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CONSERVATION AND PROTECTION OF THREATENED PINE SNAKES (*PITUOPHIS MELANOLEUCUS*) IN THE NEW JERSEY PINE BARRENS, USA

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***Abstract.*—Managers, regulators, and the public are interested in the conservation of threatened, endangered, or iconic species. While snakes are not usually thought of as iconic, Pine Snakes (*Pituophis melanoleucus*) are an indicator species of the New Jersey Pine Barrens. In this paper we examine the threats Pine Snakes face, and measures undertaken to reduce these risks. Major threats include habitat loss, fragmentation, increasing numbers of predators, declining prey base, forest fires, poaching, off-road vehicles, and an increase of road traffic. Over the 40 + y of our study, the largest disruptions to hibernacula and nests were by poachers and predators, while the highest mortality of snakes on the surface was a result of predation and road-kills. Poaching of adults is an important threat, but difficult to assess due to the secrecy of people illegally collecting snakes. Conservation measures include: (1) enforcing laws, regulations, and patrolling, (2) enhancing habitat for foraging, nesting and hibernation and use of cages or wire to protect nests in areas with high levels of predators, (3) accepting protocols for snake assessment prior to allowing development, (4) using clean clothing and equipment when entering snake areas (especially when fungal disease has been identified), and (5) educating conservations officers, regulators, and the public about the behavior, ecology, and role of Pine Snakes in the Pinelands ecosystem.**

Key Words.—conservation measures; environmental management; public participation; threats; sensitive species; reptiles

INTRODUCTION

We live in a complex and changing world, with more people moving to coastal regions, including associated uplands. More than one-half of the human population lives within 160 km (100 mi) of coasts (Crosset, K., T. Cultiton, P. Wiley, and T. Goodspeed. 2013. Population trends along the coastal United States 1980–2008. Available from http://oceanservice.noaa.gov/programs/mb/pdfs/coastal_pop_trends_complete.pdf. [Accessed 18 July 2016]). Coastal areas provide a wide range of goods and services to society, including clean water, recreation, fisheries, and aesthetics (Burger 1996; deGroot et al. 2002; Weis and Butler 2009; Costanza et al. 2014). With more people comes more development, land use changes, need for infrastructure and increased pressures on plant and animal communities. Encroaching urbanization reduces available habitat for wildlife and increases fragmentation (Zampella 1986). Animals living close to urbanized areas face additional stresses from increased contact with humans and their associated subsidized predators. The Pine Barrens is over 405,000 ha (one million ac) in size, lies between New York City and Philadelphia, USA, and is part of the central Jersey coastal system. Habitat loss, fragmentation, encroachment of urbanization and increased interactions with people are evident in the New Jersey Pine Barrens (Zampella 1986; Zappalorti and Mitchell 2008; Burger and Zappalorti 2011a).

Protecting sensitive plant and animal communities in urbanized and coastal areas depends upon understanding their biology, life-history traits, habitat needs, and threats. Worldwide, reptiles are declining at an alarming rate (Gibbons et al. 2000), especially in urban areas (Cook 2008), making it essential to learn as much as possible about their biology to help foster their conservation. The task of studying the biology of species usually falls to university and resource agency scientists, along with a range of other stakeholders.

Pine Snakes are an iconic species of the Pine Barrens and are an integral predator that can grow to over 2 m long (Sweet and Parker 1990; Burger and Zappalorti, unpubl. data). The genus *Pituophis* has three species in the US: Pine Snakes (*P. melanoleucus*), Bull and Gopher Snakes (*P. catenifer*), and Louisiana Pine Snakes (*P. ruthveni*). *Pituophis melanoleucus* has three subspecies: Florida Pine Snakes (*P. m. mugitus*), Black Pine Snakes (*P. m. loding*), which is federally listed as threatened (US Fish and Wildlife Service 2015), and Northern Pine Snakes (*P. m. melanoleucus*), which is listed as threatened in New Jersey (New Jersey Department of Environmental Protection. 2016. New Jersey's endangered and threatened wildlife. Division of Fish and Wildlife's Endangered and Nongame Species Program.

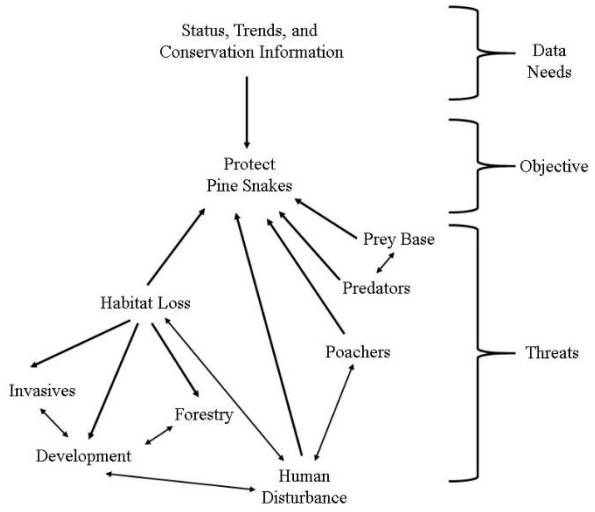

FIGURE 1. The interactions of major components and threats Pine Snakes (*Pituophis melanoleucus*) face in the New Jersey Pine Barrens.

Available from http://herpetologicalassociates.com/docs/Burger&Zappalorti%20Rep.Biol.Behav.Cons.2011.pdf

The New Jersey Pine Snakes are adept at burrowing, and dig their own nests, and modify and dig their own hibernacula (Burger and Zappalorti 1991, 1992; Burger 2006; Zappalorti et al. 2014; Burger and Zappalorti 2015). Pine Snakes are quite fossorial, and in New Jersey they are most active from mid-April to late-October (Burger et al. 1988), similar to Gopher Snakes (Rodrigues-Robles 2003). They nest in late June to early July, and incubation temperatures affect behavior and survival of hatchlings (Burger and Zappalorti 1988a; Burger 1989a; 1991a; 1998a, b). The young follow chemical trails to find hibernacula, and to avoid predators (Burger 1989b; 1990; 1991b; Burger et al. 1991).

There is almost no information about Pine Snake distribution and abundance in most other states (Virginia south to Alabama), although they are rare in all states (New Jersey Division of Fish and Wildlife 2009). The species is listed as threatened in New Jersey, but the New Jersey Pine Barrens appears to have a more stable population than the other states, although the species is still extremely vulnerable to habitat loss and alterations, fire regimes, and human activities, among other threats (Golden and Jenkins 2003; New Jersey Division of Fish and Wildlife 2009; Burger and Zappalorti 2011a). In this paper we examine the many threats and risks that free roaming Northern Pine Snakes (*Pituophis melanoleucus*) face in the New Jersey Pine Barrens. We provide examples of indicators of these threats, and suggest various conservation solutions. We present data on disruptions to hibernacula and nests, and causes of mortality for Pine Snakes over a 40 + y period.

MATERIALS AND METHODS

Our study of Pine Snakes has extended over 40 y, with the objectives of (1) understanding the biology of Pine Snakes, (2) understanding the threats and risks faced by Pine Snakes (and possible mitigation measures), and (3) protecting and conserving Pine Snake populations in preferred habitats. During this time we regularly monitored Pine Snakes in a number of nesting and hibernation habitats each year. Some were studied visually, some snakes were followed by radio tracking, and all Pine Snakes were marked with PIT tags (Burger and Zappalorti 2011b). Detailed methods for specific studies can be found in Burger and Zappalorti (2011a) and in the individual papers cited in the Literature Cited section.

RESULTS

Pine Snakes in the New Jersey Pine Barrens face a variety of threats to their existence (Fig. 1; Table 1), and different government agencies and non-governmental organizations (NGO) have been involved in various conservation measures for the species (Table 1). Some of the threats can be addressed by state agencies, and by other stakeholders (conservation groups, volunteers, and consultants), but other threats are a result of human demographic shifts, particularly the movement of retirees or people with summer homes along the shore, or vacationers to the Pine Barrens. These increasing human activities make the chances of snake encounters more likely, usually to the detriment of the snake. Some people move to south Jersey because they are close to the coast and home sites are less expensive in these inland areas. Increased numbers of people often result in the loss of large tracts (about 500–1,500 ha) of important snake habitat, thus causing fragmentation and degradation. This action increases vehicular traffic on roads and increases in human commensals that are predators, which adds to Pine Snake declines.

We have identified numerous threats to Pine Snakes based on our long-term studies in the Pine Barrens (Table 2). Over the years we have worked in the same general nesting and hibernation areas of the snake. While driving on paved and sand roads to and from these areas, we have encountered both live and dead Pine Snakes. However, it was impossible to determine how many snakes perished because nests and hibernacula were not excavated by us prior to predation or poaching (Table 2). A further threat is development, which in a broad sense includes both residential and commercial facilities, as well as the new roads and increased traffic on old roads. Another recent threat is the popularity of All Terrain Vehicle recreation in Pine Barrens habitats.

TABLE 1. Main threats faced by Pine Snakes (*Pituophis melanoleucus*) in the New Jersey Pine Barrens, possible mitigation measures, and responsible agencies or individuals to improve conservation efforts. These are not exhaustive, but provide examples of major threats or risks.

Threat Type	Major Threat	Management and Conservation Measures	Responsible Agencies, Organizations and Individuals
Habitat Loss	Development	Laws, regulations and enforcement; Mitigation (provision of habitat enhancements); Public opinion and activism; Public can protect snakes and their habitat; Education	NJDEP, Pinelands Commission, Public pressure on agencies.
	Forestry Practices	Enhance open sandy places for nesting; Enhance open places near hibernacula; Create open places within forests for nesting; Create brush piles at edge of openings for basking and cover; Thin trees and shrubs in nesting and hibernation areas.	Mainly NJDEP (Parks and Forests), Pinelands Commission.
	Infrastructure Development	Reduce sand roads through and near nesting areas; Add rumble strips across paved roads that are used extensively by snakes (decrease crossing times); Build wildlife tunnels	NJ Department of Transportation. NJDEP (Endangered and Nongame Project)
	Utility right-of-ways	Keep them open to reduce natural succession; Do not use herbicides; Thin or manage in the winter to avoid injury to snakes; Avoid use of chemicals in these highly-used areas.	Utility companies
	Fire	Manage controlled burns; Conduct periodic controlled burns so fires are never too hot.	State agencies, Pinelands Commission
	Invasive Species	Reduce sand roads or traffic on sand roads near nesting areas to prevent introductions; Clean boots and equipment before entering critical habitat areas (nesting, hibernation).	NJDEP, state land managers, land owners.
Human Disturbance	Off-road vehicles	Build barriers to prevent ORVs from entering (berms, fences, chain-link fences) and maintain them; Encourage licensing so that laws can be enforced; Close illegal off-road areas or trails and continue to monitor and close them off; Create ORV parks in non-critical snake habitat; Education and public campaigns.	State agencies and enforcement on public lands, private land owners.
	Poaching for pet trade and hobbyist	Enforcement and stiff fines; Empower the public to watch for poachers and report them (but not approach them). Use cameras on sensitive areas to catch and prosecute poachers (as examples); Hatch eggs in laboratory to prevent poaching and return to their original nests for emergence (watching until the hatchlings are in cover); Education	NJDEP and law enforcement; private land owners. Pinelands Commission.
Predators	Natural Predator	Use nest protection (wire cages or predator guards); Use wire over hibernacula entrances; Hatch eggs in laboratory to prevent poaching and return to their original nests for emergence (watching until the hatchlings are in cover).	NJDEP, land owners, and scientists.
	Subsidized Natural Predator	No release of rehabilitated predators; Education of communities about leaving food about; Hatch eggs in laboratory to prevent poaching and return to their original nests for emergence (watching until the hatchlings are in cover).	State agencies, Pinelands Commission and landowners.
	Human commensals	Education about not allowing cats, dogs and other pets to wander in natural areas; Signage around communities near sensitive snake habitat.	NJDEP, Pinelands Commission, conservation organizations and land owners.
Disease	Fungal disease	Clean boots, hands, and equipment with Clorox whenever any snake has been found in a given area.	Everyone entering critical areas.
Prey Base	Population variations	Manage for game birds (which involves planting corn and other crops that enhance small mammal populations).	No direct agencies.
Data gaps	Lack of enforcement	Provide key information for law enforcement personnel about critical snake movement periods (when they are most vulnerable, when nesting and going to hibernacula); Provide cameras and other devices to catch poachers.	NJDEP, law enforcement, park police.
	Lack of key data	Determine the factors reducing populations, and encourage studies to provide key data; Lobby for funding.	NJDEP, Pinelands Commission, university scientists and other scientists.
	Lack of personnel and money	Determine key personnel needed; Lobby for funding; Organize conservation community to provide funding from governments and others.	NJDEP, Pinelands Commission, public.
	Education about Pine Snakes	Determine data gaps, encourage scientists and other to address them. Find funding.	All state and private organizations.

The main threats to Pine Snakes (individuals and populations) are habitat loss, human disturbance, predators, fire, poachers, and possibly a declining prey base (Tables 1 and 2; Fig. 1). We suggest several

TABLE 2. Predation and causes of death to Pine Snakes (*Pituophis melanoleucus*) in Burlington, Cumberland, and Ocean counties, New Jersey, USA (after Burger et al. 1988; 2007; Burger and Zappalorti, 2011; unpubl. data). For snakes that were killed by predators on the forest surface, we give the number of confirmed killed by bird and mammal predators.

Cause of Death of types of Predation	Winter Dens (Snakes Within)[a]	Nests (Snakes or Eggs Within)[b]	Snakes on Surface
Years of Observations	1986–2016	1976–2016	1965–2016
Number of years studied	31	41	51
Scarlet snake (*Cemophora coccinea*)	0	2	0
Short-tailed shrew (*Blarina brevicauda*)	2	0	0
Eastern Coyote (*Canis latrans var*)	1	21	15
Striped skunk (*Mephitis mephitis*)	5	1	0
Red fox (*Vulpes fulva*)	4	24	2
Raccoon (*Procyon lotor*)	3	3	2
Red squirrel (*Tamiasciurus hudsonicus*)[c]	7	0	1
Unidentified mammals (mainly coyote)	1	2	4
Red-Tailed Hawk (*Buteo jamaicensis*)	1	0	20
Great Horned Owl (*Bubo virginianus*)	-	0	1
Unidentified raptor	-	0	9
Red Mites (Acariasis,species unknown)	0	0	1
Human Poaching	46	118	3[e]
Sand Road Kills	-	-	8
Paved Road Kills	-	-	219
Off-road Vehicles in Nesting Areas	4	10	2
Number of Nests Churned-Up	-	37[d]	-
Forest Fire	1	-	15
Froze	4	-	2
Totals	78	218	304

a = a hibernacula could have been destroyed one year by predators, and used by snakes in subsequent years of our study.
b = it is unclear how many eggs or laying females were in these nests.
c = Red Squirrels did not kill snakes in hibernacula, but made them unusable.
d = the churning up of nests was prevented after a large sand berm and chain link fence prevented access (Burger et al. 2007).
e = beaten by people to kill them

indicators to assess the effect of threats on Pine Snakes (Table 3). While there are many different indicators that can be used, it is important to select one (or a few), and monitor them for 10 to 20-y to determine trends that might need to be addressed by government agencies or other stakeholders. We suggest some of the possible mitigation or protective measures for Pine Snakes, along with the primary agencies or other stakeholders responsible for execution of these measures (Table 1). Some of them, such as laws and regulations, and enforcement are already in effect. Others, such as deploying cameras to catch poachers and working with communities to reduce enhancement of commensal predators, are just beginning.

Pine Snakes were listed as threatened by the New Jersey Department of Environmental Protection (NJDEP) from the early 1970s. The New Jersey Pinelands Commission and the NJDEP, Division of Fish and Wildlife regulations, required presence or absence surveys of proposed development projects for the identification of critical snake habitat (e.g., snake hibernacula, nesting or birthing areas, or important foraging or resting areas). Our study areas are primarily in the Pinelands Preserve, which requires approved study plans before any development can proceed. To receive their permits, developers and their consultants must now use approved sampling protocols recommended by the Pinelands Commission and the NJDEP, Division of Fish and Wildlife, for assessing rare snake presence. This action has brought more consistency in how contractors performed snake studies and thus on regulations imposed on developers. This was a very important regulatory advance in the protection of threatened and endangered snakes and their habitat in New Jersey. As an example, from 1977 to 2016, Herpetological Associates (HA), an environmental consulting company, conducted studies for clients on 49 Pine Barrens projects that had the potential to support at least one or more of the three state-listed snakes: Timber Rattlesnakes (*Crotalus horridus*), Corn Snakes (*Pantherophis guttatus*), and Pine Snakes. Of these proposed development projects, HA confirmed the presence of Pine Snakes, Corn Snakes, or Timber Rattlesnakes on 24 of the properties. Herpetological Associates wrote mitigation plans and

TABLE 3. Possible indicators to assess the major threats to Pine Snakes (*Pituophis melanoleucus*).

Threats	Possible Indicators
Habitat Loss	Change in amount of available forest/ha; Change in amount and number of open areas for nesting.
Invasive species	Number of invasive species/ha; Geographical distribution of invasive species; Invasive species coverage/ha.
Development	Number of new houses or businesses/ha or per township; Built area (on suitable habitat) based on satellite photos.
Infrastructure	Number of Sand roads/areas; Number of paved roads/areas; Change in number of sand roads/paved roads; Number cars/h on sand roads and paved roads
Forestry	Amount of Pine Barrens forest loss/ha; Number of open areas for nesting and hibernation sites/ha (or ha identified on satellite photos); Amount of adjacent wetlands/ha.
Human disturbance	Number of people entering forest areas/ha; Types of human disturbance; Count number of vehicles (including ORVs) at key sand roads and illegal dirt paths (install cameras); Number of vehicle registrations (including ORVs when they must be licensed)
Poachers	Number of nests poached/year by direct observation of known nesting areas; Number of snakes poached/year based on law enforcement data; Number of poachers arrested based on law enforcement data.
Predators	Number of predators (predator diversity); Number predators by species/area; Predator assessment of nests lost (e.g. tracks).
Prey Base	Number of small mammals/ha; Prey diversity/ha; Distribution of small mammals by habitat.

recommendations that included deed restrictions of the critical habitat on the property, protecting critical nesting areas or birthing sites with 200 to 500 m buffers, reducing the total number of houses and clustering the development, donation of important snake habitat to NGOs, funding snake research both on and off site, creation of snake managements fields to enhance prey base and basking opportunities, and building artificial hibernacula (Zappalorti and Reinert 1994).

In some cases developers agreed to fund long term radio-tracking studies to determine where critical snake habitat occurred on their property, which sometimes delayed for two years their development permits. In one case a developer funded a 7-y radio-tracking study of Pine Snakes and a major mitigation plan on a NJDEP wildlife management area. In 1984 the Ocean County Municipal Sewerage Authority (New Jersey, USA) installed a sewer line along an old abandoned railroad right-of-way (ROW) that was confirmed Pine and Corn Snake habitat. Herpetological Associates designed a mitigation plan that included building 25 artificial hibernacula evenly spaced along the 2 km ROW. Due to lack of maintenance, some of the structures have collapsed in or the wooden ties have been eaten by termites. Some of the hibernacula were vandalized by snake poachers. Nevertheless, in 2016, 45% of these artificial hibernacula continue to be used by snakes as shedding stations, summer retreats, or for winter hibernation (Zappalorti and Reinert 1994, Robert Zappalorti, unpubl. data).

DISCUSSION

Threats to Pine Snakes.—Pine Snake populations need three habitat conditions to persist: (1) suitable open sunny nesting sites, (2) suitable winter hibernation sites, and (3) vast foraging areas, all without nearby paved roads. However, predators such as Coyotes (*Canis latrans*), foxes, Raccoons (*Procyon lotor*), skunks, and raptors are also present in the Pinelands forest, but a stable Pine Snake population can withstand the loss of individuals from predation. On the other hand, human poaching can have negative effects on a population by constantly removing snakes from their habitat, especially gravid females. Optimal nesting and hibernation sites are small clearings with sun penetration to the ground that are near forested areas that are suitable for foraging and provide subterranean summer dens (New Jersey Division of Fish and Wildlife 2009; Burger and Zappalorti 2011a). For Pine Snakes, Bullsnakes, and Gopher Snakes, home range size is related to habitat quality (Burger and Zappalorti 1988a; Gerald et al. 2006a, b; Kapfer et al. 2010; Miller et al. 2012; Zappalorti et al. 2015) The main threats to Pine Snakes are habitat loss and fragmentation, human disturbance (particularly vehicular traffic, both on and off-road), and poaching.

Mortality on paved roads, as well as on sand roads, is a problem for many snakes (Rudolph et al. 2000, 2007; Row et al. 2007; Andrews et al. 2008; DeGregorio et al. 2010). Although snakes may avoid roads under some conditions (Shine et al. 2004), it is not clear whether this happens in Pine Snakes. In our study, as in others, we report the number of road kills, but do not have data on the number of road crossings by individual snakes. Models that do examine these factors indicate that roads can increase the probability of extinction (Row et al. 2007), and we have found that populations disappeared from areas bounded by heavily used paved roads (New

Jersey Division of Fish and Wildlife 2009; Joanna Burger and Robert Zappalorti, unpubl. data).

Originally natural lightning-started fires likely kept some areas open that were suitable for nesting and basking. Native Americans burned patches of forest or grasslands to increase deer production, and this inadvertently created open areas for Pine Snakes to nest (Russell 1981). When European settlers arrived, they inhabited the Pine Barrens, but the original settlers (their descendants still proudly refer to themselves as Pineys) cleared small plots in the pine forests for farming blueberries and cranberries, raising chickens, or creating hunting shacks (Burger 2006). The edges of the farm fields were open and suitable for nesting Pine Snakes; the farm crops also attracted mice and other rodents that provided prey for snakes. When the small farms disappeared, natural succession resulted in the openings reverting to pine forests. Now maintaining sufficient suitable nesting and hibernation sites is critical because this habitat is disappearing. This requires vegetation removal to allow sun penetration to the ground. Without suitable open nesting areas, eggs (in nests below the ground) are incubated at lower incubation temperatures than is optimal, and embryos take longer to develop. This has been demonstrated in the laboratory. Hatchlings incubated at slightly lower than optimal temperature, took longer to shed and search for food the first time, and they were behaviorally impaired (took longer to move, catch prey, avoid predators: Burger et al. 1987; Burger 1989a, b; 1991a; 1998a; Burger and Zappalorti 2011a). Although fires can maintain open areas (Forman and Borner 1981), fires kill Pine Snakes that fail to get below ground quickly enough.

Protection measures and mitigations to protect Pine Snakes.—There is little published information on the preferred prey base for Pine Snakes, but our long term studies have shown they eat small mammals (especially rodents), birds, and their eggs. By weighing individual snakes each March before they have begun to feed, we have found that in some years, some snakes have gained substantial weight while in other years, weight gains were less (Joanna Burger and Robert Zappalorti, unpubl. data). We suspect that there may be a correlation with an increase of large predators such as Coyote, fox, Raccoon, and feral cats, which also feed on mammals, thus causing an inadequate prey base for snakes. A reduction of ground nesting birds and small mammals may be more stressful on hatchlings and small snakes that are not proficient at finding and capturing prey, or may have a more restricted available size range of prey. While an available prey-base study has not been initiated, such a study could make use of volunteers to set and check traps, and monitor, while at the same time patrolling areas to discourage poaching. Further, the clearing of fields and planting of crops (corn) for deer and birds (e.g., quail, Wild Turkey, *Melleagris gallopavo*) would increase the prey base, and we have often found more snakes in these enhanced open areas than in others (unpubl. data).

Eggs are often removed by poachers. Hatchlings are also very vulnerable to predators and poachers when they exit their nest sites. Initially they are vulnerable because the female exudes a liquid that binds the eggs together when they dry (so they do not move during development). Additionally, when the eggs hatch there is a slight odor that attract predators. Once they begin to emerge, they are exposed and visible on the sand surface until they move into nearby vegetation (Burger and Zappalorti 2011a). Poachers know when to look for them. As evidence, this past breeding season we lab-hatched and released marked hatchlings back into their original nests at different ages post-hatch. We found that more of the hatchlings successfully reached and overwintered in known hibernacula than those from nests that hatched naturally (unpubl. data).

Pine Snakes require open areas for nesting and for hibernation sites (Burger and Zappalorti 1986; 2011a; Zappalorti and Burger 1986), but these need to be close to suitable forest for foraging and summer dens (Burger and Zappalorti 1988b; 1989). Cutting large swaths of forest removes effective habitat, results in fragmentation, and churns up potential nesting areas. Pine Snakes do not nest in very soft sand (sugar), nor in sand with many trees or shrubs because of the dense roots, but prefer some roots from Sedge Grass (*Carex pennsylvaticus)* or goldenheather (*Hudsonia* spp.) to stabilize the soil (Burger and Zappalorti 1986; 1988a). On the contrary, removal of 1 ha areas of trees and shrubs can open the canopy and be optimal for Pine Snakes (Burger and Zappalorti 2011a), as well as for other snakes (Webb et al. 2005).

In addition to habitat loss through incursions by developers into the Pinelands Natural Reserve, which can only be addressed by governmental agencies (e.g., NJDEP, Pinelands Commission), the major threats are predators, poaching, and road kills. Pine Snakes obviously evolved with a suite of native predators, but increases in human populations introduce additional cats (which eat small snakes) and increase native predator populations by providing readily available food sources (fox, raccoon, and skunk populations increase near habitation). Illegal activities are a continual threat to Pine Snakes, including poaching, driving off-road vehicles through the Pine Barrens forest killing snakes or destroying nesting areas, and deliberately or accidentally running over them on sand or paved roads, narrow firebreaks, plow lines, and illegally created dirt-bike trails (Burger et al. 2007; New Jersey Division of Fish and Wildlife 2009; Burger and Zappalorti 2011a). New Jersey Pine Snakes are particularly sought by snake collectors because they retain a distinct black and white

pattern that collectors find appealing. Thus poaching is a problem, and poachers often target gravid females or nests with eggs (Burger et al. 1992). Poaching of Pine Snake nests can be as high as 40% per year (Burger and Zappalorti 2011).

Off-road vehicles, such as dirt bikes, make deep tracks in the sand throughout the pine forest, which are often used by Pine Snakes and other animals, making them vulnerable to the high-speed vehicles. In other places, with other species, off-road vehicles have had major effects on populations, including reptiles (Garber and Burger 1995, New Jersey Division of Fish and Wildlife 2009, Bondello and Brattstrom 1979; Michael Bondello and Bayard Brattstrom, unpubl, report). In New Jersey, as in other states, developing and enforcing policies that ban or limit off-road vehicles have proven to be impossible (New Jersey Department of Environmental Protection. 2002. DEP Commissioner Campbell announces off-road vehicle policy reinforces ban on public sands; seeks maximum fines [News Release 2 October 2002]. http://www.state.nj.us/dep/newsrel/releases/02_0095.htm). In 2016 one of our radio-tracked Pine Snakes (a 12–15 y old female) that had just left her hibernation site was run over by a dirt bike on an illegal trail in early March. Volunteers and other stakeholders can help this problem by educating people, watching for and reporting illegal activities (especially the location of dirt bike trails).

With increasing development in the pines, especially of retirement communities, there are more and more roads that border Pine Snake habitat, in some cases separating foraging from hibernation and nesting sites. Fragmentation is a problem for snakes, particularly as roads and other obstructions separate foraging areas and hibernation sites, and foraging and nesting sites (Kjoss and Litvaitis 2001; Blouin-Demers and Weatherhead 2001; New Jersey Division of Fish and Wildlife 2009; Burger and Zappalorti 2011a). Snakes have to cross sand and paved roads to get between wintering, mating, nesting, and foraging sites. Some of our radio-tracked snakes moved over 3.2 km (2 mi) between these sites and their foraging territories (Burger and Zappalorti 2011a; Zappalorti et al. 2015, Joanna Burger et al., unpubl. data). Highway mortality can be significant, and many of the Pine Snake locations in state data bases are from road kills. In comparison, the maximum distance the related Gopher Snakes in British Columbia travelled from a hibernaculum was 2.4 km (Williams et al. 2012). Bonnet et al. (1999) found that mortality increased with the distance travelled. Roads not only kill snakes, but they influence the movement patterns, and some snakes avoid paved roads (Andrews and Gibbons 2005), which may lead to foraging in lower quality habitat, not finding the best hibernation or nesting sites, or limiting gene flow and genetic diversity (Clark et al. 2010). Fragmentation (often by roads) is a particular problem for species with limited dispersal abilities (Sherwood et al. 2002; Forman et al. 2003; Byers and Mitchell 2005).

Mortality on paved roads will increase in the future with increased human populations in New Jersey. The spatial pattern of road kills is non-random (Clevenger et al. 2003), which suggests that there may be some mitigations possible (at least on less-travelled paved roads). We suggest that rumble strips placed on these roads in key cross-over migration areas would make it easier for Pine Snakes to gain traction and cross more quickly. Special culverts/tunnels for Pine Snakes may also help reduce road mortality, with the addition of scent trails produced by having captive snakes enter the culverts several times. Some snakes are killed on paved or sand roads where it is obvious from the tire or sand tracks that people swerved to hit a snake, rather than swerved to avoid one. This is also an area where volunteers, especially local people living in the Pine Barrens, can educate the rest of the local people of the ecological role of Pine Snakes and the importance of conserving this threatened species. This is particularly effective when teenagers have been part of research projects; they become wonderful vociferous ambassadors for Pine Snakes in their schools and communities.

CONCLUSIONS

The Northern Pine Snakes in New Jersey, USA, are faced with habitat loss and fragmentation, increases in predators and potential decreases in prey availability, and mortality due to roads, off-road vehicles, and poachers. The Pine Barrens, one of the most densely populated areas in the world, and are part of the coastal ecosystem with increasing human pressures. Urban areas are losing reptile biodiversity at a fast rate (Cook 2008), especially larger species with large home ranges (for a reptile) and specialized habitat requirements (Klemens 1985; McKinney 2002). This case study illustrates that at the heart of the protection and conservation of a threatened species is understanding the threats they face, the risk to different life stages posed by these threats, and possible mitigation measures to conserve them in a changing world, especially for snakes in urban environments.

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