JOURNAL OF TOXICOLOGY AND ENVIRONMENTAL HEALTH, PART A
https://doi.org/10.1080/15287394.2019.1615587

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ARTICLE

A paradigm for information needed to protect at-risk species: northern pine snake (*Pituophis melanoleucus*) in the pine barrens as a case study

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ABSTRACT
New methods of examining the risk to endangered, threatened and rare species are required to identify vulnerability. A paradigm for examining risk is presented that describes anthropogenic threats, species activities, and vulnerabilities, and uses Northern pine snakes (*Pituophis melanoleucus*) in the New Jersey Pine Barrens as a case study. The paradigm includes (1) conceptual model of natural, anthropogenic, and interactive stressors, (2) template of the functional attributes of threats from human activities, and (3) template of effects from different human activities. Pine snake behavior throughout the year was used to examine the temporal overlap in high snake vulnerability periods and desired human activities in a shared habitat. New data on autumn behavior of pine snakes are also provided. Passive integrated transponders (PIT tag) tracking technology indicated that the fall basking activity period is both longer in duration, and at a higher intensity than previously presumed. During the autumn, individual snakes moved in and out of dens an average of 6 times over a two-month period. Younger snakes at a small hibernaculum were more active than those at hibernacula with larger and older snakes. The high activity period of pine snakes overlaps with the timing of preferred off-road-vehicle (ORV) use, controlled burns, and other human activities, increasing snake vulnerability, potentially causing behavioral disruptions, injury, and death. The conceptual model illustrating relationships between attributes of human activity and effects may be utilized to determine risks to other listed species, and those of special concern in different habitats. This paradigm also provides managers with template tools to assess risks to species that may also be used to provide information to the public.

KEYWORDS
Competing claims; species protection; pine snake; fall hibernation activity; snake; fire: off-road-vehicles; management; forestry

Introduction

Human activities, both commercial and recreational, have long conflicted with, and encroached upon, important habitats of plants and wildlife. The world is experiencing a high rate of habitat loss, habitat degradation and in some cases – species extinction (Pimm and Raven 2000; Pimm et al. 2001). Resource agencies, conservation organizations, resource trustees, regulators, and the general public have various responsibilities or interests in protecting habitats and rare species. These groups will benefit from setting priorities (Pimm and Raven 2000), and developing paradigms for protection of threatened and endangered species, as well as unique and rare habitats (IUCN & UNEP) 2009). Protection requires identifying both natural and anthropogenic threats, determining which threats pose the greatest risk, and comparing key vulnerabilities of different species. The natural risks to animals and their populations including predators, competitors or disease may be overwhelmed by anthropogenic risks, including human commensal predators, human disturbance, poaching, recreation, contaminants, habitat management for other purposes, road-building, fragmentation, and development (Burger and Zappalorti 2016; Kapfer et al. 2010). Long-term datasets may be essential to identify the type, frequency, and intensity of threats and effects (Burger, Zappalorti, and Gochfeld 2018; Therrien et al. 2017). These threats are rising in urbanized coastal zones as well as in adjacent

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forested areas attributed to increasing human populations.

Coasts are inherently attractive to individuals as these locations provide a wide range of goods and services (Costanza et al. 2017, 2014; Weis and Butler 2009), including aesthetics and existence values (Davidson 2013; Kontogianni et al. 2012). Not only do coasts provide clean air, clean water, and recreational, consumptive and commercial opportunities but also act as buffers against the damages of hurricanes, other severe storms, and sea level rise (Bascom 1980; Plant et al. 2010). Well over half of the World's population resides along coasts even though land less than 10 m above sea level covers only 2% of the World's land (NOAA (National Oceanographic and Atmospheric Administration) 2012; Crosset et al. 2013). With increasing numbers of individuals moving to the coast, development has spread into the New Jersey Pine Barrens, which enhanced fragmentation and habitat loss (Burger and Zappalorti 2011; Zampella 1986). The Pine Barrens is a unique habitat with several threatened and endangered species that are at elevated risk from development, and other activities including road-building, fire, controlled (= prescribed) burns, poaching and increased human disturbances (Forman et al. 2003; Forman and Borner 1981). Fire also exerts positive benefits, such as producing mosaics of different habitats, especially in fire-adapted habitats (Nimmo et al. 2012). Rapid and easily understood assessment methods are thus essential to determine risks to species from both human and anthropogenic stressors.

Reptiles are declining globally at an alarming rate (Gibbons et al. 2000), especially in urban areas (Cook 2008), making it essential to learn as much as possible regarding their biology to help foster their conservation. Obtaining data on vulnerable periods when snakes are particularly active and clumped in predictable locations are needed. One of the hazards pine snakes, and other at-risk species face, is that there are competing claims and responsibilities for habitat. Areas of the Pine Barrens essential for pine snake survival are managed for (1) other endangered or threatened wildlife, (2) game wildlife of interest to hunters (e.g. turkey, deer, bear, and other game mammals), (3) other recreation (e.g. hiking, regulated and un-regulated off-road-vehicle [ORV] races), (4) logging and forestry, (5) other human uses, and 6) prevention of fire damages and injuries to local human communities (controlled burns). Each of these management objectives asserts priorities from special interest groups, and the actions taken and outcomes are often in conflict. Resolution of these conflicts requires knowing what the threats are, which are most severe, when they are most severe, and which are amenable to resolution (for each competing claim).

It is important to mention, however, that many management practices might benefit pine snakes, other reptiles, and amphibians. Protection of buffer areas around ponds for breeding frogs might provide protection for snakes using wetlands. Controlled burns might open up the forest canopy as well as create open patches for nesting or elevated foraging opportunities (Beaupre and Douglas 2012). Several investigators reported no marked effect of fire on reptiles (Greenberg and Waldrop 2008), and in some cases, reptiles exhibited significant increases in abundance (Mathews et al. 2010). However, fires also produce injury or death to snakes and other wildlife that are caught above ground during a fire (Beaupre and Douglas 2012). A range of factors might affect reptile response to fire which are discussed more fully in Greenberg et al. (2018), but the objective of the present study was to deal with temporal aspects of different human activities on pine snakes, and specific seasonal vulnerability times for pine snakes.

The aim of this study was to present a paradigm to: (1) develop a conceptual model of the relationship between natural and anthropogenic threats and effects, (2) develop a template of functional attributes of human disturbances, and (3) describe, in a template, the possible effects from these human activities. Finally, the investigation uses Northern pine snakes (*Pituophis melanoleucus*) in the New Jersey Pine Barrens as a case study. The Northern pine snake is one of the top-level predators in the Pine Barrens, listed as threatened in New Jersey, and is threatened or endangered in most other States where it occurs (Golden et al. 2009). It is at risk from a wide range of anthropogenic threats, including human disturbances, road-building, wildfires, controlled burns, and development (Andrews, Gibbons, and Jochimsen 2008; Burger and Zappalorti 2016; Burger et al. 2007; Clark et al. 2010). This model and concepts developed, however, may also be applied to a wide range of reptile and amphibian species in different habitats.

Methods

General approach

This study is based upon research and general observations, combined with information from the literature to develop a paradigm to examine the factors affecting 'listed species' in New Jersey and other states. This approach focuses on competing claims for the same habitat and associated resources. First, a general model was developed for the relationship between natural and anthropogenic events that affect listed species, followed by two templates: (1) a list of functional attributes of varying types of human activities, and (2) consequences of these activities. The paradigm and concepts were then applied to Northern pine snakes living in the New Jersey Pine Barrens. Throughout the paper, pine snake refers to the Northern Pine Snake.

As an initial step, the main natural and anthropogenic threats to Northern pine snakes in the New Jersey Pine Barrens were examined. Threats were considered as mainly natural or anthropogenic or enhanced by human activities (see conceptual model below). The threats to pine snakes were described qualitatively and quantitatively in Burger and Zappalorti (2016).

Background on pine snakes

Pine snakes are predators that may grow to 2 m in length, eat small mammals and birds (their eggs and chicks), and might live for 20+ years. These vertebrates hibernate in communal winter dens (hibernacula) that they dig and modify themselves (Burger, Zappalorti, and Gochfeld 2000; Burger et al. 1988), and these dens are used for decades (Burger and Zappalorti 2015; Burger et al. 2012). Pine snakes begin breeding at age 3–4 years old (Burger, Zappalorti, and Gochfeld 2018), and females dig their own nest sites, which might also be communal (Burger and Zappalorti 1992). Despite the large extent of the Pine Barrens, habitat suitable for nesting is limited (e.g., suitable sandy soil, compaction quality, soil moisture and sun exposure to the ground surface). The species is of conservation concern throughout its range because of habitat loss, human disturbances, fragmentation, predation and poaching (Burger et al. 2017; Burger and Zappalorti 2011, 2016; Burger, Zappalorti, and Gochfeld 2018). Although pine snakes face a range of natural hazards such as predators, competitors, and habitat constraints (Burger and Zappalorti 2016), these stressors are not the focus of this investigation.

Methods for pine snakes

This study was conducted in Bass River State Forest, Burlington County and in the Crossley Preserve, Ocean County, New Jersey. Pine snake studies were conducted for over 30 years, which enabled determination of the major threats, and overall temporal patterns of vulnerability (Burger and Zappalorti 2011, 2016; Zappalorti and Mitchell 2008). The major *unknown* vulnerability for pine snakes was lack of detailed information during the period of entry and exit from winter hibernation. Snakes were suspected of remaining near hibernation sites during these periods, but detailed data were lacking. That is, it was not previously known whether snakes entered a hibernaculum and remained for the winter, moved between hibernacula, or the variation in the time different snakes entered hibernacula. Application of the information template required data for this period in order to understand whether snakes were vulnerable to human activities when people wanted to engage in these specific activities (e.g. ORV races, controlled burns). Snakes were marked by injecting passive integrated transponders (PIT) tags (AVID Co.), which allows each recaptured individual to be individually identified. These tags require a hand-held radio-frequency reader to confirm identification. The development of new technology-enabled passive, continuous recording of snake activity at the entrance of hibernacula. An AVID Industrial Reader (AVID Identification Systems, Inc, in Norco, California) was used at one hibernaculum from October 2017 to December 31, 2018, and at five others in 2018. This provided information on activity and thus vulnerability of snakes during the fall hibernation period. Any snake passing by, or entering or leaving one of these hibernacula was recorded along with a minute/hour time stamp. Data were downloaded every 2–3 weeks throughout the year. The power source was a 12-volt marine battery. No equipment was visible on the surface, and the recorder at the hibernacula entrance was buried 5 to 8 cm under sand and never disturbed. The soil surface temperatures were recorded continuously, all year, near one of the hibernacula entrances using an Elitech RC-5USB Temperature Data Logger.

All procedures for the 30+ year study of Pine Snakes in the New Jersey Pine Barrens were performed with protocol approvals from Rutgers University (Protocol 86–017, renewed every 3 years since 1986), and appropriate state permits from the New Jersey Department of Environmental Protection. In all cases, the welfare of the snakes came first.

Results

Conceptual model for categories of threats

Species face several types of threats, including natural (biological, physical), anthropogenic (direct and indirect), and interactions among the threats. Biological threats include predators, competitors, and diseases, while physical threats include storms, droughts, earthquakes, floods, and others (Figure 1). Direct anthropogenic threats include chemical exposure, killing and poaching, human activity, and human disturbance. Indirect threats include loss of prey because of contaminants or habitat loss, or increased natural or invasive predators attributed to people that brought them in or made food available (increasing local populations of predators), among others. Interactive threats are those that display both a natural and an anthropogenic cause. For example, a fire may be of higher intensity because of fuel buildup, whereas prescribed burning reduces and controls this risk. A flood may occur because of heavy rains (a natural storm event), but the continued build-up of homes with driveways and commercial parking lots reduces natural permeability of the soil, creating more intense flooding. Further, building on flood plains reduces the natural catchment area for flood waters, causing more extreme flooding downstream.

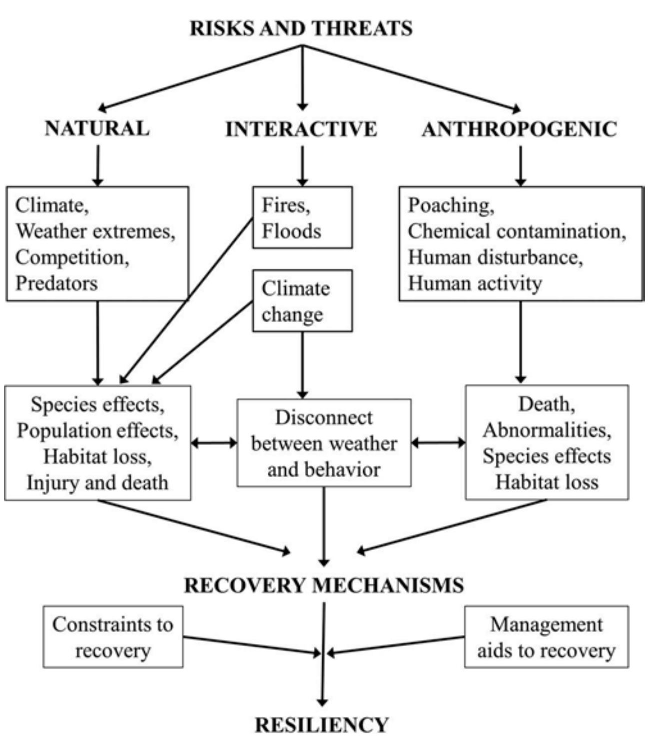

Figure 1. Schematic of the threats and risk species face, particularly related to physical events, anthropogenic events, and interactions. Some human activities are listed in the tables.

A conceptual model illustrates some of the threats and potential effects (Figure 1). Biological threats clearly exert an impact, but the emphasis in this investigation is related to anthropogenic effects, and their interactions with physical events, the abiotic environment (soil, water), and available important habitat(s). These threats provide a risk to species, which may result in behavioral changes, abnormalities, and disconnects between weather and behavior, and even death. Extreme or unusual weather might affect behavior. If a species normally enters hibernation in mid-November, but global warming leads to higher temperatures than normal in November, snakes or other animals may go into hibernation later than usual. If snakes arrived at the hibernation site at the usual time, but did not enter hibernation, then these reptiles may well

spend time basking near the hibernaculum entrance (putting them at risk). This late season basking at their dens may lead to predation of snakes by hawks and mammals (Personal communication). Similarly, later cold temperatures in the spring may result in species leaving hibernation later, providing less time to forage and successfully breed that year (which occurred in the spring of 2018, Burger, Personal communication).

As presented below, tables form a template that enables scientists, conservationists, and managers to examine some of the anthropogenic environmental threats that a species faces in a human-dominated world. Each of the individual tables may be adapted to fit other species elsewhere, living in other local ecosystem.

Templates of functional attributes and effects of human activities

Human activities often have attributes in common, and these might be examined to understand the risks produced, especially with respect to physical disruption. These are functional aspects of human activity in that the attribute itself would exert the same effect regardless of the human activity involved. For example, heavy equipment, whether for logging, road building or fire prevention, digs up soil, disrupts soil invertebrates, destroys seed banks, and breaks down shrubs and trees. The degree of physical disruptions partly depends upon the type of activity and number of people, vehicles, or equipment (Table 1). Other investigators working with different species may well add additional human activities, as well as additional functional attributes. This Table is meant to provide an example of the types of human activities and attributes to consider in the protection of species at risk.

The functional attributes in Table 1 represent a hierarchy of disturbances, from pedestrians, to vehicles, to heavy equipment accompanied by trailers, chemicals, sprayers, trenching equipment, or extensive clearing of land for development. It is useful to consider the frequency and intensity of each activity, which often relates to the number, type, and weight of equipment. One or two individuals walking through an ecosystem might not disrupt it, but heavy vehicles dragging other equipment will remove surface soil, compact the remaining soil, damage vegetation, and kill some animals (Table 2). In some habitats, footpaths and vehicle tracks will remain visible for years. Subsequently, these physical disruptions lead to habitat degradation for some species, and ultimately, to ecosystem consequences.

The effects are derived from the continuum of physical disruptions that might culminate in complete removal of the ecosystem structure including soil, understory vegetation, and disturbance of wildlife. Hiking groups transiently create noise, paths, displace mobile wildlife, and may damage some native plants. The greater the number of subjects, the greater soil compaction, which results in changes in water flow. Almost all human activity possesses the potential to spread invasive species (Mooney and Hobbs 2000). For example, even a lone hiker walking through the pine forest may carry the seeds of an invasive species (such as *Phragmites*), in the treads of their sneakers.

To the functional attributes of some human activities, and resultant effects, two additional factors need to be added: temporal and spatial variation. Species are vulnerable to different disruptions depending upon the time of year, and stage in the

Table 1. Template of the functional attributes of different human activities that occur in Pine Barrens habitats. As the intensity of activity increases (from people walking to the last listed), so does the severity of the risk of potential injury to ecological resources. An X indicates whether each attribute is associated with a human activity. Obviously wildfires, predators and competitors exert an influence on population viability, but the objective of this table is to show the attributes and equipment associated with human activities that can affect behavior and ecology of sensitive or rare species. Control = prescribed burn.

Functional attributes	Pedestrian traffic[a]	Poaching	ORV	Logging	Control burn	Build road	Develop land[b]
People walking through sensitive plant and wildlife habitat areas for various reasons	X	X	X	X	X	X	X
Car and truck traffic through the habitat			X	X	X	X	X
Equipment to clear forest				X	X	X	X
Heavy equipment + trailers[c]				X	X	X	X
Heavy equipment, + trailers + chemicals					X		X
Heavy equipment + trailers+ chemicals, trench equipment					X	X	X
Heavy equipment + trailers, chemicals, trenching equipment, clear-cutting					X		X
Heavy equipment + trailers, chemicals, trenching equipment, soil, clear-cutting, land developed, impervious surfaces							X

a. May include hikers, surveyors, scientists, photographers, bird watchers, or others walking through the Pine Barrens forests.
b. Utility installations, agricultural, residential, commercial or industrial development of natural habitats.
c. May pull additional equipment involved in controlled burns, logging, creating wildlife management fields, and road building.

Table 2. Template of some of the possible adverse effects of functional attributes on species and ecosystems. Many of these attributes are associated with activities that have a positive benefit for pine snakes (e.g. opening up forest patches for nesting snakes).

Functional attributes	Possible effects
People walking through area	Create noise and vibrations, leave footprints, displace mobile species such as birds, butterflies and other insects, lizards or frogs, small mammals. Small chance of spreading invasive species (Mooney and Hobbs 2000).
Car and truck traffic through area	Create noise and vibrations, create trails, create small puddles. Displace mobile species. Larger chance of spreading invasive species (also involves road kills).
Heavy equipment for land clearing	Habitat fragmentation. Create noise and vibrations; displace mobile species, create ruts and deep puddles; create paths, compact soil; destroy some vegetation
Heavy equipment + trailers, trees, hoses	All of the above effects, plus deep ruts and paths; destroy vegetation; remove some trees. May cause fragmentation of habitats (Forman 1995; Fahrig 2003).
Heavy equipment, + trailers + chemicals	All of the above, plus contaminate soil with chemicals that may affect soil invertebrates. Likely to alter surface water patterns, and may leave small pools or ponds.
Heavy equipment + trailers, chemicals, trench soil	All of the above, plus disrupt soil invertebrates and small mammal burrows; disrupt wood invertebrates; remove seedbank in trenched soil area.
Heavy equipment + trailers, chemicals, trench soil, clear-cutting	All of the above, plus change sunlight patterns on forest floor; change temperature of soil and potentially soil invertebrate community; produce slash; may increase fire potential from slash; chemicals may cause abnormalities, or death of soil invertebrates or other animals.
Heavy equipment + trailers, chemicals, trench soil, clear-cutting, built-up landscape & impervious surfaces	All of the above, plus depending upon size of buildings, render habitat completely destroyed; cause death of soil invertebrates and burrowing animals; cause death or injury to animals that wander from adjacent habitat into built area; increased human disturbance in adjacent habitat. Permanent destruction of the ecosystem. Increases commensal predators that use adjacent natural habitats to find prey.

life cycle. Snakes that are hibernating below ground are not vulnerable to physical disruption if it does not disturb or destroy the entrance to their hibernaculum. Similarly, birds are not affected by disruptions when these species have migrated south for the winter. Spatial differences in habitat also influence disruptions on plants and animals. Some species of snakes may use open habitat for some behaviors including nesting, egg deposition, or basking, but prefer interior forest for others such as foraging, concealment, and resting. Further, the most severe adverse effects occur when animals are clumped spatially, such as when (1) snakes are entering or leaving hibernacula, (2) colonial bird species are nesting, or (3) frogs are concentrated on a pond for breeding, or are ground-dwelling (e.g. snakes, lizards), and cannot always find refuges or flee fast enough.

Case study: pine snakes, threats, and vulnerability

Human activities might potentially impact behavior and ecology of pine snakes in a number of different ways. Table 3 lists some of the potential effects of disturbances on pine snakes, and associated human activities. Some effects may be minor or short term (e.g. disrupt scent trails), while others may exert a chronic influence on behavior, reproduction, and population stability such as compacting soil or creating an open area no longer usable for snake nesting. Compacting soil degrades nesting habitat, degrades or destroys tunnels of small mammals that depletes prey for pine snakes, or makes digging nests difficult.

Table 3 also provides managers and the public with a rapid method of illustrating the relative adverse impacts of different human activities. Clearly, human traffic (one or two individuals) exerts less of an impact than several ORVs. Similarly, ORVs produce less of an impact than building sand roads, which are less damaging than creating or improving paved roads. These are the impacts of physical disruption and not from removal or killing snakes.

Table 3. Possible effects of different human activities that can impact pine snake behavior, ecology, and population viability. An X indicates the effect is likely with the human activity. This case study can serve as a model for other species in other habitats, or for species groups (e.g. nesting birds, breeding frogs).

Possible effects	Pedestrian Traffic	Hiking Groups	Poaching	ORV	Log ging	Fire	Road	Develop ment
Create noise and vibrations that cause snakes to leave the vicinity; leave footprints that could disrupt scent trails.	X	X	X	X	X	X	X	X
Create paths through forests, disrupting scent trails and leading to corridors for predator movement.	X	X	X	X	X	X	X	X
Any soil disruption can destroy scent trails in sensitive regions; disrupt vegetation in nesting areas.	X	X	X	X	X	X	X	X
Spread invasive species that degrades nesting areas for pine snakes.	X	X	X	X	X	X	X	X
Habitat degradation that displaces pine snakes from small areas of habitat.		X	X	X	X	X	X	X
Large patches of habitat degradation can displace pine snakes from larger areas of habitat or destroy nesting habitat or hibernacula.			X	X	X	X	X	X
Damage native vegetation that provides shelter from the sun or places to hide from predators.				X	X	X	X	X
Damage native vegetation in nesting areas that reduces suitability (few roots for preventing collapse of nesting tunnels and chambers).				X	X	X	X	X
Damage native vegetation that may decrease prey availability.				X	X	X	X	X
Disrupt soil used for nesting by pine snakes (e.g. make sugar sand that can't be used for nesting).[a]				X	X	X	X	X
Alter surface water flow, providing damp conditions for egg development (nests are underground). Creating fire trenches can also alter water flow.					X	X	X	X
Compact soil, degrading nesting habitat for pine snakes, and degrading habitat for burrowing mammals (prey for pine snakes).					X	X	X	X
Remove trees, destroying habitat for pine snakes to forage in, and reduces prey necessary to maintain stable populations.					X	X	X	X
Remove soil (or disrupt soil), removing seed bank, soil invertebrates and burrowing mammals (removing prey for pine snakes, and disrupting soil for digging nests or hibernacula).						X	X	X
Fragment habitat by barriers (roads) may disrupt gene flow and isolate populations, may provide barrier that results in death of snakes.							X	X
Building sand or other roads brings in additional predators, more chance for invasive species, and road kills.							X	X
Building and filling in habitat in small areas or sections of Pinelands (removing habitat for foraging, nesting, resting/basking, and hibernation snakes)							X	X
Building in large areas, destroying swaths of habitat for pine snakes. Also introducing commensal predators[b] on pine snakes, and increasing human interactions in adjacent habitats, increasing fragmentation.								X

a. In sand, ORVs and other traffic create sugar sand, which also destroys soil invertebrates, burrowing animals, and is not suitable for snake nesting.
b. Commensal predators include cats, rats, dogs that are associated with humans.

As indicated previously, temporal patterns in a species behavior affect vulnerability. However, determining vulnerability also involves understanding when it is optimal to perform certain management actions such as cutting trees, clearing forest openings for fields, managing fire by plowing fire-cuts, building new roads, or grading existing sand roads. It is noteworthy that these activities have two aspects that need to be questioned: (1) when should the planned action be implemented in terms of effects on the snakes? and (2) when is the optimal time to implement the planned management action (in terms of the management itself)? This varies by geographical regions, habitat type, and presence of human communities (location, density, dispersion; Greenberg et al. 2018). It is also imperative to understand when species of concern are vulnerable spatially, temporally, and behaviorally.

Pine snakes generally hibernate (or are in the vicinity of hibernacula) from mid-September to mid-November in the fall. In the spring these invertebrates start to emerge from late March through late April. Pine snakes mate in May and early June, and gravid females excavate nest burrows and lay eggs in late-June to early-July (Burger and Zappalorti 1992, 2011, 2016; Personal observations). The young hatch in late-August to early-September (Table 4, Personal Observations). Table 4 also indicates the times when it is optimal (and possible) for human activities to occur, such as controlled burns, forest practices, ORV races, and sand road-building. New Jersey's prescribed burning period is October 15 to March 15, but may be extended to April 1 under some conditions (State of New Jersey, Department of Environmental Protection, Forest Fire Service (NJ,

Table 4. Relative vulnerable periods for pine snakes in the New Jersey Pine Barrens with respect to preferred times for human activities. The human activities indicate the periods it is optimal for them to occur for their own objectives. An x indicates when activities occur, and v indicates extreme vulnerability for pine snakes. Each two month period normally has 8 weeks (thus 0 = no activities, and X = snake participation in that activity then (blank means snakes are not involved in that activity during this period. There are other times when a snake or two may move about, but shown are the major times.For human activities, x = when people prefer to do so.

	Jan-Feb	Mar-Apr	May-June	July-Aug	Sept-Oct	Nov-Dec
PINE SNAKE ACTIVITY PATTERN						
Pine snake[a] hibernating	xxxxxxxx	xxxxxx00			00xxxxxx	xxxxxxxx
		vvv			vvv	vvvv
-Mating		000000xx	xxxx0000			
		vv	vv			
-Nesting			000000xx	xx000000		
			vv	vv		
-Foraging		xxx	xxxxxxxxxx	xxxxxxxx	Xxxxx	
Optimal time to avoid any disturbance to snakes		XX	X XX	X	XXXX	XXXX
PREFERRED TIMES FOR HUMAN ACTIVITIES						
Optimal time for controlled burn[b]		xxxxx			xxxxxxxx	
Possible time for controlled burn	xxxxxxxxx	xxxxxxx			xxx	xxxxxxxx
ORV[c] – Optimal time		xxxxxxxxx	xxxxxx		xxxxxxxxx	xxx
Possible time		xxxxxxxxx	xxxxxxxxxx	xxxxxxxx	xxxxxxxx	xxx
Optimal time for harvesting trees[d]		xxxxxxxx	xxxxxxx		xxx	
Possible time for harvesting trees		xxxxxxxxx	xxxxxxxxxxx	xxxxxxxx	xxxxxxxxxx	xx
Optimal for Road-building[e]		x	xxxxxxxxxx	xxxxxxxx	xxxx	
OPTIMAL TIME FOR PINE SNAKES TO BE EXPOSED TO HUMAN ACTIVITY[F]	XXXXX Mid- Dec to mid Feb			XXXX Mid July- Mid Aug		XXX Mid -Dec

a. Based on a 30+ years of study.
b. Based on discussions with firefighters, and (State of New Jersey, Department of Environmental Protection, Forest Fire Service (NJ, DEP, FFS) 2019).
Based on dates for organized ORV races in NJ.
d. (Pinelands Forestry Advisory Committee (PFAC) 2006).
e. C. Williams (road construction oversight inspector). Some construction possible all year except for inclement weather (C. Williams, pers. comm.).
f. Optimal time when human activities will cause the least disturbance and disruptions to Pine Snake behavior and survival.

DEP, FFS) 2019), and burning practices are similarly limited (Pinelands Forestry Advisory Committee (PFAC) 2006). It is clear that managed fires to reduce fuel on the ground cannot occur in the winter when the ground is covered with snow (no debris to burn), or in mid-summer when winds might blow smoke to tourist communities along the coast. The Pinelands Commission's recommendations note that utilizing heavy equipment may present an immediate threat to individual pine snakes near hibernacula, and that the risk is greatest from November to April. The periods when these human activities occur may vary in different parts of the country. What Table 4 does indicate, however, is that there is overlap between vulnerable behaviors of pine snakes and the optimal times for management for fires, ORV races, and road-building.

Knowing the periods (from beginning to end) of particular snake activities above ground is not sufficient to indicate the severity of a risk. Field observations during the nesting season indicated that gravid females select open, sunny clearings where they excavate a nest. This is typically a 2–3 week period of late June and early July (Burger and Zappalorti 2011, 2016, Personal observation). It may take 2–3 days for a female to dig her nest tunnel (K. Ng, Personal communication). The gravid female pine snake is exposed above ground to hawk and mammal predators. If ground temperatures become too high from being exposed to the sun, female snakes will move to a cooler, shady retreat. While in the open nesting area, gravid females may be easy for predators or poachers to find, and a gravid female laden with eggs is easy to capture because these reptiles bask, and often do not move when approached (Personal observation).

Passive-recording technology allowed for an examination of the actual behavior of snakes around hibernacula in 2017 and 2018. Until these data were collected, snakes were believed to use hibernacula as summer dens, spending little time above ground during the heat of summer. The PIT tag recordings demonstrated this was not true for the monitored dens. The snakes were elsewhere, perhaps in other dens, in logs, or under pine needles and brush for most of the summer (at another location, three radio-tracked adult pine snakes returned to hibernacula during extreme high summer temperatures which are above 35° C.

In the autumn, snake activity around the hibernacula was recorded (Table 5); snakes went in and out and moved among dens but did not go in and stay. The period of ingress and egress activity around the Bass River hibernacula lasted at least two months, and the average number of times a snake went in or out was nearly six times/snake, more than expected. Over the two-month period, a mean of 2–3 snakes were active in the vicinity of the Bass River hibernacula entrances every day (Table 5). At the Crossley Preserve den in Ocean County (also called the Davenport hibernaculum), where only two hatchlings and one two-year old occurred, pine snakes averaged 43 recordings/snake of activity moving in and out of the entrance, over two months (Figure 2). The hatchling shown in Figure 2 went in and out when the temperature was near 0° C; whereas the two-year-old snake was predominantly active above 5°C. For much of the day, this hibernaculum is exposed to full sun, making the actual microclimate warmer (the thermometer was covered with moss mainly in the shade). At the two study areas, there was some snake activity almost daily (even into late December at Davenport). On a warm day, one of the hatchlings came out for a couple of hr (Jan 6). Thus, snakes were concentrated in small areas around the hibernacula, and were active for a long period, indicating high vulnerability. If an ORV race, an ORV on an illegal trail, a managed fire, or logging activity occurred in this area (or any with hibernacula) at this time, a large segment of a local population may suffer greatly.

Table 5. Vulnerability of pine snakes is high when they are entering hibernacula in the fall because they concentrate in the vicinity of their hibernacula, going in and out as a function of weather (fall activity around hibernacula was from passive continuously recording Industrial Reader).

Characteristic	Bass River hibernacula	Crossley hibernaculum
Number of hibernacula	4	1
Years examined	2017, 2018	2018
Number of snakes	18 and 25	3
Activity period	3 October – 3 December	2 November – 27 December[a]
Ages of pine snakes	Hatchling – 17 yrs	Hatchling – 2 yrs
Average number of times entering/ leaving/passing by	5.6 ± 0.7	43 ± 14.6
Total number of activity hits in 2018	140	165
Average number of times snakes were above ground during the entire activity period during fall entry in the hibernacula	2.3	2.9
Duration of days above ground	61 days	57 days

a. One of the hatchlings came out on Jan 6, 2019, on an above freezing day.

Discussion

Functional attributes, general effects, and human activities

Understanding the functional attributes of human activities enables resource trustees and land managers to understand the degree of physical disruptions that different human activities might produce. These attributes are a continuum from one individual walking through a habitat, to heavy

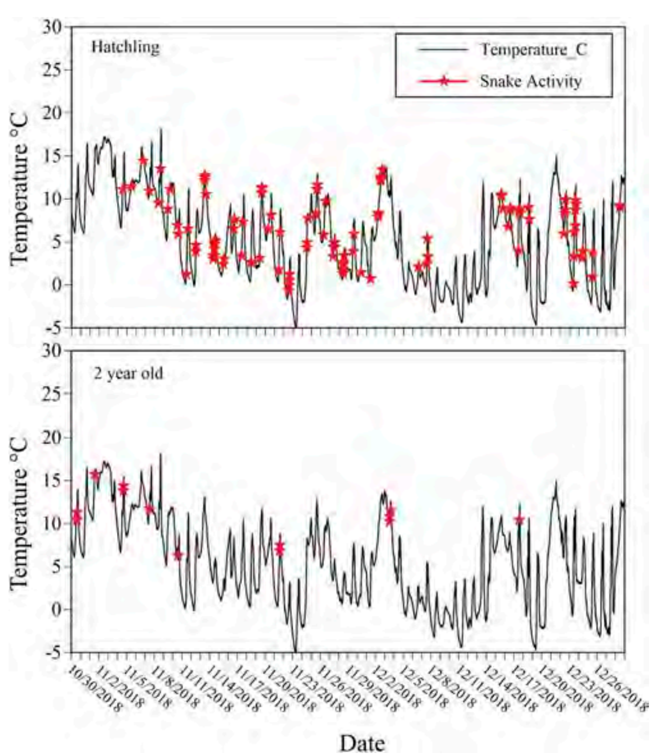

Figure 2. Activity pattern of a hatchling, and a two-year old pine snake at the Davenport hibernaculum in 2018. Every star indicates when a snake entered or left the hibernaculum. Activity is shown relative to soil temperature (at the surface, under a clump of moss).

equipment, pulling trailers, displacing soil, mining sand, and eliminating vegetation. These attributes are associated with effects that are predominantly associated with disruption. While the intensity of effects may be a gradient in different habitats, the actual consequential outcomes may be similar. It has been noted that pine snakes in the field respond more strongly when more people are present, and are moving about more, compared to when only one individual moves slowly (Personal observations). Species have evolved with recovery mechanisms to natural environmental threats faced, such as storms, floods, or multiple predators, but cannot necessarily respond quickly to anthropogenic stressors, especially if the habitat is lost (Wilcove et al. 2000). Often recovery from disasters requires the ability to reproduce quickly by producing a large number of young, having higher survival of young, or by breeding at a younger age. These natural mechanisms, however, are not available to all species such as the pine snake due to delayed maturation, small clutch size, and predation of eggs. Management actions may speed recovery by reducing the threats such as poaching, road kills, or habitat loss, or by improving conditions such as improving or creating habitat by management. Determining the natural, anthropogenic, and interactive threats is a first step to managing recovery.

The conceptual model provides an overview of the possible relationships among anthropogenic influences on species and ecosystems, and the Tables provide scientists, resource trustees, and managers a path forward to examining the threats that species face from different human activities. By using the first three Tables, anyone interested in comparing the risks to a species or group of species is able to describe the important effects attributable to each type of human disturbance. Table 3 provides an example of an at-risk species – the threatened pine snake.

Physical disruption versus outright killing

The above model and discussion of anthropogenic effects on species and communities largely dealt with physical disruptions of the habitat but did not discuss injury, removal, and killing, either deliberately or accidentally by people. Poachers disrupt the habitat in a similar manner as individuals walking or hiking through the pines. However, poachers also intentionally turn logs, dig up nests to capture gravid females, or remove pine snake eggs and other reptiles for their personal collections, for trading, or for sale (Burger and Zappalorti 2016), which severely impacts populations. Similarly, road-building results in physical disruptions to the habitat and fragmentation, but once completed, vehicles using these roads kill large numbers of snakes and other reptiles and amphibians, as well as interrupting gene flow (Andrews, Gibbons, and Jochimsen 2008; Clark et al. 2010). This is unintentional killing, but a significant source of mortality nonetheless. Similarly, ORV driving in nesting areas may unintentionally kill gravid females or hatchlings (Burger et al. 2007) as their cryptic coloration renders them inconspicuous. Finally, some individuals intentionally kill snakes when these people encounter them, particularly in residential neighborhoods that were formerly snake habitat. It is difficult to assess the importance of this source of mortality, but with meaningful educational programs, this risk needs to be reduced.

Management implications

When there are competing claims for resources, or the habitats that individual species use, there is a critical need for biological information on threats, stressors, and vulnerabilities of each species, as well as information on differing management objectives. That is, not only must managers know when species are most at risk (and from what), but they also need to know the optimal time to implement management actions such as prescribed forest fire. Varying management actions (protecting endangered or threatened species, controlled burns, allowing recreation or hunting) have different costs and benefits. The benefits should not be ignored, but generally require further studies (Keyser et al. 2004). Often the different claims or responsibilities among management objectives are in direct competition. A formal process for regularly negotiating conflicts would be valuable. Such deliberations are most productive when a range of agencies, NGOs, and the public are involved (National Research Council (NRC) 2008).

Data on critical periods, vulnerabilities, and stressors are needed to make sound, evidence-based decisions (Cvitanovic, McDonald, and Hobday 2016). This suggests that it is important for managers of habitats to fight the urge to manage only within their domain, but rather to cross management boundaries by interacting with various land managers from as many different agencies and groups as possible. This usually results in adaptive management whereby different options are selected, evaluated, and management actions may be changed to add more protection to a particular group of organisms (Armitage, Berkes, and Doubleday 2010; Army Corps of Engineers (ACE) 2004). GIS and other techniques may be required to keep track of the spatial extent of management alternatives (Atkinson and Canter 2011). Resolving conflicts often involves making hard choices between diversity, ecosystem well-being, and human objectives (McShane et al. 2011). Presumably, the overall goal is to increase the ability of species, populations, and ecosystems to maintain stable conditions or populations, leading to sustainability (Holling 1973). The conceptual model and Tables presented in this study are intended to provide an additional tool that might help to make science-based decisions (Sorvari and Seppala 2010).

This investigation presented a model to (1) examine the functional aspects of threats from human activities to threatened and endangered species, (2) develop a conceptual model of the relationship between natural and anthropogenic threats and effects, (3) define functional attributes of human disturbances, and (4) describe effects attributed to these human activities by utilizing Northern pine snakes as a case study. This study addresses the issue of how to manage some Pine Barrens forest habitats when there are competing land-use claims and responsibilities. Wildlife managers and conservationists want to enhance and protect rare, threatened and endangered species, natural ecosystems, and biodiversity, especially listed species such as pine snakes and other rare reptiles. Forest managers often want to manage the forest for maximum economic benefit with respect to various logging regimes. Park managers want to manage partly for recreationists, and fire marshals want to reduce fuel with controlled burning to prevent canopy fires that threaten neighboring communities. Each group has responsibilities and priorities, although different agency managers are recognizing the importance of competing claims and working to preserve as many environmental goals as possible. Using the Tables presented here, managers are able to examine the vulnerabilities of the species, evaluate the resources of the habitat they manage, and present the threats, risks, and vulnerabilities (including the most appropriate season to implement actions) to a large multi-discipline team.

If pine snakes are on the surface during prescribed burns, these vertebrates are vulnerable to forest fire; and thus the issue becomes how to optimize protection while providing opportunities to conduct controlled burns. Pine snakes are also vulnerable to ORVs (Burger et al. 2007). An important question is – When can ORVs be allowed to traverse snake habitat? This involves determining if, and when pine snakes are most vulnerable, which occurs when these species are concentrated and most active. Data on fall activity show that pine snakes are active for over two months in the fall before finally entering (and remaining in hibernacula) for the winter. A long period of high activity near the hibernaculum was unexpected, but illustrates the importance of collecting specific data on vulnerable periods so that management decisions can be science-based. It is unlikely that the same extended period of high activity around the hibernacula occurs during the spring emergence when the snakes disperse into the pine forests to forage. Except for a few instances, pine snakes leaving hibernacula in the spring did not return to the hibernacula until fall. Table 4 illustrates the pine snake annual cycle and the relative vulnerability of each activity at each time. This illustrates the short-term vulnerability of pine snakes (at least in the NJ Pine Barrens). It is unlikely that some human activities (e.g. ORV trails through intact forests, clear-cutting with soil removal, impervious development) provide any benefits for pine snakes.

Finally, similar analyses for other vulnerable snakes, as well as other species, in the Pine Barrens might enable a comparison among species to determine the types of human activities that pose the greatest risk, the temporal and spatial patterns of that risk, and relative vulnerabilities of different species. These biological constraints on vulnerable species need to be balanced against other societal interests of aesthetics, recreation, and economic needs, and habitats that need to be managed to foster human use, natural resource protection, and long-term sustainability.

Acknowledgments

This study was partly supported by Rutgers University, the Tiko Fund, Herpetological Associates, Inc., and the New Jersey Conservation Foundation. The project and protocol were approved by the Rutgers Institutional Animal Care Committee (E6-017), and permits were obtained from the New Jersey Department of Environmental Protection, Division of Fish and Wildlife (Endangered and Nongame Species Program). Thanks are extended to several people who provided help with the pine snake research, including Kris Schantz, David Jenkins and Dave Golden of the Endangered and Nongame Species Program, the Division of Parks and Forestry of the New Jersey Department of Environmental Protection (Cynthia Coritz), and The Nature Conservancy. Over the years, many of Rutgers University ecology graduate students and personnel of Herpetological Associates have assisted in these studies. I particularly thank Matt McCort, David Schneider, Mike Torocco, Dave Burkett, Ryan Fitzgerald, and Taryn Pittfield. The welfare of the Pine snakes always came first in our considerations.

Funding

This work was supported by the The Tiko Fund;The New Jersey Conservation Foundation;Rutgers University; Herpetological Associates.

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