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Chapter 1

THE NORTHERN PINE SNAKE (*PITUOPHIS MELANOLEUCUS*) IN NEW JERSEY: ITS LIFE HISTORY, BEHAVIOR AND CONSERVATION

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ABSTRACT

At the northern limit of their range, the Pine Snake (*Pituophis melanoleucus*) is listed as a threatened species by the state of New Jersey. They occur in the southern portion of the state in an area known as the Pine Barrens, where they are isolated from other conspecifics much farther south in Tennessee, Virginia, Kentucky and the Carolinas. The major threat that Pine Snakes face throughout their range is habitat loss. Pine Snakes excavate long nest tunnels and lay their eggs underground. In the fall they dig or modify abandoned mammal burrows or stump-holes as hibernation sites where they survive the winter. Because they are at the northern limit of their range, females select open sandy areas in the forest with complete sun penetration to the underground nest. Shaded areas with trees or shrubs could cause eggs to incubate at lower temperature limits in the nest and cause hatchlings to be behaviorally impaired. Their nesting behavior in open fields renders them vulnerable not only to predators, but to human poachers and off-road vehicles that can run over females within nesting tunnels, destroy the nests, or crush and kill eggs or hatchlings. Poaching of eggs and adults during the nesting season, or at other times of the summer, is a severe threat to Pine Snakes. Other threats include loss of nesting and hibernation sites, fragmentation of important foraging habitat, enhanced predation from human commensals (dogs and cats), and natural predators whose populations have increased due to the presence of humans (Coyote [*Canus latrans*], Fox [*Vulpes fulva*], Raccoon [*Procyon lotor*] and Skunk [*Mephitis mephitis*]). Properly planned research and intensive long-term studies have proven not to cause disruptions to Pine Snake ecology or behavior. Because New Jersey Pine Snakes have a distinct black and white pattern not found in this species from elsewhere in their range, they are highly prized by collectors. Measures to protect Pine Snakes are discussed, particularly habitat protection, enhancement of known nesting areas, construction of hibernacula, and protection of nesting and hibernation habitats from off-road vehicles. An extensive conservation and educational campaign is needed to raise public awareness about the harmless Pine Snake, the important role they play in the food chain in the Pine Barrens ecosystem, and to develop ways to protect and enhance their population and habitat.

INTRODUCTION

Maintaining healthy vertebrate populations in urban and suburban areas is an important goal for conservationists, urban ecologists, wildlife managers, public policy makers and the general public. With increasing urbanization and suburbanization in coastal and Pinelands areas, there are increasing pressures on dwindling wildlife populations, particularly caused by habitat loss (Wilcove et al. 1998). Although the effects of people on wildlife in wild areas have been studied extensively, relatively little attention has been devoted to these issues in heavily populated areas (Knight and Gutzwiller 1995, Rees 1997, Goldingay and Newell 2000, Burger et al. 2007), such as the New Jersey Pine Barrens. Because such wildlife populations are often fragmented, low in numbers, or difficult to study (Dowd 1992, Garber and Burger 1995, Fernandez-Juricic 2002), information necessary to develop conservation plans or protect the rare species may be lacking. This is particularly true with relatively large, top-level predators within any class of vertebrates. Yet it is the top-level predators that are often low in numbers, and thus vulnerable to the effects of humans, including direct mortality, increased predation rates of human commensals (e.g., dogs, cats) or those wild mammals that can increase with human development (e.g., Raccoons [*Procyon lotor*], Foxes [*Vulpes fulva*], Coyotes [*Canus latrans*]), along with habitat loss and fragmentation.

To survive and reproduce, all animals need to avoid predators, find sufficient food and mates, and select appropriate habitats for breeding, feeding, resting and for all phases of their life cycle. In addition, animals face pressures from humans, including road mortality, fragmentation of their habitat and critical habitat loss. Snakes, especially large ones, are particularly vulnerable because their populations are generally low, their home ranges are larger than smaller snake species, their movements are relatively slow, and they suffer from adverse public opinion- many people want to kill large snakes or at least remove them from their environments. These characteristics make large snakes particularly vulnerable in places densely populated with people. “Not in my back yard,” a phrase generally reserved for toxic waste facilities, also seems to apply to large snakes. The task of conserving large snakes in heavily populated areas is thus difficult and daunting, particularly in the face of continued development and habitat destruction. Reptiles, and particularly snakes, have been largely ignored in conservation biology (Gibbons et al. 2000), yet they are strongly affected by habitat loss and fragmentation (Reinert 1994). For example, the Florida Pine Snake (*Pituophis melanoleucus mugitus*) populations are declining, largely due to habitat loss (Franz 1992, 2002). This is particularly true with large snakes, such as Pine Snakes, that have relative large activity ranges and specific habitat needs (Burger and Zappalorti 1988a, 1989, Gerald et al. 2006a). Snakes are in need of conservation strategies (Dodd 1993), especially ones that are species-specific or deal with important conservation issues with particular snake species (e.g., Himes et al. 2006, Burger et al. 2007). Translocation or shifting of snakes within their activity range also deserves careful consideration and efficacy studies (Reinert 1991, Tuberville et al. 2005, Teixeira et al. 2007).

In this chapter we examine how the behavior and ecology of Northern Pine Snakes (*Pituophis m. melanoleucus*) makes them vulnerable to a wide range of stresses, from habitat fragmentation and destruction, to predation, and to direct human effects (killing, poaching, disruption of behavior). Conserving populations of Northern Pine Snake in New Jersey is a matter of continual vigilance, legal protection, habitat protection and reducing human disturbances. Pine Snakes are listed as *threatened* in New Jersey, a status that has recently been unsuccessfully challenged by the New Jersey Builders Association (Golden et al. 2009).

There are a number of sub-species in the genus, *Pituophis* in the eastern and central United States which includes the Bull Snake (*Pituophis catenifer sayi*), and the Sonoran Gopher Snake (*P. c. affinis*). Recent DNA studies (Reichling 1995) suggest the Louisiana Pine Snake (*P. ruthveni*) is more closely related to Bull and Gopher Snakes than the eastern Pine Snakes (*Pituophis melanoleucus*), that are represented by three sub-species:

- *P. m. melanoleucus* (Northern Pine Snake)
- *P. m. mugitus* (Florida Pine Snake)
- *P. m. lodingi* (Black Pine Snake).

All three of the *P. melanoleucus* species (Florida, Black Pine and Northern Pine), are rare throughout their range (Tennant and Bartlett 2000). In this chapter we discuss only the Northern Pine Snake. New Jersey is the most densely populated state in the Nation, and has experienced habitat loss over the past 20 years at an alarming rate: there has been an annual loss of roughly 0.27 %/year (Hasse and Lathrop 2008). This rate of loss has been similar for the habitat of the Pine Snake (about 0.29%, Golden et al. 2009). Thus, examining conservation of the Pine Snake is of paramount importance, particularly as an example of a large reptile surviving within a highly urbanized and densely populated region (Figure 1).

BRIEF NATURAL HISTORY OF NEW JERSEY PINE SNAKES

Range

Pine Snakes in Kentucky, Tennessee and North Carolina are the closest known viable populations to the New Jersey Pine Snake populations (Stull 1940, Conant and Collins 1998). They also occur in portions of Alabama and South Carolina (Stull 1940, Conant and Collins 1998). The disjunct nature of the New Jersey Pine Snake makes their conservation particularly important, and they are an iconic species of the Pine Barrens. The Northern Pine Snake population in the New Jersey Pine Barrens has historically been isolated from other conspecifics that occur farther south by at least 100 miles. For instance, they have historically and recently been reported from Maryland (Stull 1940, McCauley 1945, Grogan 1973, Grogan and Heckscher 2001).

Figure 1. Classic defense posture of an adult male Northern Pine Snake ready to strike.

There are 6 historical records for this snake in Maryland and 4 for Delaware (Grogan and Heckscher 2001, White and White 2002), yet its current status for Maryland and Delaware is undetermined. Five of the Maryland records are from the Eastern Shore. Various earlier authors (Kelly et al. 1936, McCauley 1945, Wright and Wright 1957) considered it a species whose range included the Delmarva Peninsula. There are museum records from Virginia and West Virginia (Mitchell 1994), however they have not been found there in the last 20-years.

In the Pine Barrens ecosystem, Northern Pine Snakes are relatively long-lived, top-level predators which occur in 8 southern New Jersey counties (Zappalorti et al. 1983, Burger 2006, Golden et al. 2009). Their primary prey consist of small mammals, especially rodents, birds, and bird eggs. They are one of the few snakes that excavate long tunnels in which to deposit their eggs in underground nests (Kauffeld 1957, Carpenter 1982, Burger and Zappalorti 1986a, 1991, 1992). They hibernate in underground burrow systems that they modify from stump-hole tap roots of pine trees, or in the abandoned burrows of Fox, skunk or woodchuck. The snakes modify their hibernacula by digging deeper into the soft sand, forming hibernation chambers that have an extensive small tunnel system along with side chambers (Burger et al. 1988, 1992). Even where current populations exist in New Jersey, they are not numerous compared with other species of snakes such as Black Racers (*Coluber constrictor* - Burger 2006).

Habitat

The Pine Barrens of New Jersey represents a post-Pleistocene sand ridge area with unique geomorphic features which supports unique plant and animal communities adapted to dry nutrient-poor conditions. The plant communities include short-leaf pine (*Pinus echinata*), pitch pine (*P. rigida*), Virginia pine (*P. virginiana*), and hardwoods such as sand hickory (*Carya pallida*), post oak (*Quercus stellata*), blackjack oak (*Q. marilandica*), and water oak (*Q. nigra*). While they will forage in a variety of available habitats, only certain portions of the forest are optimum (i.e., ecotone between grasslands and Pine-Oak Forest, open utility right-of-ways, open sandy nesting areas, and protected winter dens). Pine Snakes select areas dominated by pitch pine forest (McCormick 1970), but will also use pine and scrub oak forest, oak-pine forest, and the ecotone between these selected habitats. They also occasionally forage or cross forested wetlands, white cedar (*Thuja occidentalis*) Swamps and Pitch Pine Lowland Forest habitats (McCormick 1970, Burger and Zappalorti 1986, 1988a, 1989, Woodward and Barthalmus 1996). There are no gender differences in habitat selection (Burger and Zappalorti 1989). When not foraging, or searching for mates or nest sites, Pine Snakes often remain in dense vegetation that provides shade and ground cover (Burger and Zappalorti 1988a). They hide in hollow fallen logs, mole tunnels, stump holes or under debris piles to avoid predators.

Breeding

Pine Snakes mate in late April and throughout May when adult males are highly aggressive in their search for females. When a male encounters a female he grasps the female on the neck with his jaws and coils over the dorsal of the female. The male wraps his tail under the female and inserts one of his hemipenis into her cloaca (Figure 2). Fertilizations is internal and the male may remain with the female for up to 10 days and copulate more than once (Zappalorti, personal observations). Females excavate nests and lay eggs from mid-June to early-July in relatively open areas with sun penetration to the ground (Burger and Zappalorti 1992, Golden et al. 2009). Northern Pine Snakes do not occur north of the New Jersey Pine Barrens, perhaps because the summer season and ambient temperature is not sufficient farther north to provide adequate incubation heat (Burger 1991a).

That is, Pine Snakes rely on heat from the sun to incubate their eggs, and they nest in open clearings to allow for sun penetration, often in places disturbed by man (Zappalorti and Burger 1985). Generally gravid females nest in openings or clearings within the Pitch Pine and Oak Forest in uplands. Nesting habitats include railroad bed embankments, sandy shoulders of paved or dirt roads, old fields, and natural forest clearings. Females excavate tunnels that are up to 1.5 m long, with a nest chamber that can be up to 21 cm below the surface of the ground. While some nest burrows have only one clutch of eggs, we have found community nests with up to 4 clutches in side chambers (Burger and Zappalorti 1991). Although incubation temperature does not affect sex ratios at conception, males are more vulnerable to mortality during egg development (Burger and Zappalorti 1988b). Females lay an average of 9 eggs, although the maximum clutch size is 16 (Burger and Zappalorti 1991). Females are highly philopatric, often returning to excavate and lay in the same spot for up to 5 years (Burger and Zappalorti 1992).

Figure 2. An elaborate aggressive courtship typically occurs in late April or May. Copulation in Northern Pine Snake involves insertion of hemipenes into the female, obvious in the lower photograph.

Females even return to sites that are close to disturbed housing construction and road-building (Zappalorti and Burger 1985). Hatching takes about two months (55 to 100 days; Burger 1991, Burger and Zappalorti 1992), and emerging young quickly seek cover to avoid predators. Incubation temperature affects nearly all aspects of behavior, including mobility, foraging, prey capture, anti-predator behavior, shedding periods, time to first capture prey and eat (Burger et al. 1987, Burger 1989a, 1991a,b). These behaviors have implications for survival; snakes incubated at low temperature have the greatest behavioral impairment, and lowest survival rate (Burger 1998). While some young emerge immediately upon hatching, most remain in the nest for 10 days to two weeks, only dispersing after they shed to look for their first meal (Burger 1989).

Hibernation

Pine Snakes hibernate for the winter either at individual sites or at communal dens, sometimes in old stump-hole root systems or they locate an abandoned mammal burrow in which to spend the winter. We have found Pine Snakes hibernating with other conspecifics (up to 33 snakes in one den), along with other species of snakes such as Black Racers, Hognose Snake (*Heterodon platirhinos*), coastal Plains Milk Snake (*Lampropeltis triangulum x elapsoides*) and Corn Snakes (*Elaphe guttata*, Burger et al. 1988, 2000, Zappalorti and Burger, unpub. data). Most of these hibernacula are dug by the snakes, by following old tree roots, although they will also dig side chambers in abandoned mammal burrows (Burger et al. 1988). There are usually several side chambers off the main tunnel, which can be as long as 6 m (Figure 3). Chambers with snakes can be between 50 and 120 cm below the ground surface, depending upon winter temperatures. Snakes tend to use the same hibernacula (or hibernacula system) in consecutive years (Burger et al. 1992, 2007, ms). When several hibernacula are in the same general area, snakes often shift from one den to the other in different years (Burger and Zappalorti, personal observations). Hibernation sites are often used in the summer for resting, avoiding predators and high surface temperatures (Burger et al. 1988). Young and adults locate hibernation sites by following the chemical scent trails of other Pine Snakes, as clearly demonstrated by laboratory experiments (Burger 1989b), and they are capable of distinguishing the odors of conspecifics from predators (Burger 1989b, 1991b, Burger et al. 1991).

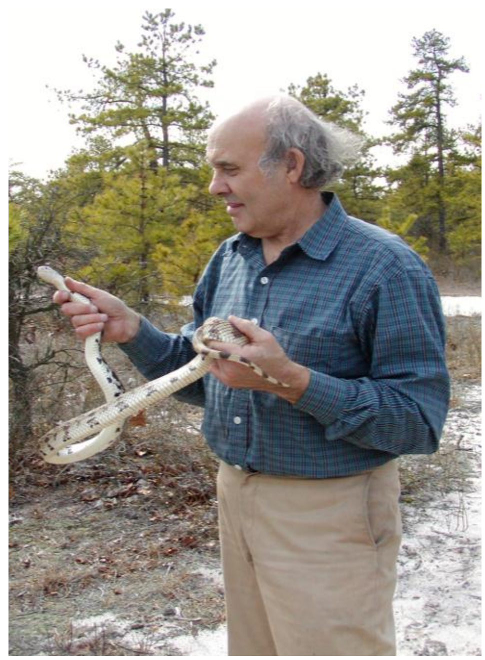

Figure 3. View of a Pine Snake hibernaculum. The left shows a hibernaculum that has been dug up; the lower arrow points to a snake tunnel, with leaves on the surface (upper arrow), and different soil horizons. The snakes usually dig in the hard-packed yellow sand. The right shows Mike Gochfeld with a snake removed from a hibernacula, as well as the surrounding habitat.

Contaminants

Levels of heavy metals in the bodies of hatchlings are relatively low (Burger 1992), suggesting that they encounter low levels of heavy metals in their usual prey. However, the levels of some heavy metals (lead, mercury, chromium) were higher in the skin of hatchlings than in internal organs, which suggests that shedding is a mechanism to reduce metal levels in the tissues of Pine Snakes (Burger 1992).

Methods and Research Approach

The information described in this chapter is based upon over 25-years of Pine Snake research both in the field and laboratory. All studies were conducted under appropriate permits issued by the New Jersey Department of Environmental Protection and were approved by the Rutgers University Institutional Animal Care and Use Committee. We studied the behavior of Pine Snakes in the New Jersey Pine Barrens in Burlington, Cumberland and Ocean Counties. The nesting areas, hibernacula, and radio-tracked Pine Snakes we studied were located in Bass River State Forest, the Crossley Preserve (Kauffeld 1957), on Nature Conservancy property, on various Division of Fish and Wildlife Management Areas and on private land. The types and degree of habitat management on these areas differ, as does the degree of protection. More specific locations are not given because of the threat of illegal poaching. Our studies have shown that in some years nearly 40 % of nests were poached (Burger et al. 1992).

Our protocol was to locate, capture and mark any gravid pine snakes at a nesting area, to capture digging females when they left their nests in the heat of the day to rest under logs or in shade, and to dig up hibernacula to examine site fidelity and the longevity of our marked snakes. Snakes encountered within our study area were captured, marked with passive-integrated transponders (PIT tags, Elbin and Burger 1994), and released where initially found. For some studies, snakes were surgically fitted with radio-transmitters. Known Pine Snake nesting areas were searched from mid-June through mid-July for gravid females and nesting burrows. Each known nesting area had from 3 to 18 marked females living in the vicinity, as determined by long-term observations and radio-telemetry (Zappalorti et al. 1983, Burger and Gochfeld 1985, Burger and Zappalorti 1992, Burger and Zappalorti, ms). Nest burrows can be recognized by the snake's trail in the sand, a distinct sand fan at the tunnel entrance, a small entrance hole, and diagnostic dump pile opposite the burrow opening.

The results of individual studies on habitat selection, nest site selection, nesting behavior, anti-predator behavior, hibernation behavior, and effects of incubation behavior on Pine Snakes can be found in the individual papers given in the bibliography at the end of the chapter. In this chapter it is our intent to examine only those behavioral and ecological factors that affect conservation, including habitat features, nesting behavior, hibernation behavior, predators, and human disturbance and poaching.

VULNERABILITY

There are a number of threats to Pine Snakes, with no indication that these threats have decreased, while there is every indication that they have and will continue to increase (Burger 2006). The major threats to Northern Pine Snakes include loss and fragmentation of important habitat, restriction of critical habitat (suitable habitat remains, but it is small and increasingly fragmented in nature), loss of open areas for nesting (due to succession, or to destruction by off-road vehicles or other anthropogenic causes), human disturbance (destruction of nests and eggs, killing of snakes), poaching, predation, and human-induced changes in predator numbers (e.g., some predator numbers have increased due to inadvertent food availability because of humans, or clearing of forest for construction and opening-up habitat, increased numbers of dogs and cats). Fragmentation of habitat increases the exposure of snakes to most of these hazards, including increased predator pressure and being killed by vehicles as they cross roads to seek nesting or feeding areas.

In addition to direct habitat loss or fragmentation due to development, Pine Snakes suffer losses due to off-road vehicles that can churn up and destroy nests and kill emerging hatchlings (Burger et al. 2007). Such disturbances have led directly to population declines and loss of recruitment. Further, the intense development within the Pine Barrens of senior citizen retirement communities, residential housing projects, and commercial development all increase the direct killing and harassment of snakes, particularly large ones such as Pine Snakes.

Snakes are vulnerable to predators while feeding, digging nests, or overwintering in hibernacula (Burger et al. 1992). Predation happens particularly when they are hibernating because their body temperatures are near ambient temperature, while mammalian predators are active all year (Burger et al. 2000). Predators on snakes include Coyote, Fox, Striped Skunk (*Mephitis mephitis*) and Short-tailed Shrew (*Blarina brevicauda*), as well as King Snakes (*Lampropeltis getula*, Burger 1989a, 1990). Scarlet Snakes (*Cemphora coccinea*) are notorious reptile egg eaters and we have observed them puncture Pine Snake egg shells in the nests by chewing the leathery shell and drinking the contents of the egg (Burger et al. 1992). Because Scarlet Snakes are so secretive, it is difficult to determine how frequently this happens. Active snakes can partly reduce predation by avoiding the scent trails of predators such as other snakes (Burger 1989b). Inactive snakes, however, particularly those hibernating, are vulnerable to a whole host of predators (Burger et al. 2000).

New Jersey Pine Snakes have a striking black and white pattern that is sometimes mixed with orange, red or purple spots on the posterior portion of the dorsal scales (Figure 4). Such colorful patterns remain throughout their life, making them highly prized by collectors for the pet trade (Schwartz and Golden 2002).

Both eggs and snakes are often removed from the wild by illegal collectors. In some years, nearly 40 % of the nests we studied were destroyed by poachers. Gravid females are also taken while they excavate nests that can take up to 4 days to complete (Burger and Zappalorti 1991).

Figure 4. Striking black and white pattern of New Jersey Pine Snakes makes them vulnerable to snake collectors and the illegal pet trade in NJ Pines.

We developed a conceptual model that shows the points in the annual Pine Snake's life cycle when they are most vulnerable (Figure 5). Although not shown in the model, when Pine Snakes travel from one location to another within their summer foraging habitats, they often must cross sand, gravel or paved roads where they are killed by motor vehicles (Andrews and Gibbons 2005, Andrews, et. al, 2009). Depending upon age class, season and sex, snakes have different daily activities. In other words, Pine Snakes are more vulnerable during some stages of their life cycle than in others. For example, their eggs and hatchlings are vulnerable to a great deal of predation from a wide range of mammal and human predators. Nesting females are exposed to Red-tailed Hawks (*Buteo jamaicensis*), Coyote and Foxes. Non-breeding adult snakes and juveniles are less vulnerable because they mainly stay hidden in the forest. These age classes do not wander in search of mates (adult males), or are not vulnerable while digging nests and laying eggs (adult females). In the following sections we describe the major threats, followed by information about conservation with respect to each threat.

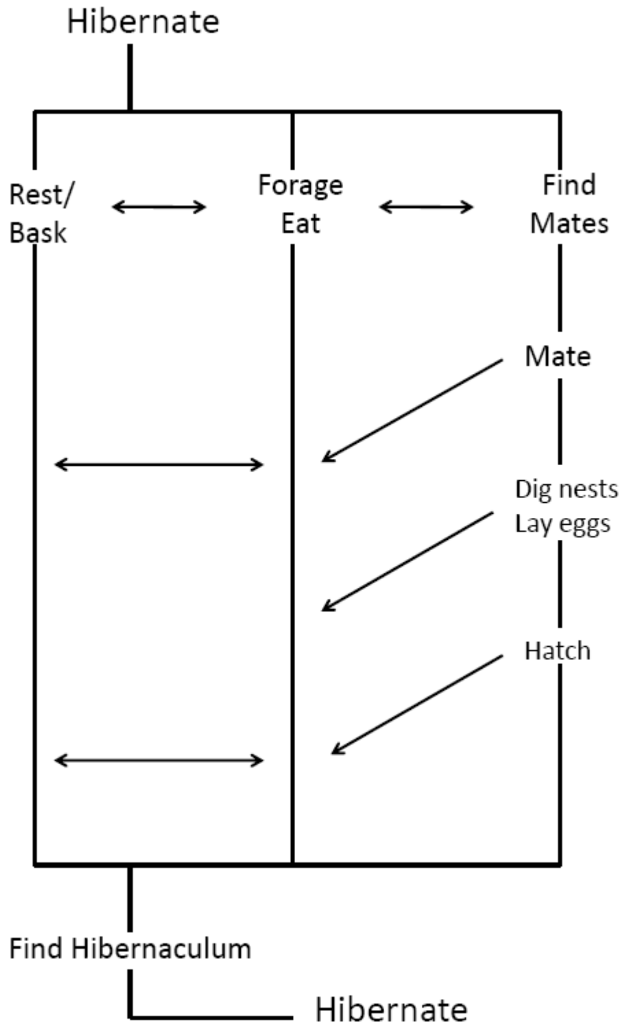

Figure 5. Model of vulnerability of snakes, given the three main activities of Pine Snakes (rest/bask, forage and eat, reproduction) that occur between hibernating.

HABITAT AND CONSERVATION

Habitat Loss

Loss of habitat (and fragmentation) can occur directly by various development and building more paved roads, or indirectly by reduction of suitable habitat or patch size, which renders the available habitat less suitable. That is, if prime habitat is decreased (but that which remains is still relatively pristine), the remaining habitat may be less suitable because it is no longer large enough to support a viable Pine Snake population.

Based on data from 20 adult radio-tracked Pine Snakes, their activity home ranges during a 2009 study varied from about 28.9 to 391.4 hectares (71.0-acres to 967-acres). The greatest distance between any two of the radio-tracking points was about 5 km (3-miles), with an average distance of 2.3 km (standard error of 2.4 km, Zappalorti et al. 2009). In 2010, the activity home range size of 16 radio-tracked northern Pine Snakes ranged from 91.35-hectares to 407.77-hectares (69.52-acres to 1104.99-acres). Of the 16 radio-tracked pine snakes, 11 had home ranges greater than 100-hectares, whereas four snakes had home ranges larger than 200-hectares (Zappalorti personal observations).

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Viable populations require enough space for individuals to forage effectively, and find both hibernation sites and basking/resting sites, and where females can find appropriate nesting habitat. There is little question that over time, there has been a general loss of habitat in the New Jersey Pine Barrens due to development (Golden et al. 2009). But more importantly, there has also been a loss of suitable nesting habitat; individually-marked females from previous years were observed trying to dig nests in the side of an embankment that was being bull-dozed for development (the sand was churned up and completely unsuitable), but because females have such strong nest site fidelity, they returned to their former nest sites regardless of the disturbance (Zappalorti and Burger 1985). That nesting area no longer exists because it was not within the Pinelands jurisdiction protection area.

Clearly the biggest threat to the conservation of Pine Snakes is habitat loss due to development and fragmentation. Table 1. presents the overall habitat requirements (discussed more in depth in this and following sections) of Pine Snakes in the New Jersey Pine Barrens, as a function of their daily activities, and how their requirements vary by age and gender. This table is meant to provide examples of how Pine Snakes use their Pine Barrens habitat, and the complexities of considering daily activities of different age and size classes. Pine Snakes require a number of different habitat types during their life cycle, including appropriate areas for foraging, concealed places for resting, vegetation for shading (Figure 6), basking sites while opaque, and mating/breeding, nesting, and hibernating sites (Table 2).

We compared the habitat choices of snakes found randomly with those that were fitted with radio-transmitters (Burger and Zappalorti 1988a, 1989). This table illustrates three important features: 1) Determining habitat use only from observation of randomly found snakes can give an erroneous picture of all their habitat use. 2) Pine Snakes prefer Pine-Oak, Oak-Pine, and Grassland habitats while mostly avoiding very open or highly disturbed habitats, and: 3) Radio-tracked Pine Snakes spend 50% of their time in undisturbed forested habitats than do those that are found and captured when they are nesting or by random searching. We believe this reflects a bias because of the ease of which snakes are located in open disturbed habitats, compared to dense Pine-Oak or Oak-Pine habitats that have greater ground and shrub cover. In this case, undisturbed means forest without any indication of human activities (that include abandoned farms, sand roads or railroad beds, artificially-created deer habitat). Disturbed places are generally open, with low vegetation, making it easier to see snakes. The high use of disturbed sites partly reflects habitat requirements for foraging or nesting (see next section).

Table 1. Overall habitat requirements of Pine Snakes in the New Jersey Pine Barrens based on annual life cycle. See Figure 1 for annual cycle. Data are based upon our observations and unpublished data as well as the references given

Activity	Age	Gender	Requirements
Resting/ Basking	All ages	All genders	Generally in the open for basking, on leaves, sand or logs. Resting snakes often hide under leaves, low vegetation, logs, or other places where they are concealed. In very hot weather they seek underground dens or use hibernacula (see Table 2 for specific preferences; Burger and Zappalorti 1988a, 1989)
Foraging	All ages	All snakes	Pine snakes remain in the higher Pitch Pine-Oak habitats in the cooler months, and move into the lower Pitch Pine and sometimes Cedar Swamps during the hot months (Burger 2006). They forage in all habitat types**,** normally moving less than 5 km within their home range.
Breeding	Adult reproductive stage	Both Sexes	Mating can occur anywhere, but due to the long copulation times, snakes seek shelter and protection of low vegetation or shrubs.
Breeding	Nesting and egg-laying	Females	Females require relatively open areas, with full sun penetration to the ground for optimum development of the young. Females select areas with sparse trees, shrubs or herbs, and with moist, soft soil with few roots to allow for digging, but provide structure so burrows do not collapse (Burger and Zappalorti 1986, 1991).
Breeding	Hatchlings	All	When hatchlings emerge, they generally immediately seek cover under *Hudsonia*, blueberry or other low shrubs. When about two weeks old, after they shed for the first time, they hunt for a meal.
Hibernation	All ages	All	Hibernacula are generally at the edges of clearings, in areas with sparse vegetation, and in places with sparse tree cover to allow sun penetration, although some are in denser cover. Hatchling may seek to hibernate in the roots of decaying pine trees, but older Snakes generally seek an established hibernaculum (Burger et al. 1998)
General	All	All	These separate annual cycle requirements result in the need for a mosaic of habitats that includes high and low Pitch Pine-Oak forests, open places for nesting, semi-open areas for hibernation sites, logs for basking, and cover for resting during hot weather. There needs to be a dispersion of these habitats.

It should also be noted that shifting snakes from one location to another even within the same habitat has an effect on their behavior and habitat use. Pine Snakes that were shifted because of development and loss of hibernation sites (in Ocean County) showed both different habitat preferences (Figure 7) and different behaviors (Figure 8), using radiotracking of shifted and non-shifted snakes (Zappalorti, current studies, unpub. data). Interestingly, many of the snakes shifted back to their traditional hibernation sites when they were available again.

Figure 6. Open areas are optimal for resting Pine Snakes when they contain some vegetation for avoiding sun in the heat of the day (Shown here is a gravid female).

Table 2. General macro-habitat requirements of Pine Snakes in the New Jersey Pinelands (after Burger and Zappalorti 1988a, 1989, and unpubl. data). Given are percent within each category, based on ten radio-tracked snakes and 51 snakes located by chance

Characteristic	Radio-tracked	Hand-caught	X^2 contingency (p)
Forest Type			
-Pine-Oak	89	79	
-Pitch Pine(low)	4	21	
-Cedar Swamp	1	0	4.1. (0.03)
Disturbance type			
-Undisturbed	42	2	
-Disturbed	58	98	36.1 (0.001)
Nearest vegetation			
-Pitch Pine	29	56	
-Blueberry	28	10	
-Saw Briar	11	4	
-Scrub Oak	10	8	
-Hudsonia	6	2	
-Other	16	20	24.9(0.003)

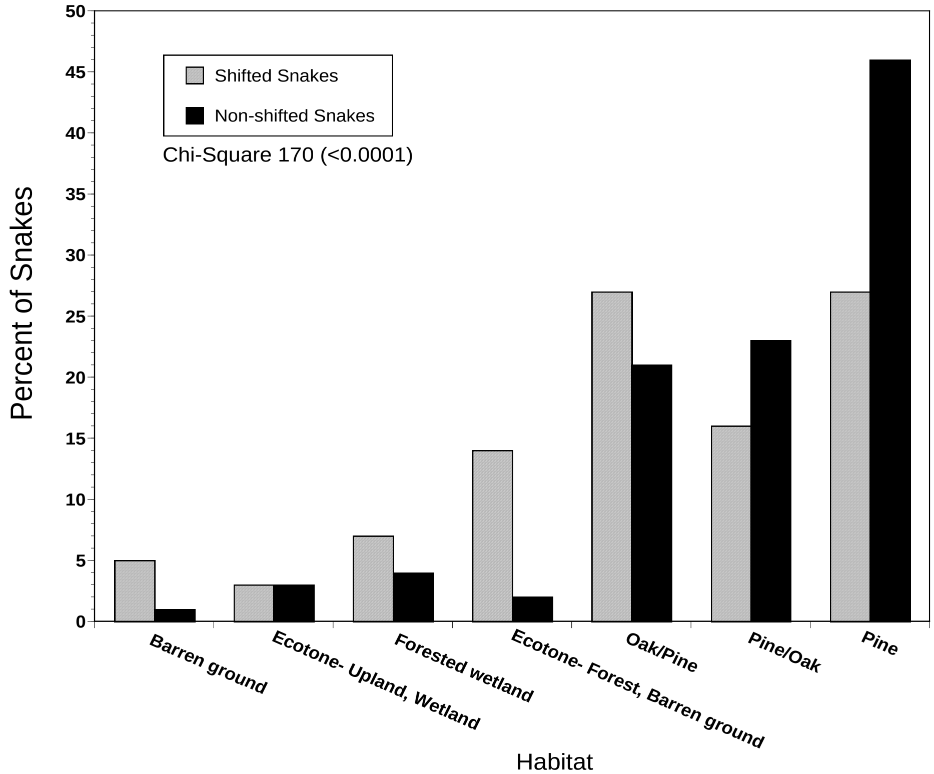

Figure 7. Habitat preferences of Pine Snakes in Ocean County (NJ) as a function of whether they were shifted (n= 12 snakes, 631 observations) or not (Based upon 1,537 observations of 23 Pine Snakes).

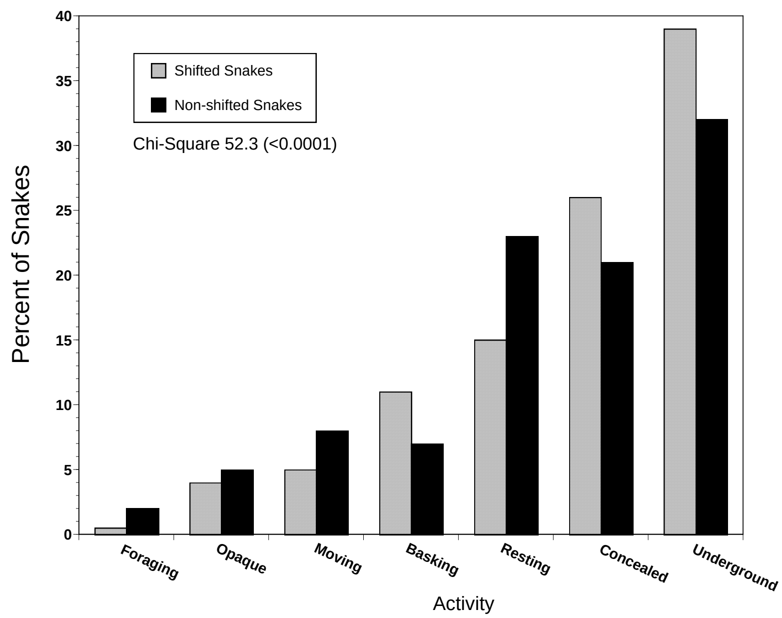

Figure 8. Behaviors of Pine Snakes in Ocean County (NJ) as a function of whether they were shifted (n= 12 snakes, 800 observations) or not shifted (n=.11 snakes, 1,301 observations)

Conservation Options

Protection of habitat for each of the life stages and daily activities is critical to maintaining viable Pine Snake populations in the New Jersey Pine Barrens. Clearly, habitat protection is crucial to preserving Pine Snake populations and the salient aspects include: 1) Appropriate habitat types for each activity, 2) Sufficient amount of each habitat type, 3) Suitable corridors between habitat types, and 4) Sufficiently large blocks of interspersed habitats to maintain vi.able local populations. Stemming the loss of overall habitat for Pine Snakes is difficult, even with legislation to protect the New Jersey Pine Barrens. Because Pine Snakes have a special status in New Jersey (as threatened), developers are required to survey potential development sites for Pine Snakes. The confirmed presence of Pine Snakes usually results in stopping (or greatly reducing or modifying) the development. However, the legislation and protection applies to parcels of land, generally without sufficient attention to the fragmentation of suitable habitat. A large percentage (about 72 %) of Pine Snake habitat is within the Pinelands National Reserve, which is protected by the Comprehensive Management Plan, and regulated by the New Jersey Pinelands Commission (Golden et al. 2009). New Jersey Coastal Zone Management (CZM) Rules protect an additional 7 % of its range, resulting in 21 % of the Pine Snake's historic range being unprotected (Golden et al. 2009). Further, the CZM regulations apply only to developments with more than 25 units, leaving the Pine Snakes unprotected in smaller developments (Zampella 1986).

NESTING BEHAVIOR AND CONSERVATION

Nesting Habitat

Female Pine Snakes generally select open sandy areas devoid of trees to allow full sun penetration as nesting sites (Burger and Zappalorti 1985). A gravid female returns to her traditional nest site year after year in a grassy open area. The nest site typically has some nearby cover where she can rest unobserved by predators during the hottest part of the day. The nesting areas usually have Pennsylvania Sedge Grass (*Carex pennsylvaticus*), and other heat tolerant grasses with soil that is easy to excavate.

Dry sugar sand is too soft and causes the tunnel and nest cavity to collapse when she is digging (or once the eggs are laid). Thus there is a delicate balance between sand soft enough for the snake to dig, but hard enough to support the roof of the tunnel. The roots of various grasses and Pennsylvania Sedge provide soil stability and some slight moisture. We examined nest site selection in Pine Snakes by comparing the actual nest sites with random points located in clearings and with random points in nearby forest areas (Table 3). Females selected open areas with little ground cover (not too many roots to impede digging), with little tree cover immediately overhead (to provide complete sun penetration), and with relatively soft sand (but not sugar sand that would collapse during excavation).

Further, these nest sites were in or near the center of the clearings and not at the edge. About 60 % of the nest sites were relatively near known hibernacula. One of the egg incubation difficulties Pine Snakes face in New Jersey is that they are at the northern limit of their range. In order to develop properly and hatch, the eggs require adequate sun penetration during the summer to allow for sufficient incubation temperatures.

Experiments in the laboratory, using temperatures that actually occur in nests in nature, showed that hatchlings incubated at the low end of the incubation temperatures range had developmental abnormalities. These hatchlings had physiology problems such as prolonged incubation, shedding times, and hatching times (Figure 9).

Table 3. Nesting habitat requirements (after Burger and Zappalorti 1986a, unpubl. data)

Characteristic	Nests	Random (clearing)	Random (non-clearing)	X2
% ground cover at entrance	1.5 + 4	36 + 35	82 + 26	80.4 (0.001)
% tree cover	1.2 + 2	11 + 18	29 + 27	16.1 (0.001)
Distance to edge of clearing (m)	29 + 22	26 + 21	13 + 6	7.2 (0.01)
Distance to hibernacula (m)	46 + 37	32 + 21	29 + 27	Not significant
Spike penetration (cm)	6.2 + 0.6	4.6 + 2	5.2 + 2	8.7 (0.003)
% soft sand (not sugar sand)	100	11	3	97.3 (0.001)

In nature, delayed time to hatch would expose them to increased predation. They also had behavioral problems such as predator avoidance, movement, balance, response to chemical cues of conspecifics and predators (Burger and Zappalorti 1988b, Burger 1989). Clearly, low incubation temperature reduces the survival of Pine Snakes in the wild (Burger 1989b, 1991a, 1998).

These behavioral effects can be modeled (based on data for each phase), to show that Pine Snake hatchlings incubated at low temperatures have little chance of eating and finding a hibernation site before cold weather sets in (Figure 10, after Burger 1991a). That is, hatchlings from eggs incubated at low temperatures require a much longer time to hatch, they take longer to leave the egg and emerge to the surface, and then require longer to hunt for food (they do not eat until they have shed). Adding these times together shows that hatchlings from nests incubated at the lowest temperatures that occur in nature would put the snakes in jeopardy (Figure 10).

Nests with low incubation temperatures are likely to be located in places where there is incomplete sun penetration to the ground. Further, although all hatchlings from the laboratory experiments were returned to the wild, and although we subsequently found snakes incubated at intermediate and high temperatures, we did not find any from the low incubating temperature groups (Burger 1998). Taken altogether, these data indicate that having sufficient sun penetration (and thus open areas) for nesting is extremely important to the continued existence of the Northern Pine Snake in New Jersey. The effects of incubation temperature on all aspects of hatchling behavior indicate the importance of clearings in the forest. Thus, availability of clearings in the Pine-Oak habitat, with sand of appropriate consistency, is a critical limiting factor. Just as female Pine Snakes are attracted to open clearings for biological reasons, these clearings are also attractive to off-road vehicle drivers for recreational reasons. Quads and motorcycles churn-up the sand, make deep ruts, and will scare-off gravid female Pine Snakes. In one visit they can render the nesting habitat unsuitable for snake use.

These open habitats are also becoming less available due to fire suppression (Golden and Jenkins 2003), succession to Pine-Oak stands, and disruptions due to human disturbance. The size and frequency of natural fires in the Pine Barrens has decreased over the last several decades (Forman and Borner 1981). Fire is one method of opening up suitable nesting habitats for Pine Snakes. Yet, with fire suppression, this method of producing suitable nesting areas is unavailable.

Figure 9. Hatching in Pine Snakes can take over 24 hours, making them especially vulnerable because of odors released from the egg. Top is of one egg, showing liquid that releases odors, middle shows a clutch of hatching eggs in a natural nest, and bottom shows the habitat where the nest was located.

In the distant past, indigenous Indians opened areas with fire to increase deer production (Burger 2006); this secondarily created suitable Pine Snake nesting habitat. Further, deer foraging areas have been opened by the NJ Division of Fish and Wildlife management personnel on Wildlife Management Areas. Although in the case of Whiting Wildlife Management Area, these same wildlife personnel disked up our hibernation and nesting study site during the critical winter period as part of deer management measures (Burger et al. 2007). This hibernation site was never used again (although we did not find out about this until much later, and so could not determine if the snakes were destroyed during the disking).

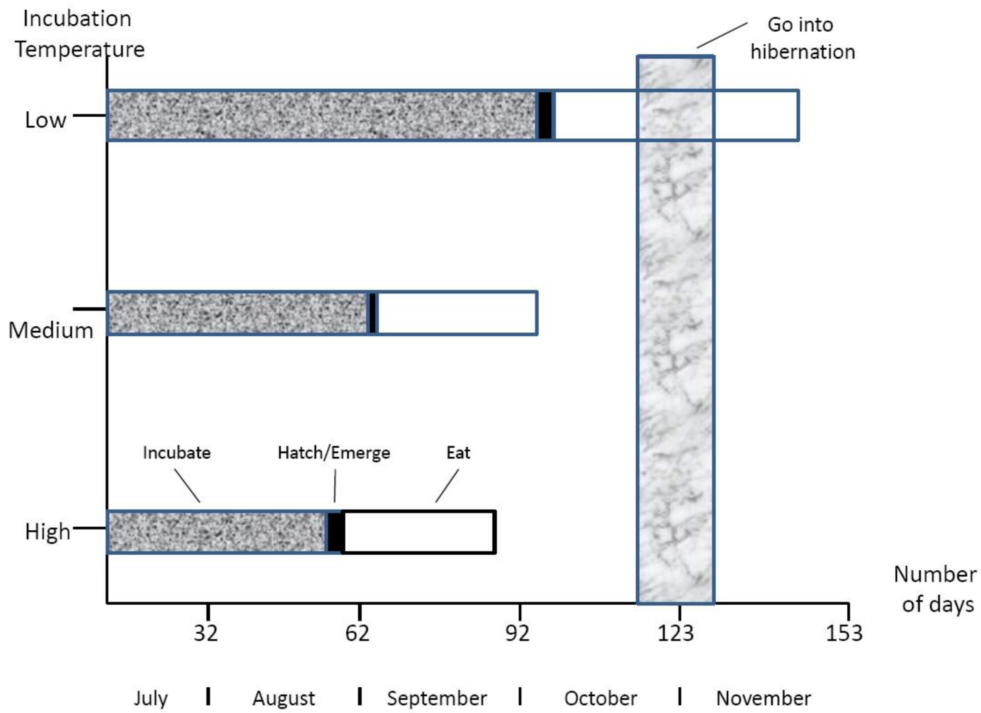

Figure 10. Effect of low incubating temperatures on the behavior and activities of Pine Snake hatchlings (from egg to hibernating by hatchlings, after Burger 1991a).

Finally, patches of suitable ecotone open space were maintained by small farms and hunting lodges located in remote areas of the Pine Barrens, many of which have now completely disappeared. These abandoned open fields interspersed within Pitch Pine-Scrub Oak upland habitats were ideal for gravid female Pine Snake nesting areas. Unlike many of the present modern-day inhabitants of the Barrens, the old time farmers appreciated Pine Snakes because they decreased nuisance rodent populations. Once abandoned and without maintenance, these farm fields gradually succeed to Pitch Pine and Scrub Oak uplands. Likewise, hunting lodges provided another method of creating Pine Snake nesting habitat because hunters frequently cleared land around their cabins and out-buildings. They came to the lodges only in the fall and winter to hunt for game, whereas the snakes had the open sandy areas undisturbed during the June - July nesting season.

We predict that over time there will be a natural loss of suitable open areas for nesting sites. This is among the many serious threats for Pine Snakes in southern New Jersey. Since this snake is on the State "threatened" list, maintaining open fields is an important management tool and this action should be considered by wildlife managers, conscientious builders, and conservationists.

Nesting Behavior

The unique nesting behavior of Northern Pine Snakes places gravid females at risk while they are digging their burrow and laying eggs. Leaving their eggs in shallow burrows also puts them at risk. Female Pine Snakes are most vulnerable when they are out in the open excavating their burrow entrance, because excavation can take several hours, or even days. While nesting, females engage in six unique nesting activities. These are:

1) Exploring traditional available open habitat.
2) Searching for chemical odors by rapid tongue-flicking, they test the soil by digging small test-holes with their rostral scale.
3) Excavating long narrow tunnels.
4) Resting between digging bouts, based on surface temperature and time of day.
5) Depositing eggs in the underground chamber.
6) Resting, after laying their eggs, for a day or more, usually in the nest chamber (Zappalorti et al. 1983, Burger and Zappalorti 1991).

During nesting activity, females typically dig during the cooler parts of the day (early morning and late afternoon/evening), but will seek shade or cover nearby during the heat of the mid-day sun.

When females are digging the nest tunnel they are very vulnerable to predators, because their head is deep within the burrow digging, scooping, and pulling sand out of the nest tunnel (Burger and Zappalorti 1991). While digging, half or more of the back end of the snake is exposed to human poachers, raptors, Coyote and Fox on the surface (Figure 11).Even when females are not immediately visible on the ground surface, they are vulnerable because of the scent-trail they leave on the sand when resting within the nest-burrow.

Additionally, the obvious presence of the sand-fan dump pile at the opening of the nest tunnel alerts mammal predators to the possibility of eggs beneath the ground. Female Pine Snakes remaining in the nest tunnel before, while laying, or after egg-laying, are easy marks from both animal predators and human poachers.

Hatchling Vulnerability

While Pine Snake eggs in nest chambers are always vulnerable to predators, the neonates are particularly vulnerable during the hatching process. It can take 24-hours for a Pine Snake to fully emerge from the egg shell and hatch (Burger et al. 1987, see Figure 9). During this time, there are increased odors filtering to the ground surface because the eggs are open. Hatching snakes in the chamber or tunnel are highly vulnerable during hatching and while they are waiting to shed their skin (while opaque). After hatching, the neonates have three possible choices which may help them survive:

1) Emerge to the surface immediately and disperse into the forest.
2) Remain in the nest chamber or tunnel until ready to shed.
3) Dig small side chambers into the tunnel walls and remain hidden.

Figure 11. Nesting females use their heads to pull out the sand (left) and then return to the burrow to pull out more sand (right), making them vulnerable to poachers and predators. Bottom shows a Pine Snake nest with two clutches of eggs laid in the same chamber.

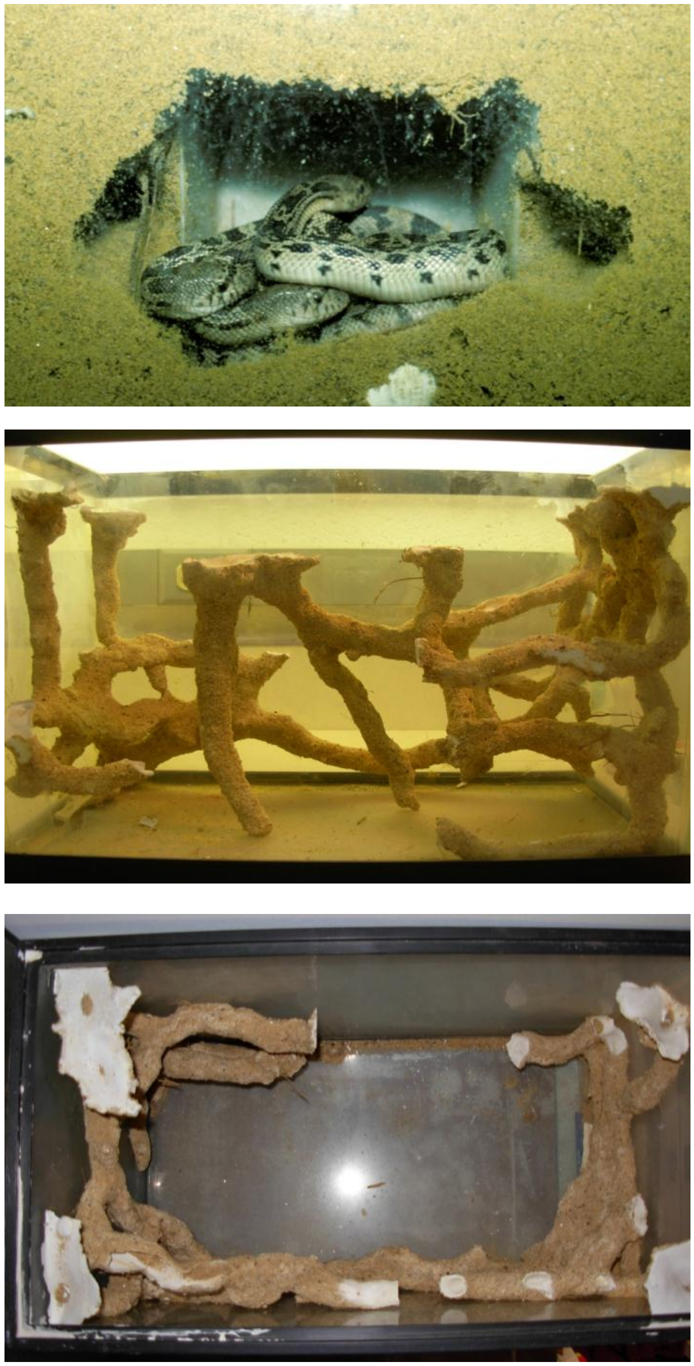

Figure 12. Side tunnels and chambers dug by hatchling Pine Snakes in artificial nest chambers in aquaria in the laboratory. The top photograph shows an artificial nest with hatchlings (viewed from side of aquarium), middle shows an extensive burrow system (viewed from side of aquarium), and the bottom shows an extensive burrow system where they made tunnels around the edges(viewed from top of aquarium).Presumably in nature they would not have turned a corner but would have extended the tunnels outward. The open space between the tunnels at the top of the bottom photograph is where the artificial nest was located (a plastic freezer container with holes on the sides so snakes could emerge, see arrow).

Emerging and dispersing immediately removes them from the danger caused by the increased odor at the nest site, but this action exposes them to predation on the surface. Since hatchlings cannot eat until they shed their skin for the first time (Burger 1989), it may be safer to remain in the nest chamber or tunnel. However, remaining in the nest chamber continues to expose them to potential predation because of the strong egg odors released to the ground surface. Before the neonates start to pip from the eggs, hatch and emerge to the surface to bask, there are no odors to attract predators. However, once they come up to the surface the air around the nest is filled with a pungent odor of hatched egg shells. Laboratory experiments indicate that one strategy is for the hatchlings to dig side tunnels and chambers away from the nest chamber (Burger 1991a, Figure 12, unpubl. data). In one particularly large aquarium, the hatchlings dug a tunnel that was 2 m long and curved around the space. This has the advantage of removing them from the immediate nest and its odors, while keeping them below ground and away from predators. These side tunnels no doubt function in this manner because we have found nests that have been opened by predators that contained chewed-up eggshells indicating that they were eaten, with some live snakes in side tunnels. This strategy may "fool" some mammal predators and most human poachers, since the small side tunnels collapse with any nearby excavation. We were able to identify these side tunnels in the laboratory only by putting plaster-of-paris down into the nest chamber after all hatchlings had emerged (Burger 1991a). Nesting areas should not be separated from other viable habitat patches; Pine Snakes normally travel no more than 5 km in their home ranges.

Conservation

Simply protecting sufficient tracts of Pitch Pine - Scrub Oak upland and hardwood forested lowland is not necessarily enough to maintain viable Pine Snake habitats. They also require open sandy places for nesting and egg-laying where there is sun penetration into the ground (to incubate the eggs; Burger 1989b, 1991a). Maintaining sufficient nesting habitat is one of the most challenging conservation issues, because it requires continued management and vigilance. The first step is to manage and preserve the known existing nesting sites. Additionally, where it is feasible, and the land is legally protected (state or federal lands), managers can maintain open areas by continued cultivation, prescribed burning, or by periodic mowing. There is a delicate balance that must be met because gravid females prefer places with some grasses and low growing plants where the roots hold moisture and help to stabilize the soil. They also nest in areas that lack dry sugar sand so that their long tunnels and nest chambers will not collapse (Burger and Zappalorti 1986, 1991). Providing open grassy fields and brushy edges, along with Pine-Oak Forest is important as foraging habitat. Large tracts of undisturbed Pine Barrens forest without paved or gravel roads through it is crucial to the long-term survival of Pine Snake populations.

HIBERNATION BEHAVIOR AND CONSERVATION

Habitat Selection

Pine Snakes excavate hibernacula in old tree roots, abandoned mammal burrows, or under human debris where it is easy to burrow into the soft sand (Figure 13). Snakes overwintering in the hibernacula are generally 50-150 cm under-ground (Burger et al. 1988, unpubl. data), well below the frost line. The depth at which the snakes reside for the winter depends somewhat on the harshness of winter temperatures. In other words, if winter temperatures are warmer, snakes may be closer to the surface. Hibernacula tunnels can be up to 800 cm long, with numerous side chambers for individuals or groups of snakes.

Table 4. Requirements for hibernacula sites (based on Burger et al. 1988, and unpubl. data). NS = not significant

	Hibernacula	Random	X^2 (p)
General			
% canopy within 5 m	20 + 15	65 + 23	36,4 (0.001)
			NS
% canopy within 20 m	56 + 23	67 + 21	
Specific requirements			
% ground cover (5 m)	46 + 7	46 + 10	NS
% cover over entrance	39 + 7	29 + 10	5.99 (0.05)
			9.99 (0.01)
Distance to tree (cm)	130 + 38	255 + 48	NS
Height of nearest tree (cm)	333 + 90	331 + 64	

We have found that winter hibernacula are usually in areas with less cover than is generally found in typical Pine Barrens forest (Table 4). Although there is no difference in the ground cover within 5 m of hibernacula entrances and random sites, the actual hibernacula entrance has more vegetation cover, no doubt to camouflage it from predators. Hibernacula can sometimes be close to the base of a tree (1-meter), but are generally not within a stand of dense trees in the forest.

Figure 13. Hibernacula of Pine Snakes in New Jersey. Shown is a view of the entrance of an artificial one with snake leaving entrance (top), artificial chamber in one of our long-term study hibernacula, with two snakes in it (middle), and Pine Snake in a side chamber of an snake-excavated tunnel (bottom).

Risks during Hibernation

Snakes avoid the thermal stress of winter by hibernating in underground hibernacula, either solitarily or in aggregations up to several thousands of individuals (Gregory 1984). Similarly, Pine Snakes hibernate in underground burrow systems that can contain up to 33 conspecifics, as well as other species of snakes (Burger et al. 1988). Black Racer, is the other species that often hibernates with Pine Snakes (Burger et al. 1992). The risks to Pine Snakes during hibernation include predation, poaching, freezing and/or burning. Most of these risks affect snakes before they enter their den when basking on the surface near the hibernacula entrance and/or while they are hibernating within the den. We have observed mortality from burning only in one female Pine Snake that emerged from her hibernacula in mid-January during a warm spell, and was caught in a fire. This may be a more common form of snake mortality, but observing these events would be rare because carcasses are quickly eaten by predators. In addition, Pine Snakes are at risk if they do not find a suitable place to hibernate before extreme cold temperatures set in, a hazard that may affect hatchlings that attempt to hibernate too close to the surface in tree roots or under logs.

Snakes succumb to freezing only when they fail to move deep enough below ground. We have observed only four instances of this: one adult female emerged to bask in the very early spring, and froze when she only moved down about 55 cm below the ground surface, and three hatchlings similarly were found within 1 m of the ground surface. Snakes that become inactive due to cold stress, or freeze on the surface near hibernacula would likely not be found because they would be eaten by predators. The main threats to snakes in hibernacula are mammal predators, human poaching and perhaps disturbance from off-road-vehicles. Pine Snakes were often observed basking near their dens on the ground surface for days or weeks before they remained in the hibernacula for the winter, depending upon ambient temperatures. During this time they are particularly vulnerable to predators and poachers that can key into these locations, killing or capturing snakes that leave the hibernacula to bask in the warm sun. While predators may not return to the hibernacula in the spring (if they found it in the fall), human poachers certainly will. For poachers, it is easier to wait for snakes to come to the surface than to dig up the hibernacula. Predators, particularly Coyote and Fox will dig in to a hibernacula, eating the snakes they find in the main chambers. Some predators, however, may not find all the snakes in the den because some individuals are off the main tunnel in long side tunnels and chambers. The digging into a den by predators, as well as poachers and scientists, can collapse small side chambers, effectively hiding and protecting the snakes. In our 25 years of studying hibernacula, we have never found a dead Pine Snake that appeared to die from sand collapse of burrows, which indicates that the Pine Snakes are able to dig out of such collapsed burrows. The effects of predators and poachers are discussed below in the relevant sections.

Pine Snake Conservation

Conservation and habitat enhancement for hibernating snakes includes:

1) Construct supplemental hibernacula in natural forest areas where they appear to be low in number, or where others have been destroyed by various types of development

(Gillingham and Carpenter 1976, Frier and Zappalorti 1983, Zappalorti and Reinert 1994, see below).

2) Design artificial hibernacula in such a way to prevent predator access. They can be constructed with cement blocks or railroad ties as an underground chamber. Place four PVC pipes leading down to the chamber (one in each compass direction), with 6-cm entrance holes to prevent mammalian predators from entering (Frier and Zappalorti 1983, Zappalorti and Reinert 1994).
3) Protect known hibernacula from off-road-vehicles by building large berms, blocking-off access roads, placing gates on management fields or other methods (Burger et al. 2007).
4) Enforce existing laws to protect Pine Snakes (Conservation Officers and Park Rangers). They should have knowledge of known Pine Snake hibernation/den areas and patrol them during spring egress and fall ingress.
5) Conduct educational campaigns to foster understanding and protection of critical hibernation sites and dens for snakes(Federal and state wildlife agencies).
6) Protect known hibernation sites from patch size decreases and patch isolation from other Pine Snake habitat.

Guidelines for the Construction of a Snake Hibernaculum

The recommended location for building a hibernaculum is in an area with sandy soils for good drainage, preferably on an elevated ridge-line (elevation above 10 meters). The den should be constructed on the edge of a field or forest opening. Each hibernacula should be located on the northern edge of a field to provide maximum sun exposure.

- Step 1. After surface vegetation has been removed with a front-end loader and stockpiled, a backhoe should dig a trench 1.8 meters wide, 2.8 meters long, and 1.8 meters deep.
- Step 2. A total of 18 railroad ties (2.6 meters in length) are needed for each hibernacula along with several stumps, logs, branches and sandy soil to cover the mound. Cut 6 of the ties in half (1.6 meter lengths).
- Step 3. Lay two full length ties on the floor of the trench along the sides. Place two of the pre-cut ties on top of the full length ties, thus forming a rectangle. Secure the ties to one another with large nails; this will keep them together and prevent them from coming apart over a long period of time. Repeat the procedure 8 times so the ties form a rectangular box with spaces between the ties.
- Step 4. Fill the rectangular box with large stumps, logs, branches and sand, almost to the top. Then place four 10 cm diameter perforated PVC pipes (3-meters long), one in each compass direction as ingress and egress points. The entrance pipes should be set at a 35-degree angle, so they are not too steep. Secure the pipes in place with wooden oak stakes to prevent movement during back-filling.
- Step 5. Make sure the ends of the PVC pipes are not blocked by debris so they will allow a snake to crawl in and out without obstacles.

- Step 6. Protect known hibernation sites from patch size decreases and patch isolation from other Pine Snake habitat.
- Step 7. Cover the top of the rectangular box with a 1.3 by 2.6 meter sheet of pressure treated 2.5 cm plywood, thus forming the roof. Cover the roof with plastic sheeting or tar-paper to protect the wood.
- Step 8. Cover the roof with about 1 meter of sand that was dug from the trench. Stack more logs, stumps and branches on the top of the sand, up to 2 meters high. Then cover the pile with more sand and top-soil.

By using pressure treated plywood for the roof and railroad ties in the construction of the snake dens (hibernacula), they will last up to 25-years or more. Pressure treated ties and roof will minimize termites from eating the wood. This construction design has been tested by Herpetological Associates over a 25-year period and free-roaming Pine Snakes, Corn Snakes (*Elaphe guttata*), and Black Racers continue to use these artificial dens. Figure 14. shows a diagram and method of construction for an artificial snake den. Over time, it is important to keep the entrance pipes free of debris, so they do not become blocked. Clogged entrance pipes will prevent the snakes from entering and using them (Frier and Zappalorti, 1983; Zappalorti and Reinert, 1994).

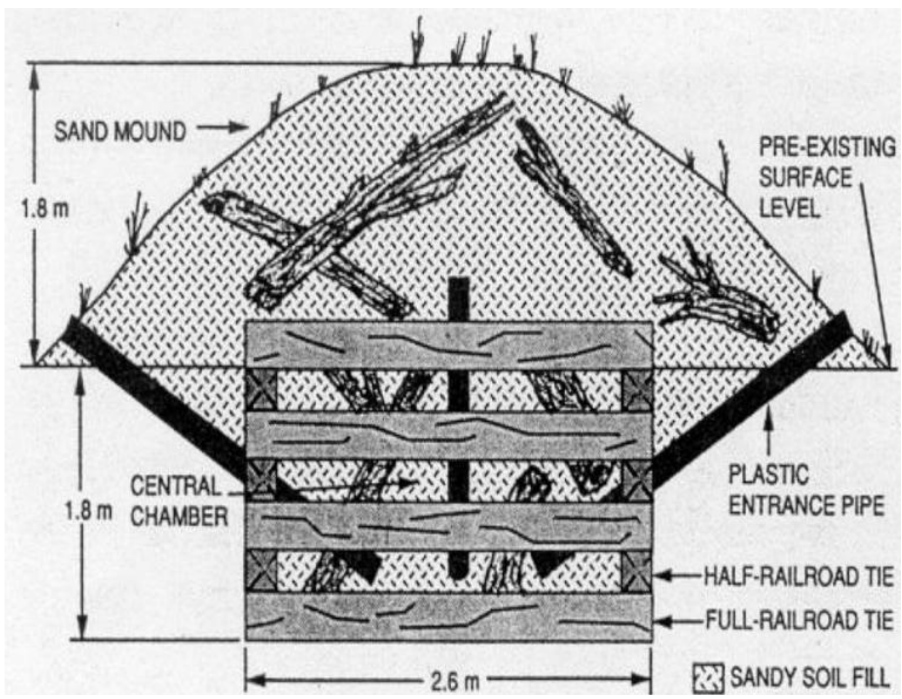

Figure 14. Side view of underground hibernation chamber for snakes and other wildlife. This drawing shows the method of construction using 18 pressure treated railroad ties and 10 cm diameter PVC pipes(Zappalorti and H. Reinert, Herpetological Associates, Inc).

PREDATORS

Native Predators

Pine Snakes are vulnerable to a wide range of avian and mammalian predators (including humans, see next section), yet they have evolved with these natural predators, and have learned to adapt with defense mechanisms or avoidance behavior. However, when predator numbers increase, either because of changes in habitat or food availability, predation on eggs, hatchlings, and adult Pine Snakes increases. On the other hand, Pine Snakes have not evolved with defense mechanisms to avoid human poachers, which is a recent phenomenon due to their high desirability by snake collectors and the pet trade. Moreover, the building of new sand and paved roads throughout the Pine Barrens and the abundance of off-road-vehicles has increased human access to remote areas.

Pine Snakes face an array of predators to their eggs in nests, hatchlings, adults during the summer and all age classes while in hibernation at den sites (see Table 5, Burger et al. 1992). Avian predation from raptors in general, and Red-tailed Hawks in particular, is a common event in the Pine Barrens, but difficult to document because the events are sporadic and rapid, and the predation occurs above ground where little direct evidence is available. On five occasions we have found partially eaten Pine Snakes, or their skeletons with beak and talon marks, indicating Red-tailed Hawk predation (Zappalorti, pers. obs.). Red Fox, Gray Fox (*Urocyon cinereoargenteus*), Coyote, and Skunks are obvious predators on adult Pine Snakes, their nests, and hatchlings. We have also observed Short-tailed Shrews eating hibernating Pine Snakes in their dens. The Shrews are small enough to enter the narrow tunnels and eat the snakes alive while they lay dormant sleeping.

Pine Snakes also face predation from other snakes, such as King Snakes. Even hatchlings have the ability to distinguish between the odors of conspecifics and King Snakes. During laboratory experiments Pine Snakes have the ability to avoid crawling over ground laced with King Snake odor trails (Burger 1989a, 1990). Similarly, hatchlings will not even move into a T-maze that contains odors from Red Fox. Such abilities are not likely to evolve if it is not adaptive. When given a choice, they readily follow odor trails of conspecifics or prey rodents (Burger et al. 1991b). King Snakes can eat hatchling and juvenile Pine Snakes, but may have difficulty overpowering large adults. Scarlet Snakes are known reptile egg eaters and will not pass-up the opportunity to drink the contents of Pine Snake eggs. There is no indication that these natural threats will decrease (or have decreased).

Human-Induced Predator Numbers

Northern Pine Snakes face predators that are human commensals (domestic dogs and cats), and increased predator numbers because of the presence of humans. That is, whenever humans develop an area with homes and commercial stores, there can be an increase in predator population numbers, particularly Coyote, Raccoons, and Foxes (three of the major threats), because of the increases of food availability (discarded food in garbage). The opening up of dense forests for housing developments and the building of new roads provides easy access for mammalian predators. For example, Raccoons and Coyote often increase in numbers in developed areas, particularly if there is sparse housing and increased food.

Conservation

While it is not practical, feasible, or desirable to eliminate natural predators, which may disrupt the overall trophic structure in the Pine Barrens, it is important to consider control for predators whose numbers have increased directly as a result of human activities and development. Where housing, particularly senior citizen complexes, are developed, buffer lands around these facilities would reduce the effect of human commensals (dogs, cats) on Pine Snakes. Such buffers may also decrease the number of predators that have increased because of the presence of people (such as Raccoons). When hibernacula are constructed (see Frier and Zappalorti 1983), predator barriers can be added, particularly to entrances. In some cases, hibernacula can be constructed specifically to reduce predation.

KILLING AND POACHING

Human Disturbance

One of the major threats Northern Pine Snakes face is from direct killing and poaching. There is still a very active "black market" in reptiles, and Pine Snakes are highly prized (Golden et al. 2009). Killing occurs primarily on roads, as it does for many snakes (Fitch 1949, Rudolph et al. 1998, Andrews et al. 2009). It may be accidental or intentional (we often see the skid-marks made by cars or trucks that have swerved and aimed at snakes on the road).

Snakes are also killed when they forage near human habitation, particularly when senior citizen housing is placed on, or near Pine Snake habitat. Most people fear snakes and killing may extend beyond the immediate vicinity of their homes. Some people will even run over a snake crossing a sand road in the forest. Thus the danger to Pine Snakes is much larger than the actual developed land. Wonton killing of snakes can be reduced mainly by educational campaigns (see below). However, with increasing development in the Pinelands, this threat will no doubt become even worse.

Humans can also provide disturbances to Pine Snakes while they are basking, nesting, moving, or hibernating. Intense disturbance during nesting can force females to abandon preferred sites, or to take longer to dig the nests, exposing them to further predation. These disturbances are likely to increase, rather than remain stable, because of increased development and recreational visitation in the Pine Barrens.

If a gravid female Pine Snake is approached too closely while she is digging, she will abort the nest opening and seek cover. If the person remains at or near the nest site, or returns on subsequent days, the female snake may abandon the nest site altogether. Thus frequent human disturbance near a nesting area can render this area unsuitable. Similarly, basking Pine Snakes will move or leave if people disturb them by approaching too closely. Normally, Pine Snakes that are disturbed near their hibernacula will quickly go back into the hole.

Road Kills

Many snakes are killed on roads (Fitch 1949, Andrews and Gibbons 2005), including Pine Snakes. New road construction removes available habitat and fragments it, but there are also a number of other secondary adverse effects, including population isolation, increased human and predator incursion, increased sedimentation, changes in temperatures, chemical pollution and human disturbance (Forman et al. 2003). Within Pine Snake habitat, however, the most severe threat is often from old, existing sand roads that serve as predator corridors and places where unthinking people run over snakes that cross the road. It is difficult to obtain evidence of Pine Snake mortality on forest sand roads, largely because determining how many snakes cross the road, and how many snakes are present in a given area is difficult. Golden et al. (2009) reported that of 536 Pine Snake records submitted to the Biotics database, the dead on the road snakes accounted for 23 %. While it is difficult to interpret this figure, it clearly indicates that Pine Snakes are being killed on the roads in the Pine Barrens.

Off-Road-Vehicles

One of the major forms of human disturbance, which is also increasing in New Jersey, is the occurrence of off-road vehicles (Table 5). These vehicles destroy nests and hibernacula when they repeatedly run over them.

First, the vehicles churn up the sand, making it less suitable for nesting or hibernation sites. If the sand is too loose or soft, the nest burrow will keep collapsing and the female may not be able to construct the end chamber for her eggs (Burger and Zappalorti 1991).

Secondly, once there is a nest there, repeatedly driving over the nest churns up the sand and may collapse or destroys the nest, crushing the eggs or hatchlings beneath, or exposing them on the surface.

Thirdly, repeated off-road vehicle activity can lead to a decline in the recruitment of hatchlings to the population (Burger et al. 2007). The documentation of this off-road vehicle activity occurred at a state-protected forest (Bass River State Forest; Burger et al. 2007). This negates the argument that Pine Snakes are protected on state lands. Protection of land is only as good as the enforcement that protects the animals themselves.

Poaching

Poaching is another major threat, and again, there is no indication that this problem has or will decrease. References to “taking” of Northern Pine Snakes date back to the early 1900s (Kauffeld 1957). Indeed as collecting for the pet trade becomes more popular, the pressure is likely to increase. The Pine Snake is highly desired by collectors because of its striking black and white pattern. When we were monitoring nests of our marked Pine Snakes, we found that 23 of our 80 Pine Snake burrows were poached overall, and in some years the rate was as high as 40% (Burger et al. 1992). The sand pattern and dump-pile differs between when a nest is dug up by humans and predators, and often the type of mammalian predator can be identified by their foot prints.

Table 5. Predation and Causes of Death to Pine Snakes in Burlington, Cumberland and Ocean Counties, New Jersey (after Burger et al. 1988, 2007, Burger and Zappalorti, unpublished data). For snakes that were killed by predators on the forest surface, we give the number of confirmed killed by bird and mammal[a]

CAUSE OF DEATH OR TYPES OF PREDATION	SNAKES IN WINTER DEN	SNAKES OR EGGS IN NESTS	SNAKES ON SURFACE
Years of Observations	1986 - 2000	1976 - 1991	1965 - 2010
Number of years studied	20	15	45
Scarlet snake (*Cemophora coccinea*)	0	2	0
Short-tailed shrew (*Blarina brevicauda*)	2	0	0
Eastern Coyote (*Canis latrans var*)	1	8	10
Striped skunk (*Mephitis mephitis*)	4	1	0
Red fox (*Vulpes fulva*)	2	10	2
Red squirrel (*Tamiasciurus hudsonicus*)	1	0	1
Red-Tailed Hawk (*Buteo jamaicensis*)	0	0	12
Human Poaching	43	80	-
Sand Road Kills	-	-	4
Paved Road Kills	-	-	180
Off-road Vehicles in Nesting Areas	-	10	-
Number of Nests Churned-Up	-	37	-
Forest Fire	1	-	6
Total	54	148	215

a = A hibernacula could have been destroyed one year by predators, and used by snakes in subsequent years of our study.

Unfortunately, although we can determine whether a nest has been dug up by a predator or person, if it's a communal nest we cannot determine if the poacher obtained only the clutch of eggs or was able to capture a gravid female as well. Any type of poaching has a serious impact, but removing breeding females is particularly worrisome. There is little that can be done about this other than rigorous surveillance and law enforcement at the height of the nesting season. Poachers know or learn (via the Internet), the nesting areas to which females regularly return, because the snake nests have obvious recognizable features.

Although relatively rare, poachers sometimes dig up hibernacula, and take all the snakes they find. In 25 years, the hibernacula in our hibernation studies have been dug up only once, largely because we camouflage them and no pipes or other indications are visible on the surface. Unfortunately, some poachers have discovered other artificial dens and have dug-up the entrance pipes, or the entire hibernaculum, and removed Pine Snakes. We have documented this illegal disturbance on five different occasions. Presumably, the poachers have seen snakes at the entrance pipes of hibernacula, watched them go down into it, and then dug down to obtain the snakes (Zappalorti, pers. observ.).

Conservation

Conservation measures to address direct killing and poaching include educational campaigns and enforcement of laws and current non-game regulations. Pine Snakes are listed as a threatened species in New Jersey, and it is illegal to kill or collect them without appropriate NJDEP permits. If caught by a Conservation Officer, making examples of poachers, both publicly and with high fines, may be a deterrent.

Accidental killing on highways and sand roads may be prevented by posting signs such as: *Motorist, please be alert for snakes and other wildlife on the road*. By increasing awareness of snakes, and the need to drive more slowly on sand roads, caring people will avoid running over snakes and other wildlife. Building tunnels under roads as passageways for snakes may work for major highways, but will not work for sand roads because there is no way to have a sufficient number of tunnels to funnel the snakes under the road. There are approximately 20,000 miles of sand roads in the Pine Barrens, making it impossible to build enough tunnels along all the sand roads in the forest.

Intentional killing of Pine Snakes, and other snake species, is more difficult to manage, and only educational campaigns and public peer pressure may reduce this cause of mortality. The message that Pine Snakes are not dangerous and do not inject venom needs to reach the public. For many years the Pine Barrens Treefrog (*Hyla andersonii*) has served as an icon for the Pine Barrens, perhaps it is time to elevate the Pine Snake as an icon of the Pinelands as well.

INVESTIGATOR EFFECTS

Understanding Effects

Finally, it is incumbent upon well meaning investigators to try to reduce the effects they have upon the behavior and ecology of their study organisms. As part of their research they should consider gathering data on potential harmful impacts of what they are doing and to be able to demonstrate negative effects. To this end, we examined the effects of the methods we used over the past 25-years of this study (Burger and Zappalorti, ms). We evaluated both our work in the field and in the laboratory with eggs, hatchlings and adults. We found that:

1) There was no difference in the rate of re-sighting pine snakes as a function of whether they were branded or had passive integrated transponder devices (PIT tags) or radio-transmitters.
2) Over half of the pine snakes that were captured, handled, and marked were re-sighted at least 5 months later, and all were alive and healthy.
3) Females that were diggings nests generally did not permanently abandon their nests (88 %), regardless of whether they were branded or injected with PIT tags.
4) Females that were observed excavating a nest tunnel from farther than 30 m did not abandon their nest sites.
5) Captured, handled and marked females continued to use the same nesting sites in successive years (65 %).

6) The number of nests that hatched successfully did not differ significantly as a function of not being opened (72 %) or being opened (62 %).
7) Hatching rates for all eggs found in nests in the wild was only 53 % (due to poaching and predators), while the hatching rate in the laboratory ranged from 92 % to 95 %).
8) Eggs hatched in the laboratory under similar hatching conditions as those in the wild, had similar hatching rates to those in nests that hatched in the field (where at least some eggs hatched in the nest, 92 % vs. 91 %).
9) Eggs incubated in the laboratory at low temperatures (21-23^{o} C) had lower hatching success (55 %) than either eggs in natural nests or eggs incubated above these temperatures (over 90 %).

Long-Term Research Project

Our longest continually-running study involved excavating 7 to 10 known hibernacula, measuring and marking all snakes, and following their movements between and among hibernacula (Figure 15). We found that:

1) Excavated hibernacula that we studied were only abandoned due to predators, land development, poaching, and wildlife habitat management.
2) Nearly half of the snakes handled while hibernating were found one or more times in successive years in the reconstructed hibernacula, and 28 % were found three or more times in the hibernacula.
3) The three Pine Snakes from hibernacula that were re-captured the most were found repeatedly in 12, 16, and 18 different years.

Taken altogether, these data indicate that pine snakes are remarkably resilient to the effects of our investigations, because they return to the same nest and hibernacula sites regardless of being handled, branded, fitted with PIT tags, surgically implanted with radio-transmitters and released back to their exact collection sites. We hasten to say that we are always very careful when handling the snakes. We follow specific field procedures to reduce disturbance, to excavate hibernacula very carefully, and to rebuild them the exact same way. We never disturbed the earth or leaf litter around the entrance so that we did not remove the chemical scent trails of the snakes (Ford 1978, 1986; Burger 1989a).

The Pine Snakes are returned to the field or hibernacula as quickly as possible (often in a couple of hours after removal). We moved carefully and quietly around females that were digging nests and laying eggs. Special attention was always devoted to removing any evidence of our work to prevent both poachers and predators from having easy or obvious access to the critical habitat of the Pine Snakes.

Conservation

Reducing effects due to research requires vigilance on the part of all investigators and their crews to ensure that all necessary precautions are taken at all times to reduce harmful effects on Pine Snakes. Exchanging information on handling and processing techniques among researchers that work on different species of snakes, but may encounter Pine Snakes, is another useful method of increasing awareness for all species of snakes.

A Conservation Strategy

Risk To Pine Snakes

Pine Snakes in the New Jersey Pine Barrens are a vulnerable population because they are isolated, require large tracts of land, and already have diminished numbers because of development. The main threats are loss of habitat, fragmentation, loss of suitable nesting and hibernation sites even within appropriate habitats, increased human disturbance and poaching, and increased numbers of predators, partly as a result of increased human populations, and development.

Figure 15. Joanna Burger and Robert Zappalorti in Pine Snake hibernacula during their 25 year study with this species, as well as Burger in one where we have not yet reached the hibernating snakes (top). These hibernacula were used for this entire period of our study.

Using the information and data presented in the above sections, we developed a conceptualization of the relative risk that Pine Snakes face from different stressors (habitat loss, road kills, poaching, predation) as a function of stages in their life cycle. Habitat loss and fragmentation affect all ages and stages similarly, and the threat is very high, and will be amplified with increasing habitat loss and fragmentation.

All other threats depend upon the particular life stage (Figure 16). Snakes are more vulnerable when they are moving from one point in their habitat to another because they may cross open areas, roads or other barriers. Their movements attract the attention of predators and they may attract the attention of snake poachers. Hatchlings are particularly vulnerable when emerging from nests because odors are released that can attract predators. Likewise, the hatchlings are in danger as they enter winter hibernation sites. Adult males are vulnerable in the early spring as they seek females, and females are vulnerable during their nesting and egg-laying season. All snakes are vulnerable when they bask, forage, during seasonal movements, and particularly when they cross roads or other developed areas.

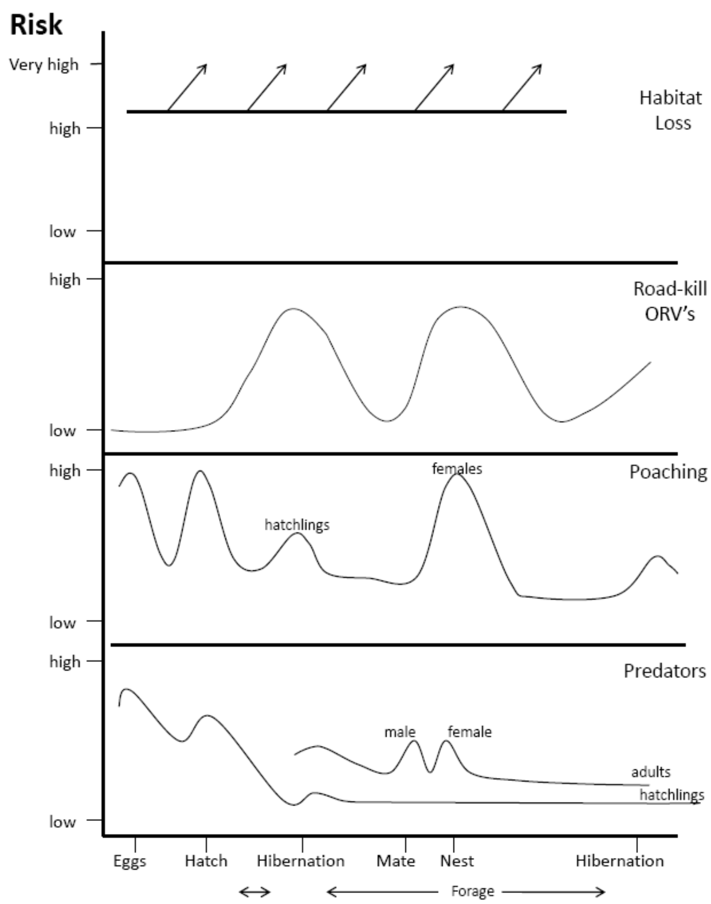

Figure 16. Relative risk of stressors on Pine Snakes as a function of stage from the egg stage to hibernation. Habitat loss is the greatest risk, and increases with increased habitat loss and fragmentation. Road kills have the greatest effect during periods of movement (from and to hibernacula, seeking mates and courtship). Poaching risk is highest when snakes are visible (in nests, when moving, or near hibernation sites). Predators also key into visibility of snakes.

The risk is not only due to life stages, but to size (Figure 17). The threat from road kills increases with age because older snakes move more in search of mates and nesting sites (as opposed to pre-breeding sub-adult snakes who remain in the forest). The risk from poaching is highest for eggs, hatchlings and/or adult females because nests are visible due to dump piles or the presence of digging females, and the hatchlings are vulnerable when piping releases egg content odors. The risk of predation, however, decreases as size increases as they become too large for many of their predators. However, the risk from habitat loss in the Pine Barrens is equal for all sizes and is the greatest threat that Pine Snakes may face. State biologists and habitat managers can use Figures 5,15, and 16 to better understand the risks that Pine Snakes face on their lands. Public policy makers can use this information in combination with data on specific Pine Snake life history aspects to determine appropriate policy and listing status. For the general public, the figures and tables will provide a foundation for understanding the threats that Pine Snakes face in the wild.

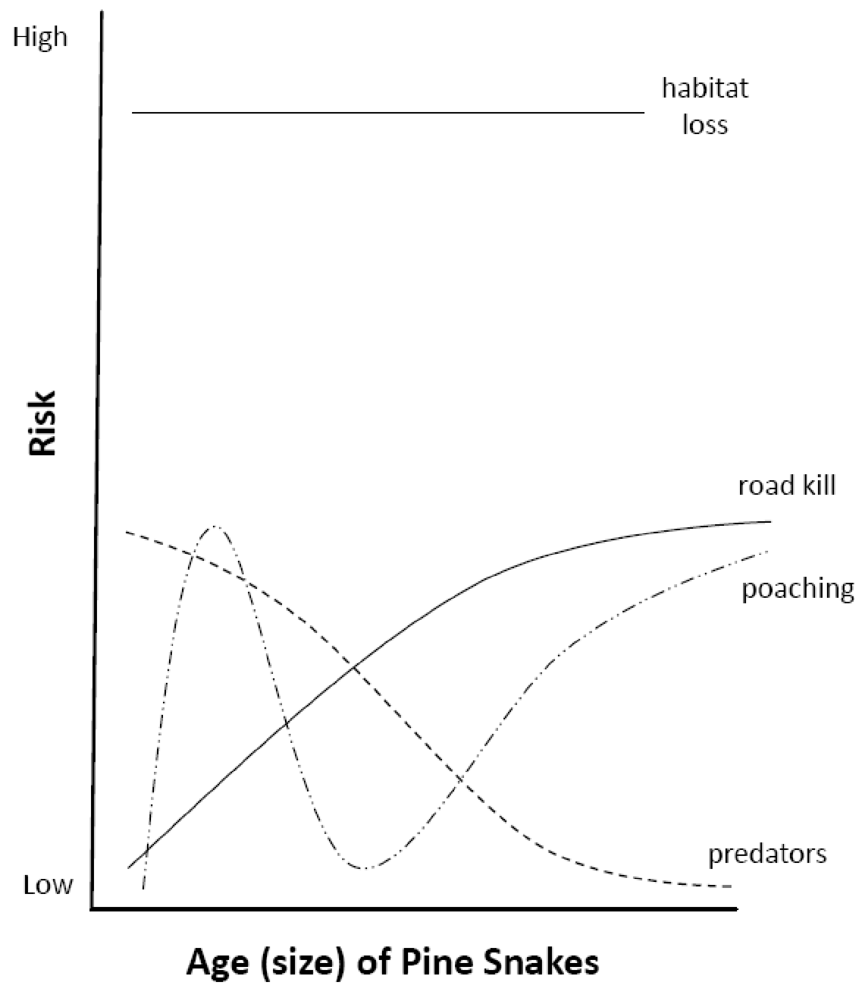

Figure 17. Relative risk of different stressors on Pine Snakes as a function of age (and relative size). Habitat loss is clearly the greatest threat, and affects all ages and sizes equally, while the effects of other stressors differ as a function of snakes of different sizes.

Protecting Pine Snakes

Protecting Pine Snake populations will require a number of actions on the part of scientists, managers, public policy makers, legislatures (retaining its threatened status), and the public (Table 6). The NJDEP's listing as threatened, ensures that developers, land owners, and governmental agencies, as well as the conservation community, will continue to look after the welfare of Pine Snakes.

Additionally, being a threatened species requires that developers have to conduct specific studies to ascertain whether there are Pine Snakes on properties slated for development. Protection from poachers also receives higher priority for a listed species.

Table 6. A Conservation Strategy for Pine Snakes in the New Jersey Pine Barrens.

Legal

1. Maintain its status as a Threatened Species
2. Enforce protection as a Threatened Species
3. Enforcement and protection of nesting females
4. Enforce applicable laws and regulations to protect habitat

Habitat Protection

1. Reduce habitat loss and fragmentation
2. Evaluation loss of habitat on a local and regional scale so that populations are not isolated.
3. Develop corridors that can connect nesting and foraging habitats that are too small on their own to maintain viable populations
4. Identify suitable nesting and hibernation sites to maintain the open requirement for sun penetration, particularly for nesting.
5. Prevent off-road-vehicle access to nesting areas.
6. Identify and provide special protections for known healthy populations that can serve as founder populations.
7. Build hibernacula to protect vulnerable populations.
8. Maintain (by clearing or preventing succession) known nesting areas within Pitch Pine-Scrub Oak uplands.

Human Disturbance

1. Post, or protect by, barriers nesting and hibernation sites from disturbance
2. Post areas with viable populations to encourage local protection
3. Encourage local land-owners (and state land owners) to be aware of nesting areas and increase protection during the nesting season.
4. Reduce off-road-vehicle entry into nesting areas

Education

1. Educate local and state officials of the importance of Pine Snake habitats and mosaics necessary to maintain viable populations
2. Educate land owners and community members to create stakeholders that will protect Pine Snakes, erect signs, and work to reduce disturbance from dogs.
3. Educate snake collectors on the importance of not collecting wild Pine Snakes or their eggs, and to self-enforce these protections.
4. Work toward curriculum changes in local schools to include the importance of top-level predators such as Pine Snakes, how to recognize them, and how to protect them.

Habitat protection remains the most important key to protecting Pine Snake populations in New Jersey. This includes not only maintaining sufficiently large patches of land, with interconnections to smaller patches or corridors, but maintaining suitable nesting and hibernation areas. Maintaining suitable habitat is largely a legal matter, as well as employing a landscape approach to making sure that large enough viable habitats are maintained. State agencies should not allow scattered and piece-meal development which results in habitat fragmentation and small patches of land unsuitable for Pine Snakes, which may isolate populations that cannot maintain viability. Specific habitat measures can include construction of predator-free hibernacula, and maintaining open areas needed for nesting.

Conservation Officers should actively patrol known nesting areas and hibernation sites during appropriate seasons. This action is crucial to protecting Pine Snakes during critical life stages. Protection from poachers and off-road-vehicles (ORV) remain high priorities for the on-going conservation of Pine Snakes. As for ORVs, it is often a matter of staying one step ahead of them by constructing whatever barriers are required to keep them out of sensitive nesting or hibernation areas. Signs are not enough, it takes physical barriers, with some law enforcement. Poaching is more difficult to deal with since poachers are constantly vigilant for law enforcement personnel, and can easily release a snake when they see an approaching officer. It may be necessary to patrol these important Pine Snake areas, but the presence of Conservation Officers can alert poachers to an area that they were unaware of.

In the end, education and an enlightened public (and public policy makers) are essential to the on-going protection of Pine Snakes (Figure 18). Having a citizenry that is attuned to the importance of protecting Pine Snakes (and other rare wildlife), is vigilant for poachers or ORV intrusion, and is willing to defend the habitat requirements of the snakes may be the best way to encourage long-term protection for Pine Snakes.

Conclusions

A viable population of Pine Snakes at the northern limit of their range is isolated in the New Jersey Pine Barrens. Their continued existence depends upon its threatened, legal status, protection of the mosaic of habitats they require for their life cycle, maintenance of suitable nesting and hibernation sites, reduction of poaching and intentional killing, and educational campaigns aimed at fostering knowledge and appreciation of these top-level predators. The New Jersey state agencies, conservation organizations, researchers and the public have a clear mandate to continue protection and educational efforts toward this end, especially given the bad public image some people have about large snakes. Education may reduce people's fear of snakes and help with the long-term survival of this species in the Pine Barrens. Pine Snakes should be made an iconic symbol of the Pinelands.

Figure 18. Education is an important aspect of protecting Pine Snakes, and it is particularly important for young people to value snakes and participate in research with them. Shown here are (from left to right) Jake DeVito, Isabel DeVito, Natalie DeVito, Maya Serabian, Jenna DeVito. They are holding the snake between our behavioral measurements and measuring to ensure correct identifications.

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APPENDIX.

SPECIAL HABITAT REQUIREMENTS FOR MAINTAINING STABLE NORTHERN PINE SNAKE POPULATIONS

OVERLAPPING IMPORTANT TOPICS

Throughout this book we discussed factors that are important for maintaining healthy and viable Northern Pine Snake populations in the New Jersey Pine Barrens. Aspects of habitat selection were mentioned in sections on nesting behavior, foraging and maintenance, and hibernation behavior. There are three aspects of protection and conservation that should be especially emphasized, and we describe these below. They are topics that overlap or dove-tail with the different behavioral categories and life history stages discussed. We provide conceptual models and data for how each of these might function with respect to both habitat selection within the Pinelands, and the snake's ability to maintain healthy populations so far north, compared to conspecifics living elsewhere in southeastern United States. In order to better understand these topics and gain more scientific data for their conservation, further investigations are recommended for Pine Snakes in New Jersey, and farther south.

OPEN AREAS WITH ADJACENT FOREST

Pine Snakes require suitable habitat for all seasons and stages of their life cycle, including places to hibernate and to nest. In the following section we argue that one of the most critical habitat requirements for Northern Pine Snakes in New Jersey is the presence of manipulated and managed open areas adjacent to a mixture of sparse and dense Pine-Oak forest. Open areas are required for nesting while grassy fields are optimal foraging habitat for small mammals and birds (Figure A-1). Hibernation sites may be selected based upon existing forest habitat conditions and underground hole availability. Forest openings must be maintained by state wildlife management and/or NGO conservation agencies in the absence of other means of insuring sufficient ecotone habitat. In the past such openings were maintained by natural or human caused fire, or forest openings created by hunt club management, or the creation of small farms and commercial agricultural plots (e.g., blueberry farmers). With the disappearance of Piney hunt clubs and small farms, natural succession in many of the open areas has resulted in them becoming less suitable for Pine Snake nesting. Small pine trees, oaks and bushes are invading these once open areas.

Figure A-1. Habitat patches for Pine Snakes include open areas for nesting (top) and for hibernation sites (top and bottom).

Given the environmental climate in the New Jersey Pinelands, and if eggs hatch that were incubated at lower temperatures, hatchling Pine Snakes are behaviorally impaired and suffer lower survivorship (Burger 1989b, 1991a). Therefore, reproduction will be increased by maintaining undisturbed open, sandy areas with complete sun penetration, where the sand is not churned up by off-road vehicles or motorcycles, and young can emerge undisturbed (Figure A-2) (Burger et al. 2007). Nesting places must have stable sand with a few sparse plants with roofs that prevent the collapse of nesting burrows. Similarly, hibernation sites located in relatively open habitats or in areas with sparse Pine-Oak forest have greater sun penetration than those in very dense forest.

In both cases, the sun (solar heat) is the salient feature of the open areas that is critical. Pine Snakes have some options - they can modify the depth of the nest or hibernation site to compensate for the environmental conditions. However, there are costs associated with increasing the depth of nests and/or hibernation sites (see Figure A-3). If a female has to excavate her nest deeper in an open area, then she would be expending more energy digging while adding more time exposed to extreme heat and predators. If they dig a shallower nest tunnel and chamber to increase the incubation temperature, then the nests would be more vulnerable to predators because of increased odor at the surface, and the sand above the nest may collapse. The eggs and/or hatchlings would be more vulnerable to possible disturbance from off-road vehicles and other traffic that might destroy the nest. Hatchling Pine Snakes dig upward through the sand to reach the surface during nest emergence (see b on Figure A-3). Unlike other subspecies of Pine Snakes farther south (Florida Pine and Black Pine), who have hole providers such as Gopher Tortoises *(Gopherus polyphemus)*, Pocket Gophers (*Geomys pinata*) and Nine-banded Armadillos (*Dasypus novemcinctus*), New Jersey Pine Snakes dig their own nests and tunnels, and do not rely on those of mammals which may provide ready-made opportunities for several different depths.

Figure A-2. Hatchling Pine Snake emerging from its nest site in late August. Note other hole where another hatchling emerged (white arrow).

Similarly the depth of Pine Snake hibernation chambers and entrance tunnels could be shallower, depending on their location relative to sun/heat penetration, but the snakes run the risk of not being deep enough. If there is a sudden cold spell or early frost (see c on Figure A-3), and digging deeper is not possible because the snakes come against hard-packed gravel/sand layer which they cannot penetrate to dig deeper tunnels, the snakes will freeze. Most winter den sites allow the snakes to move higher or lower within the entrance tunnel(s) and chamber system. While it is possible for snakes to move downward when the temperatures are still well above freezing, if they are not below the frost-line the cold precludes movement by the snakes and they may freeze. Even so, there is some shifting within the hibernacula tunnels during the winter, and in some cases, snakes even come out and bask if surface temperatures are above 18 degrees C. in January, February or March.

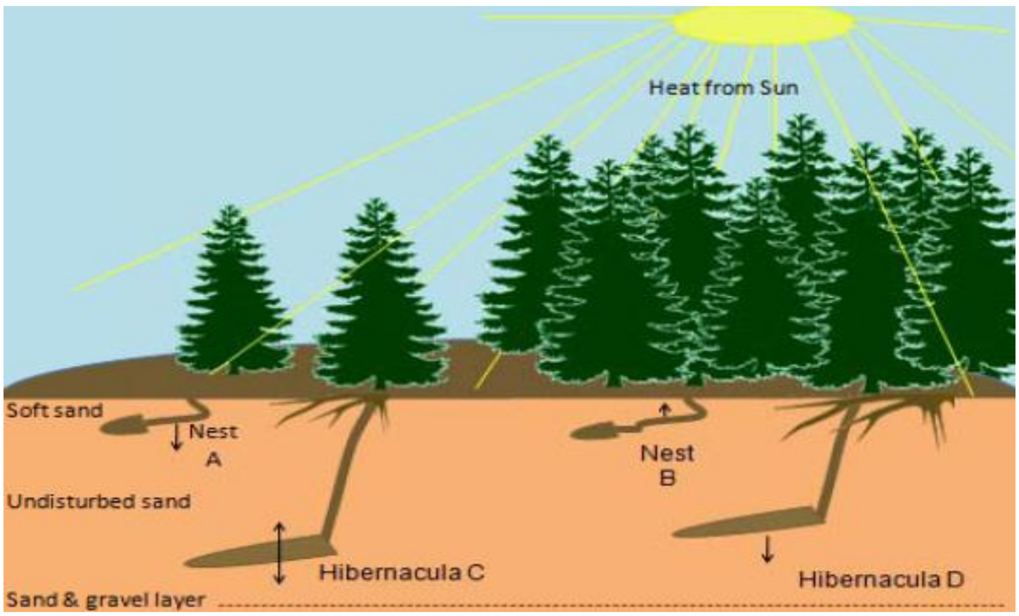


Figure A-3. Schematic of the effect of tree density on nest site selection, hibernation sites, and sun penetration. A is a natural nest site, and B is a hypothetical one in a dense forest. C is a natural hibernation site, and D shows how it may need to be deeper in dense forest.

As discussed in the chapter on nesting behavior, Northern Pine Snake females use the same exact nest site for many years. These nest sites are normally in the open (or in sparse forest) where there is complete (or nearly complete) sun penetration to the ground (Burger and Zappalorti 1986). Thus, known nesting areas are extremely important for the maintenance of viable Northern Pine Snake populations. In some case, several females use the same open "nesting areas." That is, we have found from 8 to 12 females excavating tunnels in the same traditional nesting areas (Burger and Zappalorti 1992, unpublished).

Similarly, Pine Snake hibernacula may be used extensively for several years by the same snakes (Burger et al. 2007). We have followed the use of seven Pine Snake hibernacula for 25-years, and found that although no one hibernaculum is used every year, they continue to be used by various Pine Snakes from the population (Table A-1). As previously discussed, snakes shift hibernacula from time to time for an assortment of reasons which include:

1. Voluntary switch to another den the snake has used in the past.
2. Early frost forces the snake to choose a closer den within its home range.
3. Traditional winter den was disturbed or invaded by mammal predators.
4. Traditional winter den was destroyed by human construction activities.

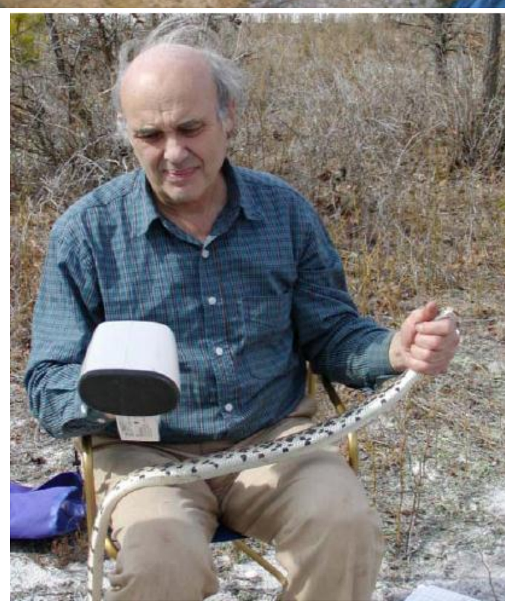
Coyote, Fox, Skunks, Raccoons and even Red Squirrel invasions can force snakes to abandon a given hibernaculum, but in our experience, the snakes eventually come back to that hibernaculum if the predators abandon the site. They could not, however, do this if their overwintering habitat has been destroyed.

Table A-1. Use of Northern Pine Snake hibernacula over a 25 year period. A circle indicates that it was occupied by at least one snake that winter. (1986 is the winter of 1985-1986 since they were checked in late winter each year)

	Buck Run Lodge			Ed's Place			Davenport Natural	
		No. 1	No. 2	No. 3	No.4	No. 5		
1986	●	●	●		●			
1987	A	●	●	S	●			
1988	●	●	●				●	
1989	●	●	●				●	
1990	●	●	●	S	●		●	
1991	●	S	●		●	●	●	
1992	●	●				●	●	
1993	●		●				●	
1994	●	●				●	F	
1995	●					●	F	
1996	●	●		●		●	●	
1997	●	●				●	●	
1998	S	●		●		●	●	
1999	●	●	●				●	
2000	●	●			●		●	
2001	●	●	●		●		●	
2002	S	●			●		●	
2003		●	●	●			●	
2004		●	●		●		●	
2005	●	●	●	●			●	
2006	●	●	●	●	●		●	
2007		●	●		●		●	
2008	●	●		●			●	
2009	●	●				●	●	
2010	●	●	●		●		●	

A= dug up very late in April, so we missed snakes; S= skunk present; F= fox.

The use of the same winter den sites by snakes year after year argues strongly for conservation and protection of areas with hibernacula. More important, there is also a behavioral component by the snakes that makes it even more imperative to protect known winter hibernation areas. Even though a given hibernacula may be “suitable” because it remains available and/or there have been no predator invasions, a Pine Snake may choose to use a different den in a particular year. For example, one marked Pine Snake that we have followed for 23-years (initially branded and subsequently pit tagged), used all five known hibernacula at our study area in different years.



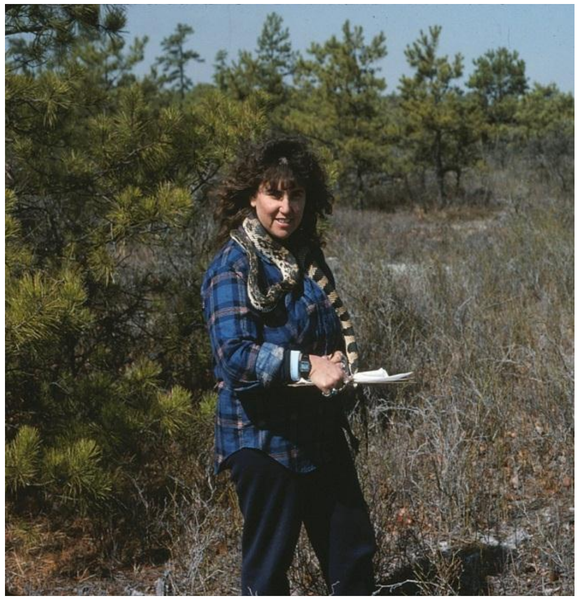


Figure A-4. In the beginning, we dig a small hole (previous page, left), enlarging it as needed. Once we find the snakes we take the soil temperature (previous page, right, R. Zappalorti). Then we scan the snakes for pit tags (top, M. Gochfeld), and record other characteristics (bottom, Joanna Burger).

During our annual March "Snake Dig," we found this same snake 19 times, which means that in 4-years of our investigation it used a nearby hibernaculum that we have not located (Figure A-4). Long-term data such as these, as well as data from other snakes, suggests that Pine Snakes learn where suitable overwintering sites are and select a particular site each year. However, we do not yet fully understand what factors the snake(s) might have used to do so.

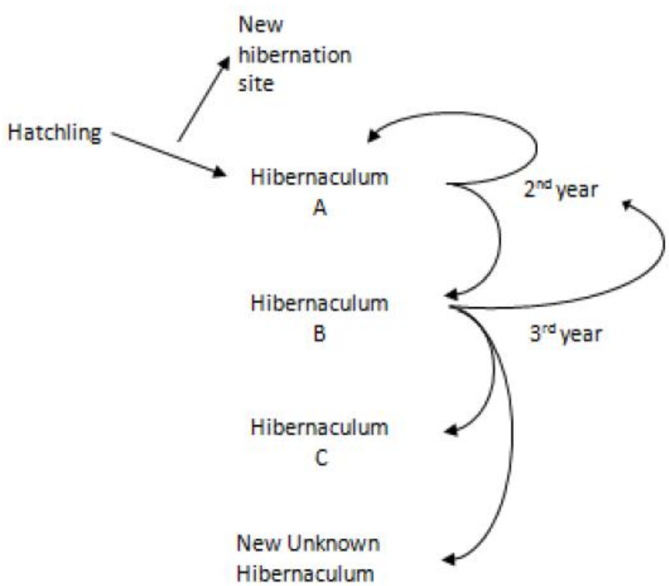


Figure A-5. Model of hibernation choices available to a hatchling as it ages.

Thus snakes have the following choices, and each of these has been demonstrated in our long-term study with hibernating snakes (Figure A-5). A hatchling may choose to find its own hibernation site during its first winter (often deep in the roots of a dead rotting stump hole), or it may follow the scent trail of a conspecific to an established hibernacula and learn where it's located. The following year it may return to the same site it used the previous year, or the snake may select another one and so on. Thus, in a given year a snake has choices, which may relate to its location relative to the onset of cold weather, distance to a previously-used site, or other factors cited above. Protecting and maintaining these areas with known hibernacula is not only smart conservation practice, but it increases the overwintering survival of the Pine Snake population.

Patch Size and Dispersion

Habitat loss was discussed extensively in this book as a critical aspect of maintaining viable Pine Snake populations within the New Jersey Pinelands. We suggest, however, that the overall size and shape of that minimum patch area matters and is important for conservation reasons. This figure shows a number of possible configurations, with the same spatial area. Clearly having one contiguous, large area is optimal (see a on Figure A-6). Even here, however, the shape matters. A circle or square provides the most area with the least edge. Edges provide places for predators and humans to enter the area, resulting in predation, human disturbance, or poaching.

If the same area were elongated even further (but still contiguous), again the edge areas would be increased, allowing for disturbances and increasing the likelihood that snakes may wander onto newly constructed roads, adjacent unprotected land or into unsuitable habitat. As an example, a long, relatively narrow utility right-of-way may contain over 600-hectares of land, but without large tracts of undeveloped forest on both sides its narrowness would render the habitat unsuitable for maintaining a viable Pine Snake population. Both adult and young Pine Snakes could wander into housing developments or shopping malls and be killed. Similarly, both natural and human-commensal predators would be more likely to invade the unsuitable habitat.

One of the great dangers in the New Jersey Pinelands is to fail to maintain areas with the minimum patch size (e.g. 607.5-hectares), and to divide them up in such a way as to reduce their suitability to maintain viable populations. Figure A-6 shows several possible scenarios for land with the same overall area. As is clear, each of these (except for A) has potential problems. Maintaining corridors that connect suitable habitat (as is shown in b and c on Figure A-6) provides a possible pathway for snakes to move between the two suitable habitat patches, but exposes them to predators and the possibility of their wandering outside of the suitable habitat. The width of the corridor is obviously critical in determining whether the snakes can easily make use of both parts of the protected habitat. The length is also critical because Pine Snakes normally move 5km or less within their home range.

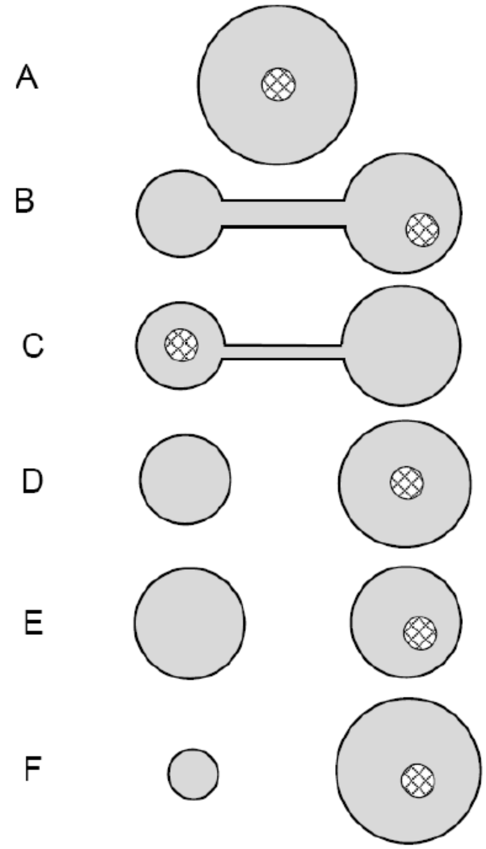


Figure A-6. Schematic of different configurations for habitats of the same area. Figure shows the degree of separation of habitat patches that render some areas no longer usable (e.g. F).

Finally, having nearby habitat patches separated completely by unsuitable habitat (e.g., a shopping mall, a senior citizen housing development, or a new highway), is the worst possible option because there is no opportunity for the snakes to move safely between the suitable habitat patches. Movement through housing developments, shopping centers, or over roads exposes them to various dangers such as predators, motor vehicle traffic, unknowing humans, and death or injury on roads. If two such protected areas were traditional habitat for a Pine Snake population, then the snakes may move between these areas that have historically been part of their home ranges, but will incur injuries or mortalities.

The possible configuration of protected and suitable habitats shown in Figure A-6 lend themselves to further study and hypothesis testing, both with regard to the minimum size necessary to maintain a viable Pine Snake population, and to the types of configurations that may be most suitable. It may be found that with different configurations, the viable minimum population size increases. This would be easier to study if Pine Snakes themselves were easier to census with any accuracy in a relatively short period of time. However, it is extremely difficult and time consuming to census them on the scale necessary to study the effect of patch size and dispersion.

Figure A-6 also shows the location of a possible nesting area (hatched circle) within each configuration. Again, the relative location of nesting areas should be considered when determining the boundaries of protected Pine Snake habitat. Optimally, nesting areas will be as near to the center of the habitat as possible, which allows maximum protection for hatchlings, juveniles and adults. Clearly, of the options shown in Figure A-6, c is the worst option because the nesting area is located in a relatively small habitat patch, and a viable population would likely be required to move to the larger habitat patch to forage. Finally, Pine Snakes would likely avoid the small patch in F because it is too small, not directly connected, and has too much edge area for the center. Adding additional small patches does not markedly increase suitable habitat because the areas are too small and too isolated to contribute to a viable population.

SEASONAL USE

The obvious seasonal use emphasized in this book is the requirement for hibernation habitat as well as habitat for Pine Snakes to breed, nest, and forage, and to carry on their daily activity patterns (resting, seeking sun, shade, or protection from predators). Suitable nesting habitats have been described extensively in the book, as well as in the above section of this appendices.

Figure A-7. Pine Snakes use different habitats for resting (top) and copulation (bottom), among the other behaviors.

However, a matrix of habitat types are required for the snake’s seasonal use and prey base availability and optimization. That is, one type of forest or ecotone habitat may have a higher prey density (or availability) at different times of the year. Likewise, temperature, moisture and shade conditions also vary in different habitat types and at different times of the year. As shown in Tables 2 and 3, and in figure 7, in the main text of this chapter, several different habitat types are necessary for a viable Pine Snake population, including these with sparse vegetation (Figure A-7).

However, these various habitats are also used at different times of the year, making some areas within the habitat seem less important when overall percents are considered, but if it's a nesting area, then that portion is more important at a specific time of year. Although a particular habitat may be used only 10 % of the time when compared with the overall habitat selected by the snakes, that 10 % may represent a critical life history behavioral function. In one radio-tracking study, most Pine Snakes were re-captured in the uplands in the spring and early summer, and again in fall. In mid-summer many of these same Pine snakes were found foraging in the lowlands, and some were even in Cedar Swamps or Pitch Pine Lowlands where it was cooler and easier to find small mammal prey and drinking water. Most Pine Snakes that were radio-tracked for two or more years were using both upland and wetland habitat types.

These data indicate that even though upland Pine-Oak forests may provide the traditional habitat requirements such as nesting sites and hibernacula, other habitat patches are used and required in order to maintain optimal Pine Snake populations. The exact pattern of movements between different habitats by individuals within and among a Pine Snake population, as well as other snake species, requires further intensive long-term study.

CONSERVATION IMPLICATIONS AND SUMMARY

The conservation implications of all three of these general requirements are clear – Northern Pine Snake populations will flourish in the New Jersey Pinelands if rare species wildlife managers, conservation organizations and other NGO groups attend to landscape scale issues of habitat requirements

If Northern Pine Snakes are to remain part of New Jersey's natural heritage, then it may not be sufficient to apply a minimum size for viable populations, without attending to the configuration of that habitat patch. Likewise, it may not be sufficient to protect forest areas with only one or two types of habitat patches, instead the maximum diversity of the patch types should be provided because it is essential in order to provide adequate foraging, ground cover, open nesting areas, and dense Pine-Oak forest within the protected land area. Smart habitat manipulation and management maintenance for Pine Snakes includes providing basking areas for thermoregulation, a source of drinking water, building log and stump mounds for shelter and cover and diverse prey resources. We encourage future snake ecologists and management researchers to examine some of the landscape scale issues that can affect population viability, if not with Pine Snakes, then with other rare snake species (Figure A-8).

Figure A-8. Open areas, appropriate patch size, and suitable habitats for all behaviors and seasons are required to maintain healthy Pine Snake populations.