table 2) that represented the northern pine snake habitat requirements.

This subset of LULC polygons was selected and dissolved/combined into species-specific patches of habitat. Next these patches were bisected using major roads. NJ Department of Transportation (DOT) Major Roadways (2008) are stored as a GIS line file representing the centerline of the roadways. A subset of roads defined by ENSP as “major roadways” (Interstate Highways, U.S. Routes, NJ State Highways, Toll Authority Routes and 500 and 600 Series

County Routes) were buffered, creating a polygon file to bisect LU/LC classifications and serve as a boundary between contiguous level 3 LU/LC classes.
Roadway lines classified as 500 and 600 Series County Routes were buffered by 25 feet, while lines classified as Interstate Highways, U.S. Routes, NJ State Highways and Toll Authority Routes were buffered by 37.5 feet. These road widths were determined by randomly selecting roads and averaging measured widths using the 2002 aerial imagery. The completed major roads polygon file was then combined with the 2002 LU/LC in order to bisect contiguous areas of habitat. The resulting patches of habitat are the species based patches for the northern pine snake.

SBP Results

The SBP model correctly classified 71% (22/31) of used locations and 68% (21/31) of unused locations. The model correctly classified 100% (31/31) of buffered used locations and 55% (17/31) of buffered unused locations. SBP method is similar to STAT_MOD in predicting the used habitat and values more of the unused habitat.

Appendix II; Table 2. The Level III classifications (NJDEP Modified Anderson System 2002) of 2002 Land Use Land Cover (top pane) making up the habitat variables (shrub habitat (□) and pine-dominated forest (□)) used in the final STAT_MOD and those used in the SBP model (□). Only the STAT_MOD model incorporated soil categories (SSURGO 2008; □) as habitat variables in the final model (bottom pane).

TYPE	LABEL	LU CODE	STAT_MOD	SBP
URBAN	UPLAND RIGHTS-OF-WAY UNDEVELOPED *	1463		□
FOREST	CONIFEROUS FOREST **	4200	□	□
FOREST	CONIFEROUS FOREST (10-50% CROWN CLOSURE)	4210	□	□
FOREST	CONIFEROUS FOREST (>50% CROWN CLOSURE)	4220	□	□
FOREST	PLANTATION	4230		□
FOREST	CONIFEROUS/DECIDUOUS FOREST **	4310	□	□
FOREST	MIXED FOREST (>50% CONIFEROUS WITH 10-50% CROWN CLOSURE)	4311	□	□
FOREST	MIXED FOREST (>50% CONIFEROUS WITH >50% CROWN CLOSURE)	4312	□	□
FOREST	MIXED FOREST (>50% DECIDUOUS WITH >50% CROWN CLOSURE)	4322		□
FOREST	BRUSHLAND/SHRUBLAND **	4400	□	
FOREST	OLD FIELD (< 25% BRUSH COVERED)	4410	□	□
FOREST	DECIDUOUS BRUSH/SHRUBLAND	4420	□	
FOREST	CONIFEROUS BRUSH/SHRUBLAND	4430	□	□
FOREST	MIXED DECIDUOUS/CONIFEROUS BRUSH/SHRUBLAND	4440	□	□
FOREST	SEVERE BURNED UPLAND VEGETATION ***	4500		□
WETLANDS	ATLANTIC WHITE CEDAR WETLANDS	6221		□
WETLANDS	CONIFEROUS SCRUB/SHRUB WETLANDS	6232		□
WETLANDS	MIXED SCRUB/SHRUB WETLANDS (CONIFEROUS DOM.)	6234		□
WETLANDS	SEVERE BURNED WETLANDS ***	6500		□
BARREN LAND	EXTRACTIVE MINING	7300		□
BARREN LAND	UNDIFFERENTIATED BARREN LANDS	7600		□
DRAINAGE CLASS - DOMINANT CONDITION	**MAP UNIT NAME**	**MU SYMBOL**	**STAT_MOD**	**SBP**
EXCESSIVELY DRAINED	EVESBORO SAND, 0 TO 5 PERCENT SLOPES	EveB	□	
EXCESSIVELY DRAINED	EVESBORO SAND, 5 TO 10 PERCENT SLOPES	EveC	□	
EXCESSIVELY DRAINED	EVESBORO SAND, 10 TO 15 PERCENT SLOPES	EveD	□	
EXCESSIVELY DRAINED	EVESBORO SAND, 10 TO 30 PERCENT SLOPES	EveE	□	
EXCESSIVELY DRAINED	EVESBORO SAND, LOAMY SUBSTRATUM, 0 TO 5 PERCENT SLOPES	EvehB	□	
EXCESSIVELY DRAINED	EVESBORO SAND, CLAYEY SUBSTRATUM, 0 TO 5 PERCENT SLOPES	EvekB	□	
EXCESSIVELY DRAINED	EVESBORO FINE SAND, 0 TO 5 PERCENT SLOPES	EvfB	□	
EXCESSIVELY DRAINED	EVESBORO FINE SAND, FIRM SUBSTRATUM, 0 TO 5 PERCENT SLOPES	EvfmB	□	
EXCESSIVELY DRAINED	LAKEWOOD SAND, 0 TO 5 PERCENT SAND	LasB	□	
EXCESSIVELY DRAINED	LAKEWOOD SAND, 5 TO 10 PERCENT SAND	LasC	□	
EXCESSIVELY DRAINED	LAKEWOOD SAND, 10 TO 15 PERCENT SLOPES	LasD	□	
EXCESSIVELY DRAINED	LAKEWOOD SAND, THICK SURFACE, 0 TO 5 PERCENT SLOPES	LasfB	□	
EXCESSIVELY DRAINED	LAKEWOOD SAND, LOAMY SUBSTRATUM, 0 TO 5 PERCENT SLOPES	LashB	□	
EXCESSIVELY DRAINED	LAKEWOOD FINE SAND, 0 TO 5 PERCENT SLOPES	LatB	□	
EXCESSIVELY DRAINED	LAKEWOOD FINE SAND, 5 TO 10 PERCENT SLOPES	LatC	□	
EXCESSIVELY DRAINED	LAKEWOOD FINE SAND, 10 TO 25 PERCENT SLOPES	LatD	□	
EXCESSIVELY DRAINED	LAKEWOOD FINE SAND, LOAMY SUBSTRATUM, 0 TO 5 PERCENT SLOPES	LathB	□	
EXCESSIVELY DRAINED	URBAN LAND, SANDY, 0 TO 8 PERCENT SLOPES	URSAAB	□	
EXCESSIVELY DRAINED	URBAN LAND-ADELPHIA COMPLEX, 0 TO 5 PERCENT SLOPES	USADEB	□	
EXCESSIVELY DRAINED	URBAN LAND-COLLINGTON COMPLEX, 0 TO 5 PERCENT SLOPES	USCOLB	□	

*UPLAND RIGHTS-OF-WAY UNDEVELOPED (1463) proved to be an imported class when developing the Species Based Patches. This class was not represented in the 1986 or 1995 LULC. The 2002 UPLAND RIGHTS-OF-WAY UNDEVELOPED polygons were unioned with the previous LULC (1986 & 1995) and areas were recoded as such. All of these areas were visually inspected and appear to meet the criteria of UPLAND RIGHTS-OF-WAY UNDEVELOPED.

** CONIFEROUS FOREST (4200), CONIFEROUS/DECIDUOUS FOREST (4310), and BRUSHLAND/SHRUBLAND (4400) are categories only represented in the 1986 LULC. In 1995, 2002, and 2007 these categories were broken down further and those subcategories were used for the 1995, 2002, and 2007 models.

*** SEVERE BURNED UPLAND VEGETATION (4500) and SEVER BURNED WETLANDS (6500) were not represented in the 1986 LULC and were not used in the 1986 habitat map.

REFERENCES

Anderson, JR, EE Hardy, JT Roach, and RE Witmer. 1976. A Land use Land Cover Classification System for use with Remote Senor Data. U.S. Geological Survey Professional Paper 964. 28 pp.

Andrén, H. 1994. Effects of habitat Fragmentation on Birds and Mammals in Landscapes with Different Proportions of Suitable Habitat: a Review. Oikos 71: 355-366.

Andrews, KM and JW Gibbons. 2005. How Do Highway Influence Snake Movement? Behavioral Responses to Roads and Vehicles. Copeia 2005: 772-782.

Bailey, MA, JN Holmes, KA Buhlmann, and JC Mitchell. 2006. Habitat Management Guidelines for Amphibians and Reptiles of the Southeast United States. Partners in Amphibian and Reptile Conservation Technical Publication HMG-2, Montgomery, AL. 88 pp.

Beyer, HL. 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools.

Boarman, WI. 1997. Predation on Turtles and Tortoises by a "Subsidized Predator." Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles—An International Conference, pp. 103–104.

Bondello, MC and BH Brattstrom. 1979. The Experimental Effects of Off-road Vehicle Sounds on Three Species of Desert Vertebrates (Report to the Bureau of Land Management, Part I, Part II, and Part III). California State University, Fullerton, CA. 134 pp.

Bonnaud, E, K Bourgeois, E Vidal, Y Kayser, Y Tranchant, and J Legrand. 2007. Feeding Ecology of a Feral Cat Population on a Small Mediterranean Island. Journal of Mammalogy 88(4):1074-1081.

Boyd, Howard P. 1991. A Field Guide to the Pine Barrens of New Jersey : its flora, fauna, ecology, and historic sites. Plexus Pub., Medford, New Jersey.

Burger, J. 1989. Effects of Incubation Temperature on Hatchling Pine Snakes: Implications for Survival. Behavioral Ecology and Sociobiology 43: 11-18.

Burger, J and RT Zappalorti. 1986. Nest Site Selection by Pine Snakes (*Pituophis melanoleucus*) in the New Jersey Pine Barrens. Copeia 1:116-121.

Burger, J and RT Zappalorti. 1988. Habitat Use in Free-ranging Pine Snakes (*Pituophis melanoleucus melanoleucus*) in the New Jersey Pine Barrens. Herpetologica 44(1): 48-55.

Burger, J, RT Zappalorti, M Gochfeld, W Boarman, M Caffrey, V Doig, S Garber, B Lauro, M Mikovsky, C Safina, and J Saliva. 1988. Hibernacula and Summer Den Sites of Pine

Snakes *(Pituophis melanoleucus)* in the New Jersey Pine Barrens. Journal of Herpetology 22(4):425-433.

Burger, J and RT Zappalorti. 1991. Nesting Behavior of Pine Snakes (*Pituophis melanoleucus*) in the New Jersey Pine Barrens. Journal of Herpetology 25(2):152-160.

Burger, J and RT Zappalorti. 1992. Philopatry and nesting phenology of pine snakes *Pituophis melanoleucus* in the New Jersey Pine Barrens. Behavioral Ecology and Sociobiology 30:331-336.

Burger, J, RT Zappalorti, J Dowdell, T Georgiadis, J Hill, and M Gochfeld. 1992. Subterranean Predation on Pine Snakes *(Pituophis melanoleucus)*. Journal of Herpetology 26(3): 259-263.

Burger, J, RT Zappalorti, M Gochfeld and E DeVito. 2007. Effects of Off-road Vehicles on Reproduction Success of Pine Snakes (*Pituophis melanoleucus*) in the New Jersey Pinelands. Urban Ecosystems. Springer Science. 10:275-284.

Byers, DL and JC Mitchell. 2005. Sprawl and Species with Limited Dispersal Abilities. *In*: Nature in Fragments, edited by: EA Johnson and MW Klemens. Columbia University Press, New York, NY. pp. 157-180.

Clark, KE, JE Applegate, LJ Niles, and DS Dobkins. 2006. An Objective Means of Species Status Assessment: Adapting the Delphi Technique. Wildlife Society Bulletin 34(2): 419-425.

Cordell, K, C Betz, G Green and S Mou. 2009. Recreation Demand Trends: an Update. Presentation: available at http://warnell.forestry.uga.edu/nrrt/nsre/index.html

Conant, R. 1975. A field guide to the reptiles and amphibians of eastern and central North America, 2nd edition. Houghton Mifflin, Boston.

Conant, R. 1979. A Zoogeographical Review of the Amphibians and Reptiles of Southern New Jersey, with Emphasis on the Pine Barrens. *In:* Pine Barrens: Ecosystem and Landscape, edited by: RTT Forman. Rutgers University Press, New Brunswick, NJ. pp 467-488.

Conant, R and JT Collins. 1991. Peterson Field Guide to Reptiles and Amphibians, Eastern and Central North America. 3rd Edition. Houghton Mifflin Company, Boston, Massachusetts.

Conant, R, JT Collins. 1998. A Field Guide to Reptiles and Amphibians of Eastern and Central North America. Third Edition, Expanded. Houghton Mifflin Company, New York, NY.

DeStafano, S and EA Johnson. 2005. Species that Benefit from Sprawl. *In*: Nature in Fragments, edited by: EA Johnson and MW Klemens. Columbia University Press, New York, NY. pp. 206-235.

Dewey, T. 2009. *Thamnophis radix,* Plains Garter Snake. University of Michigan Museum of Zoology. Online at: http://animaldiversity.ummz.umich.edu/site/accounts/information/Thamnophis_radix.html.

Dobson, AP. 1996. Conservation and Biodiversity. New York: Scientific American Library.
Drechsler, M and C Wissel. 1998. Trade-offs between local and regional scale management in metapopulations. Biological Conservation 81: 31-41.

East Coast Four Wheel Drive Association, Inc. 2009. Assessment of Four Wheel Drive Recreation in the Midwest & Northeast History and current state of the Sport Trail Use and Specialized Vehicle Construction Economic Impact of Back Country Recreation. Online Report: available at http://www.ec4wda.org/

Filippi, E and L Luiselli. 2000. Status of the Italian Snake Fauna and Assessment of Conservation Threats. Biological Conservation 93: 219-225.

Fahrig, L and G Merriam. 1994. Conservation of Fragmented Populations. Conservation Biology 8: 50-59.

Fitch, HS. 1999. A Kansas Snake Community: Composition and Changes over 50 years. Krieger Publishing Company. Malabar, FL. 105 pp.

Forman, RTT. 1979. Pine Barrens : ecosystem and landscape. Academic Press, New York, NY. 601 pp.

Forman, RTT and R Borner. 1981. Fire Frequency and the Pine Barrens of New Jersey. Bulletin of the Torrey Botanical Club 108:34-50.

Forman, RTT, D Sperling, JA Bissonette, AP Clevenger, CD Cutshall, VH Dale, L Fahrig, R France, CR Goldman, K Heanue, JA Jones, FJ Swanson, T Turrentine, and TC Winter. 2003. Road Ecology: Science and Solutions. Island Press, Washington, DC. 481 pp.

Gaston, KJ. 1994. Rarity. Chapman and Hall, London SE1 8HN, UK. 205 pp.

Gerald, GW, MA Bailey, and JN Holmes. 2006. Movements and Activity Range Sizes of Northern Pinesnakes (Pituophis melanoleucus melanoleucus) in Middle Tennessee. Journal of Herpetology, Vol. 40(4): 503-510.

Golden, DM and D Jenkins. 2003. Northern Pine Snake, *Pituophis melanoleucus melanoleucus*. *In:* Endangered and Threatened Wildlife of New Jersey. *Edited by:* BE Beans and L Niles. Rutgers University Press, New Brunswick, NJ.

Golden, DM. 2007. Species Occurrence Justification for the Northern Pine Snake. In Species Occurrence Area Version 5 Justifications. Endangered and Nongame Species Program. 2009-11-12. Trenton, NJ. Pages 247-248.

Golden, DM and TO Crist. 2000. Experimental Effects of Habitat Fragmentation on Rove Beetles and Ants: Patch Area or Edge? Oikos 90: 525-538.

Gotelli, NJ. 1995. A Primer of Ecology. Sinauer Associates, Sunderland, MA. 206 pp.

Grogan, WL Jr. and CM Heckscher. 2001. Are Northern Pine Snakes, *Pituophis m. melanoleucus*, Indigenous to Delaware? The Maryland Naturalist 44(1): 20-36.

Hansen, AJ, RL Knight, JM Marzluff, S Powell, K Brown, PH Gude, and K Jones. 2005. Effects of Exurban Development on Biodiversity: Patterns, Mechanisms, and Research Needs. Ecological Applications 15(6): 1893-1905.

Hasse, J and R Lathrop. 2008. Tracking New Jersey's Dynamic Landscape: Urban Growth and Open Space Loss 1986-1995-2002. Online Report: available at www.crssa.rutgers.edu

Kauffeld, C. 1957. Snakes and Snake Hunting. Hanover House, Garden City, NY. 266 pp.

Luckenbach, RA and RB Bury. 1983. Effects of Off-Road Vehicles on the Biota of the Algodones Dunes, Imperial County, California. Journal of Applied Ecology 20(4): 265-286.

Little, S. 1979. Fire and Plant Succession in the New Jersey Pine Barrens. *in:* Pine Barrens: Ecosystem and Landscape, edited by: RTT Forman. Rutgers University Press, New Brunswick, NJ. pp 297-314.

Mitchell, JC, AR Breisch, and KA Buhlmann. 2006. Habitat Management Guidelines for Amphibians and Reptiles of the Northeast United States. Partners in Amphibian and Reptile Conservation, Technical Publication HMG-3, Montgomery, AL. 108 pp.

NatureServe. 2009. NatureServe Explorer: An Online Encyclopedia of Life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: November 23, 2009).

New Jersey Department of Environmental Protection (NJDEP). 2002. DEP Commissioner Campbell Announces Off-Road Vehicle Policy Reinforces Ban on Public Lands; Seeks Maximum Fines, Additional Sanctions for Illegal Use (News Release 10/02/02) http://www.state.nj.us/dep/newsrel/releases/02_0095.htm

New Jersey Department of Environmental Protection (NJDEP). 2003. Final report of the New Jersey comparative risk project. Trenton, NJ.

New Jersey Department of Transportation (NJDOT). 2009. Roadway Information and Traffic Counts: Interactive Traffic Count Reports. Available: http://www.state.nj.us/transportation/refdata/roadway/traffic_counts/

New Jersey Forest Fire Service. 2009. www.state.nj.us/dep/parksandforests/fire

New Jersey Pinelands Commission. 2009. The Pinelands National Reserve. New Jersey Pinelands

Commission, New Lisbon, New Jersey. Available: http://www.state.nj.us/pinelands/index.shtml (Accessed: November 22, 2009)

Niles, LJ, M Valent, P Winkler and P Woerner. 2008. New Jersey's Landscape Project, Version 2.1. New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Endangered and Nongame Species Program. pp. 150.

Northeast Partners in Amphibian and Reptile Conservation (NEPARC). 2009. Risk Assessment: Introduced Species – is the Species Negatively Affected by Introduced Species ? (Squamates). Available: http://www.pwrc.usgs.gov/neparc/Products/RiskAssessPDFs/Squamata/IntrodSpecies_squamates.pdf

Pereira, JMC and RM Itami. 1991. GIS-based Habitat Modeling Using Logistic Multiple Regression: a Study of the Mt. Graham Red Squirrel. Photogrammetric Engineering & Remote Sensing 57(11):1475-1486.

Saunders, DA, RJ Hobbs, and CR Margules. 1991. Biological Consequences of Ecosystem Fragmentation: a Review. Conservation Biology 5:18-32.

Schwartz, V and DM Golden. 2002. Field Guide to Reptiles and Amphibians of New Jersey. New Jersey Division of Fish and Wildlife, Trenton, New Jersey.

Scott, AF and WH Redmond. 2008. Atlas of Reptiles in Tennessee. The Center for Field Biology, Austin Peay State University, Clarksville, Tennessee. Available: http://www.apsu.edu/reptatlas/frames_file.htm (Accessed: November 20, 2009)

Sherwood, B, D Cutler, and JA Burton. 2002. Wildlife and Roads: the Ecological Impact, (editors). Imperial College Press, Covent Garden, London.

Smith, RM and WF Bien. 2005. Monitoring Home Range Movements and Identifying the Location of Hibernacula of the Timber Rattlesnake (*Crotalus horridus*) and Northern Pine Snake (*Pituophis melanoleucus*) at Warren Grove Gunnery Range, Drexel University, Unpublished manuscript.

Tennant, A and RD Barlett. 2000. Snakes of North America: Eastern and Central Regions. Gulf Publishing Company, Houston, Texas.

Thomas, R. 2009. Operation Shellshock. *Presentation*, 2009 Northeast Partners in Amphibian and Reptile Conservation (NEPARC) Annual Meeting, Watkins Glen, NY.

Wiens JA 1997. Metapopulation Dynamics and Landscape Ecology. *In*: Metapopulation Biology, edited by: IA Hanski and ME Gilpin. Academic Press, San Diego, CA. pp. 43-62.

Wiens, JA, NC Stenseth, B Van Horn, and RA Ims. 1994. Ecological Mechanism and Landscape Ecology. Oikos 66: 369-380.

Windisch, AG. 1999. Fire ecology of the New Jersey Pine Plains and vicinity. Ph.D. Dissertation. Rutgers, The State University of New Jersey. New Brunswick, New Jersey. 327 pp.

Winkler, P, G Fowles, M Valent and P Woerner. 2008. New Jersey's Landscape Project, (Version 3.0 Highlands) A species-based patch approach to rare and imperiled wildlife habitat mapping for community land-use planning and species conservation. New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Endangered and Nongame Species Program. pp. 149.

Woodward, DK and GT Barthalmus. 1996. Distribution and Habitat Indices of Northern Pine Snakes in North Carolina. Proceedings of the Annual Conference of Southeast Association of Fish and Wildlife Agencies 50:271-279.

Wright, AH and AA Wright. 1957. Handbook of Snakes. Comstock Publishing Associates, Ithaca, NY.

Zampella, RA. 1986. Crossley and the Eco-politics of Endangered Species Protection: a New Jersey Case Study. *In:* Endangered and threatened species programs in Pennsylvania and other states: causes, issues, and management. *Edited by:* FJ Brenner and AF Rhoads. The Pennsylvania Academy of Science, pp 278-293.

Zappalorti, RT. 1993. Life history, Ecology and Management of the Northern Pine Snake (*Pituophis melanoleucus melanoleucus*). Unpublished report to NJDEP, Division of Fish and Wildlife by Herpetological Associates.

Zappalorti, RT, EW Johnson, and Z Leszczynski. 1983. The Ecology of the Northern Pine Snake (*Pituophis melanoleucus melanoleucus*) in Southern New Jersey, with Special Notes on Habitat and Nesting Behavior. Bulletin, Chicago Herpetological Society 18:57-72.

Zappalorti, RT and R Gianluca. 1990. Endangered and Threatened Snake Studies and Habitat Evaluations of the Route of the Proposed Mule Road Extension, Berkely Township, Ocean County, New Jersey.

Zappalorti, RT, MJ McGraw, DW Burkett, and DM Golden. 2008. 2007 Annual Report of Northern Pine Snake Management and Conservation at Stafford Business Park, Stafford Township, Ocean County, New Jersey. *Unpublished Report*

Zappalorti, RT, MP McCort, DW Burkett, and DM Golden. 2009. 2008 Annual Report of Northern Pine Snake Management and Conservation at Stafford Business Park, Stafford Township, Ocean County, New Jersey. *Unpublished Report*

GIS SOURCES

New Jersey Department of Environmental Protection (NJDEP), Office of Information Resources Management (OIRM), Bureau of Geographic Information Systems (BGIS). 2006. *NJDEP 2002 Land use/Land cover Update for New Jersey (Final).*

Online Linkage: http://www.state.nj.us/dep/gis/lulc02cshp.html

New Jersey Department of Environmental Protection (NJDEP), Green Acres. 2008. *NJDEP State Owned Protected Open Space and Recreation Areas in New Jersey*.

Online Linkage: http://www.state.nj.us/dep/gis/stateshp.html#STOPEN

New Jersey Department of Environmental Protection (NJDEP), Division of Fish and Wildlife (DFW), Endangered and Nongame Species Program (ENSP). 2009. *Biotics Database.*

Online Linkage: Unpublished.

New Jersey Department of Environmental Protection (NJDEP), Division of Fish and Wildlife (DFW), Endangered and Nongame Species Program (ENSP). 2009. *Species Occurrence Areas, Version 5.*

Online Linkage: Unpublished.

New Jersey Department of Transportation (DOT), Geographic Information Systems. 2009. *NJDOT Major Roadways.*

Online Linkage: http://www.state.nj.us/transportation/gis/map.shtm

United State Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2008. *Soil Survey Geographic (SSURGO) database for New Jersey*.

Online Linkage: http://soildatamart.nrcs.usda.gov

Environmental Systems Research Institute, Inc. (ESRI). 2001 U.S. States (Generalized)

Online Linkage: http://www.esri.com/data/data-maps/index.html

Environmental Systems Research Institute, Inc. (ESRI). 2009 World Reference Overlay

Online Linkage: http://www.esri.com/software/arcgis/arcgisonline/usa-world-bundle.html