Species Status Assessment Report for the Southern Hognose Snake (*Heterodon simus*)

Version 1.1

April 2019

U.S. Fish and Wildlife Service
Southeast Region
Atlanta, GA

ACKNOWLEDGEMENTS

This document was prepared by the U.S. Fish and Wildlife Service's Southern Hognose Snake Species Status Assessment Team: Melanie Olds (USFWS-South Carolina Ecological Service Field Office), Michael Marshall (Texas A&M), Brian Crawford (University of Georgia), and Kaye London (USFWS – Region 4).

We would like to thank our expert team for their substantive information and/or insights for our SSA analyses, Jeffrey Hall, Jeff Humphries, and Mike Martin (North Carolina Wildlife Resources Commission), Nathan Shepard (North Carolina Natural Heritage Program), Andrew Grosse (South Carolina Department of Natural Resources), John Jensen (Georgia Department of Natural Resources), Kevin Enge (Florida Fish and Wildlife Conservation Commission), Jeffrey Beane (North Carolina Museum of Natural Sciences), Jeff Camper (Francis Marion University), and Tracey Tuberville (University of Georgia, Savannah River Ecology Laboratory).

We would also like to recognize and thank the following individuals who provided substantive information, photos, and/or insights for our SSA. Thank you to Clint Moore (U.S. Geological Survey, Georgia Cooperative Fish and Wildlife Research Unit, University of Georgia), John Maerz (University of Georgia), and Mike Harris and D. Todd Jones-Farrand (USFWS- Region 4) for guidance and support toward all analyses. In addition to the expert team, thank you to Chris Smith (HerpMapper.org), Annalee Tutterow (Davidson College), Will Dillman (South Carolina Department of Natural Resources), Kurt Buhlmann (University of Georgia, Savannah River Ecology Laboratory), Matt Elliott (Georgia Department of Natural Resources), Lora Smith, Jen Howze, and Beth Schlimm (Jones Ecological Research Center), Roy King (DoD, U.S. Army, Ft. Stewart) Ericha Shelton-Nix and Ashley Peters (Alabama Department of Conservation and Natural Resources), David Laurencio and Michael Barbour (Auburn University), Nicole Hodges and Robert Jones (Mississippi Department of Wildlife, Fisheries, and Parks), and Pierson Hill (Florida Fish and Wildlife Conservation Commission) for providing species records, information, comments and/or photos.

Additionally, valuable peer review of a draft of this document was provided by John (J.D.) Willson (University of Arkansas). We appreciate his input and comments, which resulted in a more robust status assessment and final report.

Suggested reference:

U.S. Fish and Wildlife Service. 2019. Species status assessment report for the southern hognose snake (*Heterodon simus*), Version 1.1. April 2019. Atlanta, GA.

VERSION UPDATES

The changes from version 1.0 (March 2019 – Peer Review) include minor grammatical changes as well as the removal of one record/population in South Carolina and the addition of two historical records/populations in Georgia. These changes do not significantly change the analysis for the southern hognose snake.

EXECUTIVE SUMMARY

This report summarized the results of a Species Status Assessment completed for the southern hognose snake (*Heterodon simus*) to assess the species' overall viability. We considered what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, representation, and redundancy (3R's). We provide a thorough assessment of ecology and individual needs of the species, followed by a description of the factors influencing viability, and then a description of the species' current condition and predicted future condition.

The southern hognose snake is the smallest of the hognose snakes and is associated with xeric longleaf pine savannah, flatwoods, and sandhills from southeastern North Carolina, South Carolina, Georgia, Florida, and west to Alabama and Mississippi. They occupy upland habitat with well-drained, sandy soils, characterized by pine-dominated or pine-oak woodland where the canopy is open with a grassy understory. The annual cycle of the southern hognose snake is characterized by seasonal peaks of activity (Tuberville, et al., 2000, p. 21). Records for the species occur across all months, but there are generally two peak periods of detection May-June and October-November. The southern hognose snake is diurnal, with peak activity occurring in the late morning to early afternoon (Beane, et al., 2014, p. 173). Frogs and toads have been reported to make up the largest portion of the southern hognose snake diet, but they are also known to eat small lizards (Ernst & Ernst, 2003, p. 153; Beane, et al., 1998, p. 45; Ashton & Ashton, 1981, p. 85). Specific ecological needs that are essential to the survival and reproductive success of individuals include well-drained soils, suitable vegetation structure and composition, and presence of prey.

The potential factors that could be affecting the viability of the southern hognose snake include the following: (1) habitat loss, conversion, and fragmentation from loss of longleaf pine savanna habitat; (2) road mortality; (3) invasive species, such as the red imported fire ant and feral hogs; (4) effects of climate change resulting in increased temperatures, decreased precipitation, increased severe weather such as drought, flooding, or storms, changes in wildfire frequency and intensity, decreased ability to conduct prescribed burns, and sea level rise (SLR); (5) the collection of individual snakes for the pet trade and persecution by humans; and (6) impacts that a potential disease outbreak, such as snake fungal disease may have on existing populations.

For the purpose of this assessment, we defined ***viability*** as the ability of the southern hognose snake to sustain populations in the wild over time. Using the SSA framework, we describe viability of the southern hognose snake by defining populations, estimating current condition, and predicting the future condition using the metrics of the 3Rs.

Prior to conducting this SSA, a habitat suitability model was developed for the southern hognose snake with the support of species experts. Southern hognose snake records and available habitat/landscape data layers were used to identify habitat features that best predict species presence and the amount and distribution of potential suitable habitat across the species'

range. Model results showed habitat suitability, as measured by habitat suitability index (HSI) ranging from 0 (unsuitable) to 1 (most suitable), was strongly influenced by soil characteristics, land cover, and fire interval. These relationships agree with previous studies and expert opinion that the species generally favors fire-dependent, xeric habitat that is locally elevated (e.g., longleaf pine sandhills). Range-wide, there is an estimated 2.5 and 1.3 million ha of moderately and highly suitable habitat, respectively; 28% and 36% of moderately and highly suitable habitat, respectively, currently exists in patches larger than 100 ha on managed public and protected lands. More information regarding the habitat suitability model can be found in Appendix A.

For this assessment, we defined populations as contiguous areas surrounding known southern hognose snake occurrences with habitat conducive to survival, movement, and inter-breeding among individuals within the area. We used 2,227 species records from year 1880-2018 to define 222 populations. We grouped nearby records (those within 5 km of each other) into the same population while accounting for the major movement barriers (rivers and interstates).

To characterize current conditions, we estimated the persistence probability for each population using a model that incorporated southern hognose snake detections, search effort, and site conditions (including habitat suitability). Specifically, the model estimated the likelihood that a population boundary has not become extirpated and is currently (in 2018) occupied by at least one southern hognose snake, which we call "current persistence probability." We note that current persistence is not a direct measure of population size or growth rates, which are population-level metrics we could not estimate with available data, but it is still useful for assessing patterns of extirpation and viability. We measured southern hognose snake population resiliency by using current persistence probabilities (between 0 and 100%) and summarized results by grouping populations into categories representing ranges of persistence probabilities. The categories we chose were unlikely or extirpated (< 50%), more likely than not on landscape (50 – 79%), very likely on landscape (80 – 94%), and extremely likely on landscape or extant (95 – 100%). For a population to be highly resilient, it must have a relatively high current persistence probability.

Representation reflects the ability of a species to adapt to changing environmental conditions and can be measured by the breadth of genetic or environmental diversity within and among populations. Redundancy reflects the ability of a species to withstand catastrophic events over time by having multiple, widely distributed populations. Since we did not have species-specific genetic and ecological diversity information, we captured representation and redundancy by grouping EPA IV ecoregions into 9 representative units, which captured different ecological settings within the species' range, and assessing the number and geographic distribution of resilient populations across and within each unit and across the entire range. To have high representation, the species must have highly resilient populations located in each of the representative units, and resilient populations should span the latitudinal and longitudinal extent of historical populations. To have high redundancy, the southern hognose snake would need to have multiple resilient populations within a representative unit and throughout its range.

Current resiliency, representation, and redundancy have decreased from historical conditions for the southern hognose snake. Range-wide, 60% (133/222) of southern hognose snake populations have likely become extirpated (i.e., populations with a less than 50% current persistence probability). Conversely, 30.6% of populations had a greater than 80% probability of current persistence and 22.1% had a greater than 95% probability of current persistence (Table ES-1). All nine representative units have lost at least 50% of their populations (i.e., those with a less than 50% current persistence probability). Two representative units, the West (AL/MS) and Alabama Central units, have likely lost all of their populations (Figure ES-1). The Atlantic Coastal Plain (GA/FL) unit was predicted to have only 2 populations above a 50% probability of current persistence and only 1 population above an 80% probability (Figure ES-1). Therefore, this unit is also at a higher risk of unit-wide extirpation and indicates the potential for further loss of representation. The southern hognose snake has likely experienced a decrease in latitudinal and longitudinal variability (i.e., a range contraction), relative to its historic range extent. Although highly resilient populations are currently distributed across most representative units, their distribution has become clustered. This has left multiple large geographic regions only contain populations that are likely extirpated, including Alabama, Mississippi, northeastern North Carolina, central Georgia, and the eastern Florida Peninsula.

Table ES-1. Number and percentage of southern hognose snake populations in each persistence category and cumulative number of populations at or above each threshold.

Population persistence	Number of populations in each category	% of total	Cumulative number of populations at or above each threshold	% of Total
Extremely Likely on Landscape (Extant) 95-100%	49	22.1%	49	22.1%
Very Likely on Landscape 80-94.9%	19	8.6%	68	30.6%
More Likely than Not 50-79.9%	21	9.5%	89	40.1%
Unlikely < 50% (Extirpated)	133	59.9%	-	-
Total	222	100%		

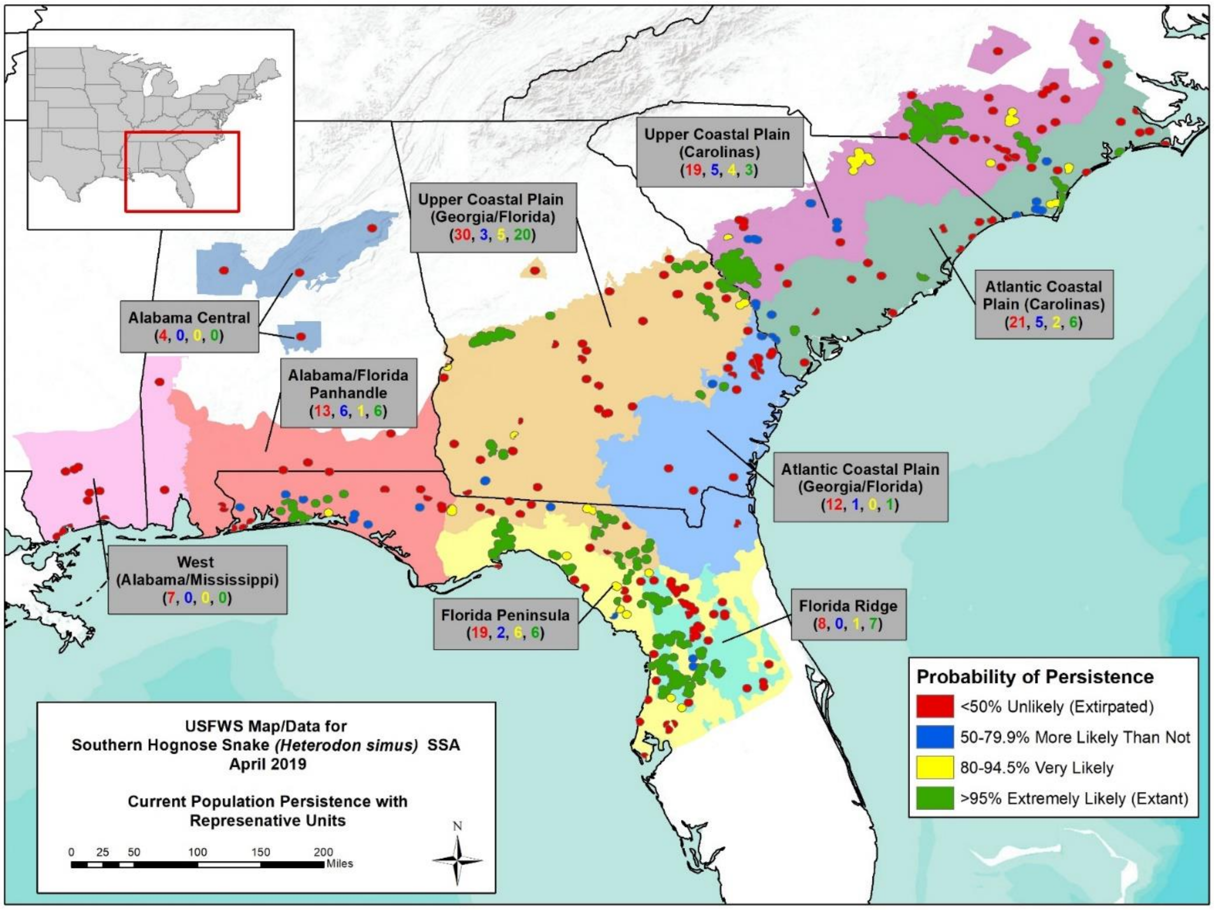

Figure ES-1. Southern hognose snake populations across representative units based on probability of persistence. Green populations are extremely likely to currently occur on the landscape, or be extant; yellow populations are very likely; blue more likely than not; and red populations are unlikely to currently exist (i.e., considered extirpated).

In evaluating future conditions for the southern hognose snake, we developed a simulation model that predicted population persistence through 2080 using current persistence and habitat conditions under seven scenarios capturing a range of plausible conditions of urbanization, sea level rise, and management actions (Table ES-2). We used the same metrics from the current conditions analysis to characterize future resiliency, representation, and redundancy, which we summarized at 2040, 2060, and 2080. Because the simulation model accounted for year-to-year variation and uncertainty, predictions varied each time we ran the model. Therefore, we additionally characterized future conditions by calculating the mean (the most likely prediction) and 95% confidence intervals for the number of persisting populations in each representative unit and range-wide each year through 2080.

Table ES-2. List of scenarios used to predict future conditions for the southern hognose snake, showing levels of urbanization, sea level rise (SLR), and management conditions considered in each scenario. Note: SLR represents inundation levels at 2080.

Scenario Name	Urbanization	SLR	Management Level
Low Stressors	Low (90%)	Low (1ft)	Status Quo
Medium Stressors	Medium (50%) (most likely)	Medium (3ft) (most likely)	Status Quo
High Stressors	High (10%)	High (6ft)	Status Quo
Decreased Management	Medium (50%) (most likely)	Medium (3ft) (most likely)	Decreased management effort on protected lands by decreasing fire frequency by 20% (One less burn every 5 years).
Improved Management	Medium (50%) (most likely)	Medium (3ft) (most likely)	Increased management on protected lands by increasing fire frequency by 20% (One extra burn every 5 years).
Protect More Populations	Medium (50%) (most likely)	Medium (3ft) (most likely)	Acquire, protect, and improve additional land within population boundaries for those populations that are very likely to currently persist (> 80% current persistence probability), but are not currently protected and improve mgmt. on all protected lands by increasing fire frequency by one extra burn every 5 years.
Protect Even More Populations	Medium (50%) (most likely)	Medium (3ft) (most likely)	Acquire, protect, and improve additional land within population boundaries for those populations that are more likely than not to persist (> 50% current persistence probability), but are not currently protected and improve mgmt. on all protected lands by increasing fire frequency by one extra burn every 5 years.

Our analysis shows that future resiliency, representation, and redundancy, is predicted to decrease from current conditions for the southern hognose snake under all scenarios. By 2040, only 3.6% of populations exhibit the highest degree of resiliency (>95%) under the medium stressor scenario, which is the most likely scenario. By 2060, there are no populations that exhibit the highest degree of resiliency for any of the scenarios besides the scenarios where management is improved for the species. By 2080, only 2 of 222 (0.9%) historical populations exhibit the highest degree of resiliency under the highest management effort scenario. In the future, there is a high risk of the species being extirpated from a third representative unit (under current conditions it is already extirpated from two units) and moderate risk of reduced representation in a fourth unit. The remaining five representative units showed declines in the number of resilient populations. Under all scenarios we see a reduction in the number of resilient populations within each of the units, as well as across the range of the species. By examining the mean number of populations persisting range-wide across scenarios (Figure ES-2), several takeaways emerge. First, the number of persisting populations decreased the most in the decreased management scenario and decreased least (but still decreased) in the protect even more populations scenarios, relative to current conditions. Second, the three stressor scenarios (low, medium, and high), yielded nearly identical predictions of the number of persisting populations. Third, the two scenarios representing highest management effort (the protect more populations and protect even more populations scenarios) yielded a greater number of persisting populations than all other scenarios, on average. These scenarios included acquiring and protecting lands occupied by populations that are currently persisting, and they resulted in a greater number of persisting populations than the improved management scenario that only included additional management of populations on currently protected lands. For all scenarios, many populations that fell within the extremely likely on landscape (≥95%) and very likely on landscape (≥80%) threshold under current conditions were predicted to have lower persistence probabilities in the future and, thus, dropped to lower categories.

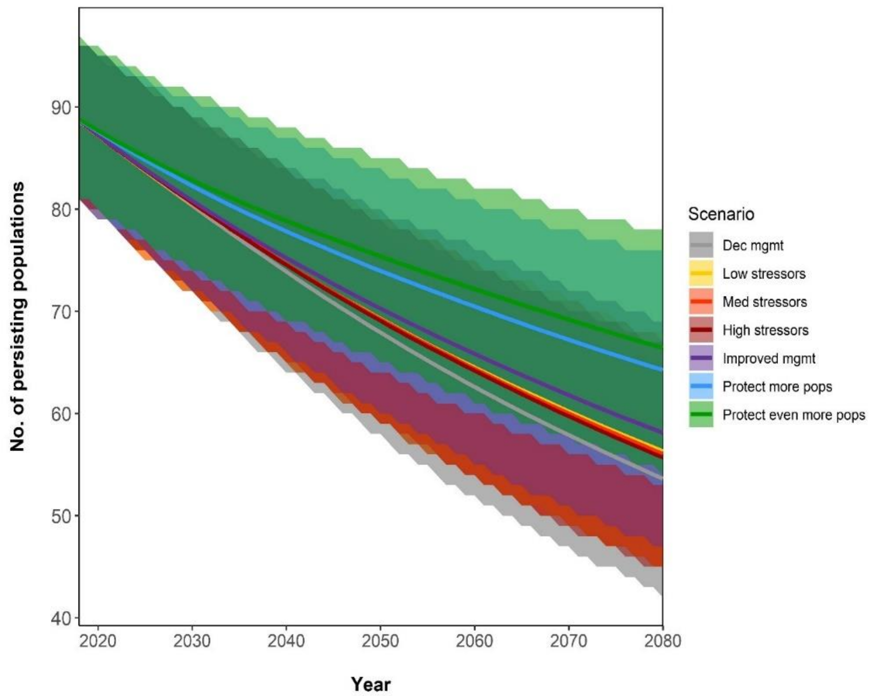

Figure ES-2. Predicted mean (± 95% confidence intervals) number of persisting southern hognose snake populations between the present year (2018) and 2080, given seven scenarios of stressors and management efforts.

The purpose of this assessment was to assess viability of the southern hognose snake. Our assessment shows that there have been range-wide declines for this species from its historical to current conditions, which has previously been suggested in the literature (Tuberville, et al., 2000, entire). The number of resilient populations is expected to continue to decrease in the future due to the effects of urbanization and SLR. Certain management efforts (i.e., acquiring, protecting, and managing land currently occupied by the species) may lessen the rate of population declines, but the southern hognose snake’s resiliency, representation, and redundancy is expected to continue to decrease in the future.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 – INTRODUCTION

The southern hognose snake (*Heterodon simus*) is a species associated with xeric longleaf pine (*Pinus palustris*) savanna, flatwoods, and sandhills from southeastern North Carolina, South Carolina, Georgia, Florida, and west to Alabama and Mississippi. We, the U.S. Fish and Wildlife Service (USFWS), were petitioned to list the southern hognose snake as endangered or threatened under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1543) (ESA), in July 2012 as a part of the Petition to List 53 Amphibians and Reptiles in the United States by the Center for Biological Diversity (Center for Biological Diversity, 2012, p. 184). On July 1, 2015, the USFWS published a 90-day finding that the petition presented substantial scientific or commercial information indicating that listing may be warranted for 30 species, including the southern hognose snake (80 FR 37568, July 1, 2015). A review of the status of the species was initiated to determine if the petitioned action is warranted. Based on the status review, the USFWS will issue a 12-month finding for the southern hognose snake. Thus, we conducted a Species Status Assessment (SSA) to compile the best available data regarding the species' biology and factors that influence the species' viability. The southern hognose snake SSA Report is a summary of the information assembled and reviewed by the USFWS and incorporates the best scientific and commercial data available. This SSA Report documents the results of the comprehensive status review for the southern hognose snake and serves as the biological underpinning of the USFWS's forthcoming decision (12-month finding) on whether the species warrants protection under the ESA.

The SSA framework (USFWS, 2016, entire) is intended to be an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA Report to be easily updated as new information becomes available and to support all functions of the Ecological Services Program of the USFWS, from Candidate Assessment to Listing to Consultations to Recovery. As such, the SSA Report will be a living document that may be used to inform Endangered Species Act decision making, such as listing, recovery, Section 7, Section 10, and reclassification decisions (the latter four decision types are only relevant should the species warrant listing under the ESA). Therefore, we have developed this SSA Report to summarize the most relevant information regarding life history, biology, and factors influencing viability for the southern hognose snake. In addition, we describe the current condition and forecast the possible response of the species to various future factors and environmental conditions to formulate a complete risk profile for the southern hognose snake.

The objective of this SSA is to thoroughly describe the viability of the southern hognose snake based on the best scientific and commercial information available. Through this description, we determined what the species needs to support viable populations, its current condition in terms of those needs, and its forecasted future condition under plausible future scenarios. In conducting this analysis, we took into consideration the likely changes that are happening in the environment – past, current, and future – to help us understand what factors drive the viability of the species.

For the purpose of this assessment, we define **viability** as a description of the ability of a species to sustain populations in the wild over time. Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time (USFWS, 2016, p. 9). Using the SSA framework (Figure 1-1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its **resiliency**, **representation**, and **redundancy** (USFWS, 2016, entire).

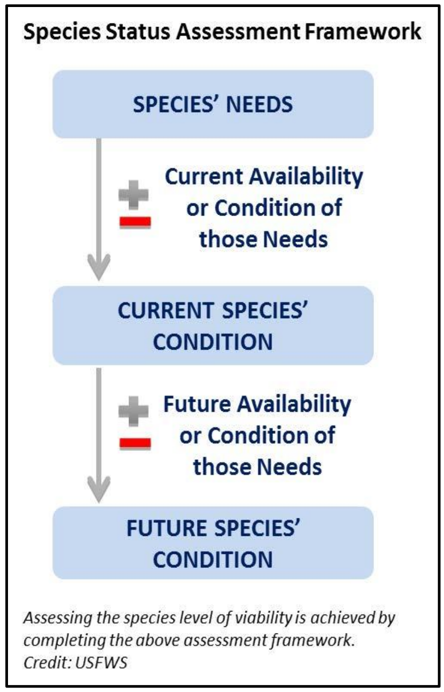

Figure 1-1. Species Status Assessment Framework.

- **Resiliency** describes the ability of a population to withstand stochastic disturbance. Stochastic events are those arising from random factors such as weather, flooding, or fire. Resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations. Generally speaking, populations need enough individuals within habitat patches of adequate area and quality to maintain survival and reproduction in spite of disturbance. Resiliency is measured using metrics that describe population condition and habitat; in the case of southern hognose snake, we used current persistence probabilities to assess population resiliency.

- **Representation** describes the ability of the species to adapt to changing environmental conditions over time. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (called environmental variation or diversity) of populations across the species' range. Theoretically, the more representation the species has, the higher its potential of adapting to changes (natural or human caused) in its environment. The number and distribution of resilient populations across a spatially explicit unit based on ecoregions was used to assess representation for the southern hognose snake.

- **Redundancy** describes the ability of a species to withstand catastrophic events. A catastrophic event is defined here as a rare, destructive event or episode that may have impacts to a population or multiple populations. Redundancy is about spreading risk among populations, and thus, is assessed by characterizing the number of resilient populations across a species' range. The more resilient populations the species has distributed over a larger area, the better the chances that the species can withstand catastrophic events. For the southern hognose snake, we used the number and distribution of resilient populations within the representative units and across the range of the species to measure redundancy.

To evaluate the viability of the southern hognose snake, we estimated and predicted the current and future condition of the species in terms of resiliency, representation, and redundancy.

This SSA Report includes the following chapters:

1. Introduction;
2. Species Ecology and Individual Needs. The life history of the species and resource needs of individuals;
3. Factors Influencing Viability. A description of likely causal mechanisms, and their relative degree of impact, on the status of the species;
4. Population and Species Needs and Current Condition. A description of what the species needs across its range for viability, and estimates of the species' current resiliency, representation, and redundancy; and,
5. Future Conditions and Viability. Descriptions of plausible future scenarios and predictions of their influence on southern hognose snake resiliency, representation, and redundancy.

Cited literature can be found after the final chapter. Additional supplemental information and analysis were used to complete this SSA Report. Information on the habitat analysis used to estimate current and future conditions is presented in Appendix A. Details for the current and future condition analysis is presented in Appendix B.

This SSA Report provides a thorough assessment of what is known of the biology and natural history and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the southern hognose snake. Importantly, this SSA Report does not result in, nor predetermine, any decisions by the USFWS under the ESA. In the case of the southern hognose snake, the SSA Report does not determine whether the southern hognose snake warrants protections of the ESA, or whether it should be proposed for listing as a threatened or endangered species under the ESA. That decision will be made by the USFWS after reviewing this document, along with the supporting analysis, any other relevant scientific information, and all applicable laws, regulations, and policies. The results of the decision will be announced in the *Federal Register*. The contents of this SSA Report provide an objective, scientific review of the available information related to the biological status of the southern hognose snake.

CHAPTER 2 – SPECIES ECOLOGY AND INDIVIDUAL NEEDS

In this chapter, we provide biological information about the southern hognose snake, including its taxonomic history, morphological description, historical and current distribution and range, and known life history. We then outline the resource needs of individuals.

2.1 Taxonomy

Figure 2-1. Southern hognose snake. Photo by J. Beane, North Carolina Museum of Natural Sciences.

The southern hognose snake was first described in 1766 by Carl Linneaus as *Coluber simus* from a specimen received from Charleston, South Carolina but it has been suggested that Linnaeus may have had an eastern hognose (*Heterodon platirhinos*) in hand (Edgren, 1953, p. 64; Meylan, 1985, p. 375.1). The species was then reassigned to the genus *Heterodon* by Holbrook (1842, p. 57), who went on to describe the species in great detail. There are currently five species recognized within the genus *Heterodon,* all of which are endemic to North America: eastern hognose snake, western hognose snake (*H. nasicus*), Mexican hognose snake *(H. kennerlyi*), dusty hognose snake (*H. gloydi*), and southern hognose snake (Integrated Taxonomic Information System, 2017, unpaginated). The current recommended standard name is southern hog-nosed snake (Crother, 2017, p. 67) but the USFWS has decided to use the more commonly used name, southern hognose snake. Other names include hissing adder, blow viper, puff adder, spreading adder, and hissing sand snake (Gibbons & Dorcas, 2005, p. 92; Conant & Collins, 1998, p. 327).

The currently accepted classification of southern hognose snake is:

Kingdom: Animalia
Phylum: Chordata
Class: Reptilia
Order: Squamata
Suborder: Serpentes
Family: Colubridae
SubFamily: Dipsadinae
Genus/Species: *Heterodon simus*

2.2 Species Description

The southern hognose snake is the smallest of the hognose snakes, with adult specimens typically ranging from 33 to 51 centimeters (cm) (12.9-21.8 inches [in.]) with a maximum total length of 74.3 cm (29.25 in.) (Conant & Collins, 1998, p. 328; Ernst & Ernst, 2003, p. 151; Ashton & Ashton, 1981, p. 85; Beane & Thorp, 2007, p. 193). Adult females are significantly longer than adult males, and males have significantly longer tails than females (Beane, et al., 2014, p. 171; Palmer & Braswell, 1995, p. 177). Males have 112-122 ventral scales (mean = 115) and tails with up to 44 subcaudal scales; females have 123-134 (mean = 127) ventral scales and 35 or fewer subcaudal scales (Ernst & Ernst, 2003, p. 151). In captivity, the current longevity record for the species is 12 years and 42 days (Beane & Thorp, 2007, p. 193).

Figure 2-2. Adult southern hognose snake (*Heterodon simus*). Photo by P. Hill, Florida Fish and Wildlife Commission.

The species' head is short with a sharply upturned keeled snout (Holbrook, 1842, p. 57; Conant & Collins, 1998, p. 328). The body scales are keeled and anal plate divided (Conant & Collins, 1998, p. 328). The head is dusky brown above the snout, with a dark transverse bar that often occurs on the snout in front of the eyes (Figure 2-2; Holbrook, 1842, p. 58; Ernst & Barbour, 1989, p. 39; Ernst & Ernst, 2003, p. 151). There is a dark brown or black stripe on either side of the neck and a short dark stripe may occur from the rear of the eye to the corner of the mouth (Ernst & Barbour, 1989, p. 39). The dorsum of the body is beige or tan with three longitudinal rows of dark brown blotches outlined anteriorly and posteriorly with black and a light orange to tan stripe along the center of the back (Ernst & Barbour, 1989, p. 39; Tuberville & Jensen, 2008, p. 356). The ventral side varies in color from white, cream, yellowish, or pinkish brown and has faint brownish pigment, usually near the tail (Ernst & Ernst, 2003, p. 151). The underside of the tail is the same color as the belly.

Hognose snakes are known for their defensive displays of hissing, flattening their necks, and death feigning. Like other hognose snake species, the southern hognose snake also will hiss and flare its neck when threatened and occasionally roll over and feign death, but it tends to be less theatrical (Figure 2-3; Tuberville & Jensen, 2008, p. 357).

Figure 2-3. Southern hognose snake displaying defensive behavior, flattening neck (left) and death feigning (right). Photos by P. Hill and K. Enge, Florida Fish and Wildlife Conservation Commission.

All snakes in the genus *Heterodon*, meaning different tooth, possess a pair of enlarged, ungrooved, posterior teeth, termed rear fangs. Venom, produced in the Duvernoy's glands, exits through ducts connecting to the fang sheath (Averill-Murray, 2006, p. 99). Though species within this genus are not considered dangerous, there are a few cases of human reactions to the venom, usually from a sustained bite (Weinstein & Keyler, 2009, p. 358). Specifically, the toxicity of the southern hognose snake has not been tested, and may only be toxic to anurans and lizards (Ernst & Ernst, 2003, p. 153)

2.3 Range and Distribution

The southern hognose snake is endemic to the Coastal Plain of the southeastern United States. States with known occurrence records include North Carolina, South Carolina, Georgia, Florida, Alabama, and Mississippi (Figure 2-4). The species was historically distributed through the southeastern United States from the vicinities of Morehead City and Raleigh, North Carolina, south to Tampa, Florida; west to the Pearl River separating Louisiana and Mississippi; and north to Calhoun County, Alabama (Meylan, 1985, p.

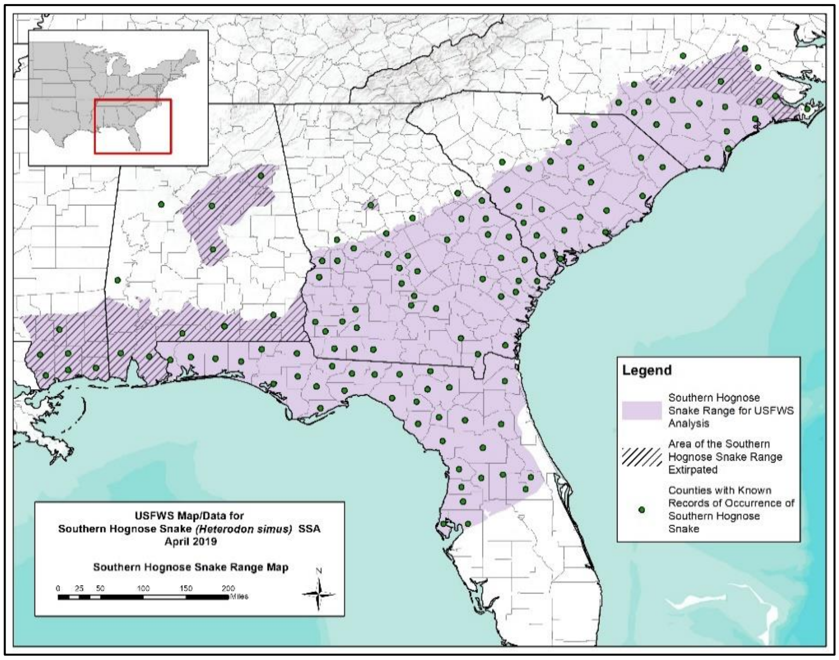

Figure 2-4. Southern hognose snake range map. The shaded range represents an estimate of the range based on locality information and known habitat needs for the species; areas presumed extirpated are in black hatching. County records indicated by dots in the center of the county, which in some cases the center point may fall outside the shaded range.

375). Historic records are known from two disjoined areas from the rest of the range, with multiple records in Autauga, Shelby, and Calhoun Counties, Alabama up to 1968, and a single historic record from Butts County, Georgia in 1952. Southeastern Louisiana was once included in the historical range for the species, but those records are considered erroneous (Meylan, 1985, p. 375; Tuberville, et al., 2000, p. 23). There is also a museum record from Miami-Dade that we did not include because it is far outside of its accepted range; in some cases old museum records list the city from which specimens were shipped by the collector, not the site where specimens were actually collected (Enge, et al., 2016, p. 20).

2.4 Individual Ecology

2.4.1 Life History

Life history of a species includes events in a species' life and characteristics that affect the likelihood that an individual will survive and contribute to the population from one year to the next. We consider the southern hognose snake to have three life stages: egg, hatchling/juvenile, and adult.

The annual cycle of the southern hognose snake is characterized by seasonal peaks of activity (Tuberville, et al., 2000, p. 21). Records for the species occur across all months, but there are generally two peak periods of detection (when this species is above ground): breeding season (May-June) and hatchling season (October-November) (Figure 2-5 and Figure 2-6). In Florida, 33.3% of records came from May–June during the breeding season, and 34.5% came from October–November (Enge, et al., 2016, p. 6). During a survey in Hernando County, Florida, most snakes were found in June and October–November, with 96% of snakes in October–December being hatchlings (Enge & Wood, 2002, p. 369; Enge & Wood, 2003, p. 192). Peak activity was May–June and October in South Carolina (Gibbons & Semlitsch, 1987, p. 400) and September–October in North Carolina (Beane, et al., 2014, p. 173). The southern hognose snake is diurnal, with peak activity occurring in the late morning to early afternoon (Beane, et al., 2014, p. 173).

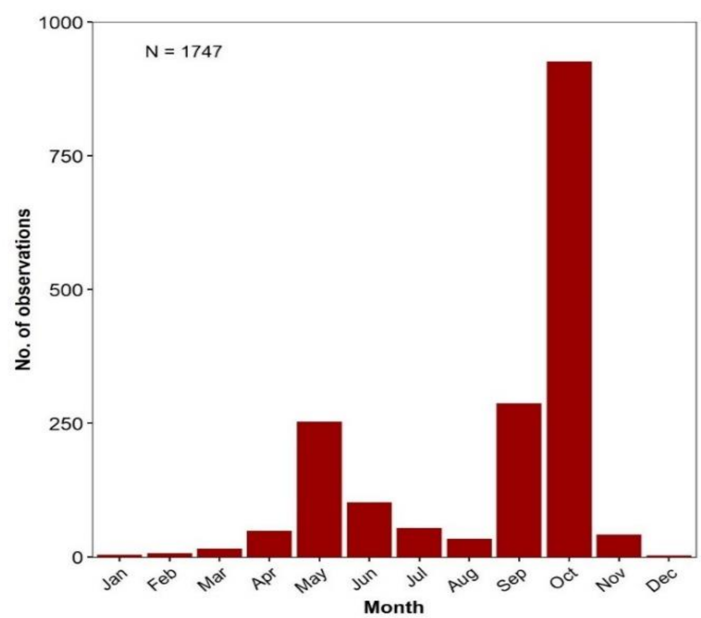

Figure 2-5. Number of southern hognose snake observations by month. There are two peaks of seasonal activity with relatively more observation records, a small one in May-June and a much larger one in September-October.

Figure 2-6. Diagram of the natural history of the southern hognose snake in Florida. Some of the information in this diagram may be based on observations of captive animals and may not fully represent what is occurring in the field (e.g., adults going dormant from August until very late September). Source: Bartolotti, 2018, unpaginated.

2.4.2 Reproduction and Sex Ratios

Figure 2-7. Copulating pair of southern hognose snakes. Photo by J. Beane, North Carolina Museum of Natural Sciences.

During the first seasonal peak of activity (spring), southern hognose snakes emerge from underground refugia for breeding (Figure 2-7). It has been speculated that sexual maturity occurs when adults reach 36 cm (14.2 in.) in total length, but others defined an adult as greater than 25 cm (8 in.) snout-vent length (Beane, et al., 2014, p. 171). Breeding occurs from mid-April through August (Ernst & Ernst, 2003, p. 152), although in North Carolina, the species has been observed breeding in the fall, with observations in late September and early November (Beane, 2019, pers. comm.). The southern hognose snake is oviparous, and in captivity eggs are usually laid in July and hatch in approximately 60 days (September–October), although oviposition in October has occurred (Price & Carr, 1943, p. 193; Palmer & Braswell, 1995, p. 179; Ernst & Ernst, 2003, p. 152). In captivity, clutch size has been reported as 6−19 eggs with an average of 9.6 (Palmer & Braswell, 1995, p. 179; Ernst & Ernst, 2003, pp. 152-153; Enge, 2004, p. 76). Eggs are oval and pale white in color and do not adhere to each other (Rossi & Rossi, 1991, p. 265). Hatchlings resemble adults, but their body color and patterning is more pronounced. Hatchling snout-vent length ranges from 13.9 to 14.7 cm (5.5 to 5.8 in.) and total body length from 13.4 to 18.0 cm (5.3 to 7.1 in.) (Jensen, 1996, p. 25; Ernst & Ernst, 2003, p. 153).

There is no information available on natural nests, as one has never been found. For the eastern hognose snake, nests were reported at 15 cm (5.9 in.) below the surface in a gravel deposit, under a rock, and at depths of 10 to 15 cm (3.9 to 5.9 in.) in sandy fields (Edgren, 1955, pp. 105-108). The eastern hognose snake in captivity digs a U-shaped burrow to deposit eggs. There are also little data on hatching success or hatchling survival, although data on the eastern hognose snake suggested high hatching rates (Edgren, 1955, p. 108).

The sex ratio has been reported biased toward males and becomes increasingly biased toward males within the largest size class – a pattern that suggests differential survivorship between the sexes or a sampling bias (Beane, et al., 2014, p. 173). Studies of two populations of eastern hognose snakes have also shown a male-biased sex ratio (Platt, 1969, p. 389; Scott, 1986, p. 54), whereas adults of the western hognose snake exhibit even sex ratios (Platt, 1969, p. 388).

Hatchlings and juveniles potentially make up a large proportion of a population of the southern hognose snakes, similar to eastern hognose snakes studied in Kansas, and in contrast to the adult-dominated population structure exhibited by western hognose snakes in Kansas (Beane, et al., 2014, p. 173; Platt, 1969, p. 390). Due to detections being largely along roads during the fall when young have just hatched and are dispersing, care should be taken when interpreting these skewed age ratios as, this could be an artifact of sampling bias and further research may be needed.

2.4.3 Foraging Ecology

Figure 2-8. Southern hognose snake eating an eastern spadefoot toad, Madison County, Florida. Photo by K. Enge, Florida Fish and Wildlife Conservation Commission.

Frogs and toads (anurans) have been reported to make up the largest portion of the southern hognose snake's diet, but they are also known to eat small lizards (Figure 2-8; Ernst & Ernst, 2003, p. 153; Beane, et al., 1998, p. 45; Ashton & Ashton, 1981, p. 85). However, a more recent study suggests lizards and anurans may contribute equally to the diet, or a possible diet shift with age or size may happen, due to the fact that lizards have only been found in the stomachs of smaller, juvenile individuals (Beane, et al., 2014, p. 173). There have been accounts of southern hognose snakes eating newborn mice in captivity, but they are usually rubbed with an anuran scent to entice the eating of the mouse (Palmer & Braswell, 1995, p. 329; Rossi & Rossi, 1991, p. 266; Enge, 2004, p. 76).

The specialized upturned snout of the southern hognose snake is used to dig out buried prey (Ernst & Ernst, 2003, p. 153; Conant & Collins, 1998, p. 328; Goin, 1947, p. 275). Previous gut content analyses showed the presence of mostly eastern spadefoot toad (*Scaphiopus holbrookii*) and six-lined racerunner (*Aspidoscelis sexlineata*). It has been speculated that the southern hognose snake forages in the early morning, before prey, such as the six-lined racerunner, emerges from its nocturnal burrows or during other periods when this lizard is likely to be inactive, such as late evenings or on cool days (Beane, et al., 2014, p. 173).

It has been hypothesized that the southern hognose snake's enlarged posterior maxillary teeth at the rear of its mouth are used to puncture inflated toads and spadefoots (Ashton & Ashton, 1981, p. 85), but the snake is more likely injecting mildly toxic venom into its prey. In a study of the effects of eastern hognose snake's venom on mice and various anurans, it was noted there were no effects to the mice while most of the anurans died (McAlister, 1963, p. 134).

2.4.4 Hibernacula

Little is known about hibernacula use of the southern hognose snake range-wide, but in North Carolina, snakes excavate their own hibernacula and burrow more or less vertically into sandy soil in inconspicuous spots (Beane, et al., 2007, p. 467). Southern hognose snakes were observed excavating and entering hibernacula, in North Carolina, from late October to late November, and emerging from late March to mid-April (Beane, et al., 2007, p. 467). Individual snakes do not depend on stump holes or other existing subterranean chambers for hibernacula and did not display hibernaculum site fidelity, though the sample size was small (n=4) (Beane, et al., 2007, p. 467; Beane, 2019, pers. comm.).

2.4.5 Individual Species Needs (Habitat)

Southern hognose snakes are commonly associated with the longleaf pine ecosystem. They occupy xeric, upland habitat with well-drained, sandy soils, characterized by pine-dominated or pine-oak woodland. They favor habitat where the canopy is open with a grassy understory (Enge, et al., 2016, p. 12).

The southern hognose snake can be found in multiple physiographic regions across its range. In North Carolina, they have been found in mixed oak-pine forests occurring on well-drained, sandy soils (Palmer & Braswell, 1995, p. 176; Tuberville, et al., 2000, p. 21). Typical habitat in North Carolina has been reported as longleaf pine-wiregrass (*Aristrida stricta*)-turkey oak (*Quercus laevis*) forests (Beane, et al., 2014, p. 169). Habitat associations for a subset of southern hognose snakes were recorded between 1985-2012; of those records, 51% were found crossing roads between open longleaf pine-wiregrass-turkey oak forests; 12% were found crossing between longleaf pine-wiregrass-turkey oak forests and disturbed forests, old fields, or agricultural areas; and 37% were found crossing roads between various disturbed forests and ruderal habitats (old fields, agricultural plots, clear cuts, and rural yards), or between ruderal habitats (Beane, et al., 2014, p. 173).

In Florida, sandhills seem to be the core natural habitat, but snakes have also been found crossing roads near ruderal habitats, such as clearcuts, residential lawns, improved pastures, and old fields (Enge, et al., 2016, p. 12; Enge, 1997, pp. 28-49; Enge & Wood, 2003, p. 198). Disturbed habitats are frequently used, but xeric hammock and scrub are seldom used (Enge, et al., 2016, p. 12; Enge, 1997, pp. 28-49). In a study conducted from 1998-2001 in Hernando County, Florida, half of the southern hognose snakes observed crossing roads were found near longleaf pine-wiregrass (*A.beyrichiana*)-turkey oak forests and 48.7% of snakes were found near old fields, agricultural areas, or disturbed forest types (Enge & Wood, 2002, p. 371; Enge & Wood, 2003, p. 189). Near Eglin Air Force Base along the Florida Panhandle, road-killed hatchlings were observed adjacent to longleaf pine-turkey oak sandhill, invaded by off-site sand pine (Jensen, 1996, p. 25; Tuberville, et al., 2000, p. 21).

Little is known about any specific habitat requirements that may be needed for nesting and hibernation. The southern hognose snake is strictly diurnal and notably highly fossorial and thus may make little use of aboveground cover (Carr, 1940, p. 80; Palmer & Braswell, 1995, p. 178). The most rigorous report of the use of burrows discussed finding animals under 20 to 30 cm (7.9 to 11.8 in.) of sand, in open areas (Palmer & Braswell, 1995, p. 178), with burrows than can be very obvious (Beane, 2019, pers. comm.). More recently, southern hognose snakes have been reported using southeastern pocket gopher (*Geomys pinetis*) mounds and gopher tortoise (*Gopherus polyphemus*) burrows (Stevenson, et al., 2018, p. 547). It is suspected that they occasionally use the southeastern pocket gopher mounds for sub-surface thermoregulation, particularly on cool, sunny days and may be using the gopher tortoise burrows for both refugia and for foraging for anurans (Stevenson, et al., 2018, p. 548).

We used existing life history literature and expert judgment to identify specific ecological needs for individuals to survive and reproduce (Figure 2-9; as well as factors influencing viability that are discussed in Chapter 3). Three main habitat elements, however, appear to be essential to the survival and reproductive success of individuals: well-drained soils, suitable vegetation structure and composition, and presence of prey.

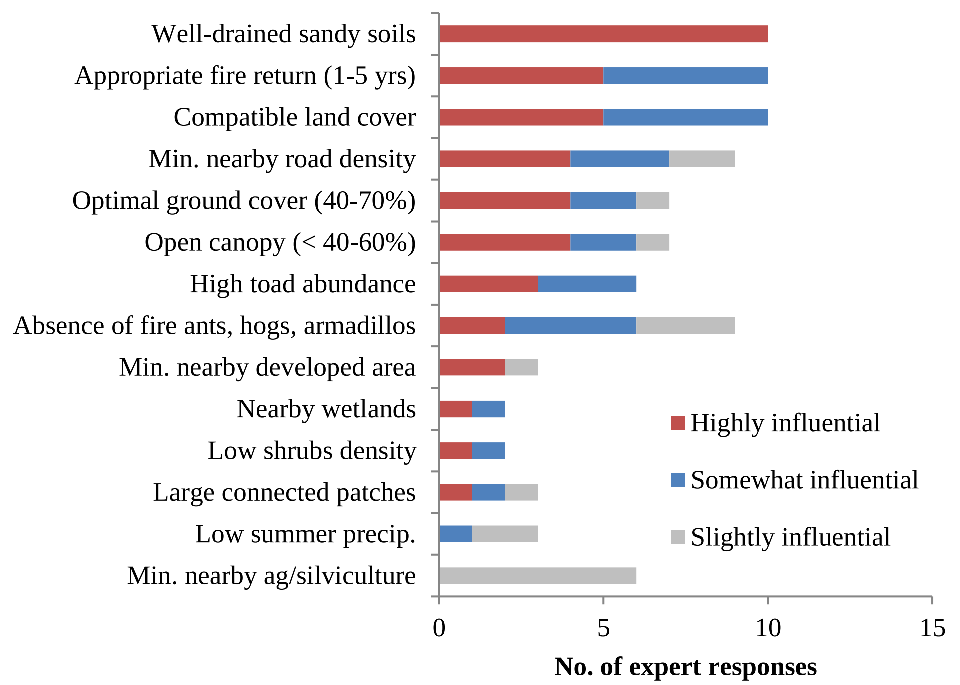

Figure 2-9. Influential habitat, landscape, and biophysical attributes for southern hognose snake presence at a site, as identified by 12 species experts. Some attributes reflect species needs while others reflect factors influencing viability (discussed in Chapter 3). Experts were asked to list attributes they associate with ideal habitat for the species. Definitions for habitat rankings: Highly – attributes must occur at a site for the species to be present; Somewhat – attributes occurring on the landscape greatly increase the likelihood of species being present, but species may occasionally use landscapes without these attributes; Slightly – attributes occurring on the landscape slightly or variably increase the likelihood of species being present, but species may use landscapes without these attributes.

CHAPTER 3 – FACTORS INFLUENCING VIABILITY

The following discussion provides a summary of the factors that are affecting or could be affecting the current and future condition of the southern hognose snake throughout some or all of its range. Risks that are not known or not suspected to have effects on southern hognose snake populations, such as environmental pollution are not discussed in this SSA.

3.1 Habitat Loss, Conversion, and Fragmentation

Loss of Longleaf Pine Ecosystem

The southern hognose snake is associated with longleaf pine savanna, particularly xeric uplands that were historically maintained by fire. The longleaf pine ecosystem is a fire-dependent ecosystem that once dominated the Coastal Plain of the Atlantic and Gulf coast regions, from Virginia to Texas (Ware, et al., 1993, p. 447). The longleaf pine uplands once covered an estimated 92 million acres (Frost, 1993, p. 20). By the 21st century, the longleaf pine community had declined to less than three million acres due to forest clearing and conversion for agriculture, silviculture (tree farming), and development (Landers, et al., 1995, p. 39; Jensen, et al., 2008, p. 16). Little old-growth longleaf remains, and of the uplands that remain, only about 3% are in relatively natural condition due to the exclusion/suppression of naturally-occurring wildfires (Simberloff, 1993, p. 3; Frost, 1993, p. 17).

Original longleaf pine communities were old-growth, open-canopied, and contained a structure of two layers: canopy and diverse herbaceous groundcover. Frequently burned, the natural condition was a canopy cover that rarely exceeded 60 percent and permitted a grassy groundcover to flourish (Noss, 2013, p. 9). In contrast, much of today's forest is young, dense, and dominated by loblolly pine (*Pinus taeda*), with a substantial hardwood component and little or no herbaceous groundcover (Noel, et al., 1998, pp. 534-535).

The longleaf ecosystem was first heavily altered by exploitation for naval stores and then virtually eliminated by widespread logging (Frost, 1993, pp. 24-37). Naval stores industries harvested pine resin for the production of tar, pitch, and turpentine—commodities in high demand during colonial times. Pine woodlands were logged for lumber and converted to agricultural fields. Impacts to easily accessible areas began with the arrival of Europeans, but technological developments of the 1800s, such as the copper still, steam power, and especially railroads, dramatically increased the rate and area of loss (Frost, 1993, pp. 23-24). In the late 1800s, logging operations moved to the previously inaccessible interior forests of longleaf, shortleaf (*Pinus echinata*), and loblolly pines. This especially intense period of logging from 1870 to 1930 resulted in the loss of nearly all of the remaining old-growth forest in the Southeast.

Although there is still uncertainty in burn regimes between various habitat types and along environmental gradients, fire frequencies in longleaf pine savanna have been estimated at one to three years (Frost, 1998, p. 76). Frequent burning has been shown to maintain species richness of the ground cover layer (Glitzenstein & Wade, 2003, p. 23). Season of fire is also widely presumed to have important effects on vegetation composition. Growing season burns, generally defined as the period of time when most plants are actively growing, coincides with the bulk of wildfires caused by lightning strikes, and has been shown to better meet management objectives for longleaf pine forests (Knapp, et al., 2009, p. 3).

Historically, lightning was the primary ignition source shaping the evolution of these fire-maintained ecosystems, but Native Americans may have played a role in maintaining them (Frost, 1993, p. 34). After European settlement and prior to the mid-1800s, farmers burned the woodlands regularly to improve forage for free-ranging livestock, but by the mid to late 1800s fencing of livestock caused a decrease in burning (Frost, 1993, p. 34). Although many people continued to use fire in agricultural fields well into the 1900s, the rise of mechanical and chemical agriculture replaced fire-based agricultural methods.

Active fire exclusion/suppression began to be institutionalized in the southeastern United States between 1910 and 1930 (Frost, 1993, p. 35). Some foresters denounced fire as detrimental to southern pines rather than an integral or useful component of the natural system. Fire suppression increased with the rise of pine plantations, a land use that began in the 1930s and continues today (Frost, 1993, p. 36). Due to the suppression of lightning-ignited fire and the natural disturbance fires provide, longleaf pine communities have converted to fire-intolerant trees and shrubs that eventually shade out the ground cover and render the forest unsuitable for much of the fire adapted biota (Jensen, et al., 2008, pp. 16-17). In addition to directly affecting reptiles, habitat loss can indirectly affect them by limiting their ability to meet ecological needs for survival and reproduction (Todd, et al., 2010, p. 50). This habitat conversion has likely negatively impacted southern hognose snake populations (Enge, et al., 2016, p. 21). Planting of densely stocked sand pines and succession of sandhill habitat to xeric hammock in the absence of fire are probably responsible for the apparent southern hognose snake population declines in the central Florida Panhandle (Enge, et al., 2016, p. 21).

In addition to fire suppression, longleaf pine communities continue to be altered for agriculture, short-rotation pine plantations, residential, and commercial purposes, most of which are incompatible with the habitat needs of southern hognose snakes. Like other reptiles and amphibians associated with the longleaf pine ecosystem, the southern hognose snake has declined in parallel with the decline of the longleaf pine ecosystem (Beane, et al., 2014, p. 168)

Although the southern hognose snake is more common in sandy, open longleaf pine forests and flatwoods, it can persist in fragmented and altered habitats. The effects of habitat conversion to agriculture on long-term viability of the species is unknown but believed to be contributing to declines (Enge & Wood, 2002, p. 365; Enge, et al., 2016, p. 21). Many southern hognose snakes have been found on roads near disturbed habitats such as clearcuts, residential lawns, improved pastures, and old fields and agricultural areas (Enge & Wood, 2002, p. 371; Beane, et al., 2014,

p. 173), but we still do not know the extent to which southern hognose snakes are using disturbed areas. Agricultural areas, where snakes are being detected have an open canopy; thus, they may be selecting these areas due to the presence of sandy soils and open canopy, whereas the surrounding areas may be fire-suppressed with a closed canopy and dominated by hardwood species. In addition, agricultural practices, such as plowing and other soil disturbing activities, may cause direct mortality to southern hognose snakes due to their fossorial nature and may alter the soil profile or characteristics, rendering soils less suitable for snakes. Southern hognose snakes are more commonly found in fire-maintained upland habitat than agriculture areas, and when found in agricultural areas those areas are typically adjacent to natural upland habitats. It is likely that natural upland habitats are optimal for individuals' survival and reproduction while agriculture and other low-impact areas of human use (e.g., pastures, pine plantations, rural and urban open areas) support survival and movement through these areas but may not support long-term viability of populations.

Timber harvesting is one of the more prominent forms of habitat alteration that shapes plant and animal communities, and the southeastern United States is the leading timber-producing region in the country (Prestemon & Abt, 2002, p. 299). Timber stands in the Southeast are typically maintained as even-aged, short-rotation planted pine forests. This forest type has largely replaced the open longleaf pine-dominated savanna community that once existed. Short-rotation planted pine forests differ from the natural ecosystem in a variety of ways, including higher stand densities, closed canopies, deep litter beds, and sparse understories, and harvesting of the short-rotation planted pine is done primarily through clear cutting (Todd & Andrews, 2008, p. 754; Means, 2005, pp. 142-143). Timber stands with high stand density and a dense mid-story with little to no groundcover do not provide adequate habitat for the southern hognose snake, but it should be mentioned that thinning dense stands of forest, as opposed to clear cutting, can benefit species that occupy longleaf forests. Thinning of dense stands can help mimic the historic condition of longleaf stands, mainly through the opening of the under- and mid-story. In fact, many forests are so densely stocked that thinning is required before a prescribed burning regime can be established.

Many reptile species have been shown to decline in abundance over time following the clearing of primary forest or conversion to plantation forest (Glor, et al., 2001, p. 719; Kanowski, et al., 2006, pp. 13-14). At a finer scale, a study from the southeastern United States found lower abundances of small snakes in planted pine forests with recent clear-cuts compared with open-canopied, partially harvested forests (Todd & Andrews, 2008, p. 757). Direct mortality has been attributed to timbering operations (Reinert, et al., 2011, p. 23), and intensive forestry practices such as shearing, raking, disking, harrowing, roller-chopping, bedding, replanting, and the use of herbicides negatively affect snake populations (Todd & Andrews, 2008, p. 760; Enge & Marion, 1986, p. 187). Not only can mechanical site preparation techniques directly kill or injure fossorial herpetofauna; they also damage the soil structures in which those species occur, making the habitat less suitable in the future (Bailey, et al., 2006, p. 45).

Urban Development

Urbanization plays both direct and indirect roles in the decline of many species (McKinney, 2002, p. 883). Urbanization fragments and replaces natural habitats with artificial structures, impervious concrete and asphalt surfaces, manicured lawns, and gardens full of exotic plant species, and increases levels of air, water, noise, and light pollution, putting the survival of many wildlife species in jeopardy (Sutherland, 2009, p. 35). Snakes seem to be particularly sensitive to effects of urbanization, and this intolerance has played a key role in the general declines reported for reptile species around the world (Sutherland, 2009, p. 52; Andrews & Gibbons, 2005, entire; Row, et al., 2007, entire; Gibbons, et al., 2000, entire).

Urbanization impacts many wildlife species from direct loss of habitat, fragmentation of habitat, increased road mortality, increased human persecution, and the increase in domestic predators, such as cats (*Felis catus*) and/or dogs (*Canis lupus familiaris*). Also, a combination of urban sprawl and migration of humans to rural areas has created an extensive wildland-urban interface (WUI), the area where houses and wildland vegetation meet or intermingle. Wildland-urban interfaces limit the ability to conduct prescribed fires due to issues associated with smoke management and fear of fires escaping and having catastrophic effects. Active fire exclusion/suppression and a lack of a controlled burning program in WUIs results in increased fuel loads and a subsequent increase in the likelihood of future destructive fires (Winter, et al., 2002, p. 15). Furthermore, because of constraints on implementing prescribed fire in WUIs, there is an increased risk of habitat degrading to the point that it is unsuitable for southern hognose snakes due to woody species encroachment.

In the southeastern United States, projections predict the urban footprint will greatly increase over the next 50 years, with median projections showing that the amount of land in urban areas will increase by 139% by 2060 (Terando, et al., 2014, p. 4). Urbanization is not predicted to be uniform across the region. The largest urban expansions are projected in the Blue Ridge, Ridge and Valley, Southern Coastal Plain, and Piedmont ecoregions, and new urban centers are projected in the Appalachian Mountains and central Florida regions (Terando, et al., 2014, p. 6).

Many “hotspots” of projected urban development are predicted to occur within, or near known occurrence records for southern hognose snakes, or predicted suitable habitat. Although we do not know the exact response of the southern hognose snake to various levels of urbanization, we do know that urbanization will likely result in the loss, degradation, and fragmentation of habitat, increased amount of WUI, increased persecution by humans, increased road mortality, and increases in domestic predators. In the case of domestic predators, killing by domestic dogs has been noted (Enge, et al., 2016, p. 22). Additionally, urbanization increases the number of mesopredators, such as raccoons (*Procyon lotor*), potentially impacting southern hognose snakes through direct predation or through indirect means by potentially affecting their prey base. Thus, we consider urbanization to be a significant threat to the southern hognose snake.

Fragmentation

Human induced disturbances, particularly from land use changes discussed in the previous sections, not only have the potential to result in loss or degradation of habitat, but also fragmentation of habitat. Habitat fragmentation is the breaking apart of continuous habitat into multiple patches (Fahrig, 2003, p. 509). Forestry and urban development increase the prevalence of roads and associated infrastructure, which increase the fragmentation of the habitat and additionally result in increased mortality from increased vehicular traffic. Fragmentation can have a variety of negative impacts on wildlife, including greater mortality rates associated with landscape modifications (e.g., roads), more frequent encounters with humans, reduced resources in smaller patches, reduced reproduction, restricted gene flow, and increases in predation and competition (Wiens, 1994, p. S97; Kjoss & Litvaitis, 2001, p. 285). Reduction of larger habitat patches into smaller patches can lead to population declines due to limited resource availability and can also negatively affect day-to-day movement (Barbour & Litvaitis, 1993, p. 326). Fragmentation may also negatively affect larger-scale movements such as dispersal and seasonal migration.

Many snake species are likely to be sensitive to habitat fragmentation because they occur in low densities, have limited dispersal abilities, have thermal constraints, and are subject to direct and indirect mortality caused by humans (Kjoss & Litvaitis, 2001, p. 286; Webb & Shine, 1997, p. 213). Of particular concern is the role that roadways play in fragmenting habitat. Depending on the size and traffic volume, newly-constructed roads can effectively become barriers that divide and isolate populations (Roe, et al., 2006, p. 162). The increasing encroachment of roads into natural areas may isolate populations, prevent movement between nest sites and hibernacula, restrict gene flow, and limit access to mates (Vanek & Wasko, 2017, p. 115). Additionally, roads not only impinge on life history requirements of species but also facilitate other threats, such as conversion of more habitat, creation of roads for access, and the spread of invasive species (Forman & Alexander, 1998, pp. 221-222), and lead to increases in direct mortality, discussed in the next section. Using population viability analyses, eastern indigo snake (*Drymarchon couperi*) populations were predicted to be vulnerable to extinction in fragmented conservation areas bordered by roads and suburbs (Breininger, et al., 2012, p. 365).

How individuals move between patches and how they respond to different habitats will ultimately determine how populations are impacted by fragmentation; thus, few generalizations can be made about the effects of habitat fragmentation on individual species. One might expect relatively sedentary species, such as the southern hognose snake, with specialized habitat requirements to be vulnerable to habitat fragmentation (Wiens, 1994, p. S101). Direct data is unavailable on the impact of habitat fragmentation on the southern hognose snake, but it has been hypothesized that habitat fragmentation is the cause for regional eastern hognose snake declines (Vanek & Wasko, 2017, p. 115).

3.2 Road Mortality

As discussed above, roads create habitat fragmentation isolate populations, pose a barrier to movement, and increase direct mortality for many snake species (Andrews & Gibbons, 2005, p. 772). Snakes are more severely affected by road mortality than other animal groups because they are thought to use roads for thermoregulation, are relatively slow-moving, and tend to arouse fear in the general public, leading to intentionally being run over (Rosen & Lowe, 1994, p. 143; Bonnet, et al., 1999, p. 40). It has been observed that reptiles are struck by vehicles at a greater rate than would be expected by chance, suggesting that drivers intentionally target reptiles on roads (Ashley, et al., 2007, p. 137). It has been estimated that vehicular traffic has killed tens or hundreds of millions of snakes in the United States throughout history (Rosen & Lowe, 1994, p. 147).

An increase in the number of mortalities from vehicles may result in reduced genetic diversity, decreased potential for dispersal into fragmented habitats, and alter demographics of the surrounding population – all of which can lead to declines or extirpation of populations of snakes. One study of black ratsnakes (*Pantherophis obsoletus*) found that, when including an estimate of road mortality to a population viability analysis, the extinction probability increased from 7.3% to 99% over 500 years (Row, et al., 2007, p. 117). An increased mortality rate for different reproductive classes can have profound consequences for a population; for example, increased mortality of females can reduce a population's growth rate more than mortality of males (Row, et al., 2007, p. 118).

A snakes' vulnerability to vehicle encounters is highest when they travel outside of their normal home range, with the highest mortality occurring in adult males during the mating season, neonates or hatchlings immediately after birth or hatching, and adult females on egg laying migrations (Bonnet, et al., 1999, p. 47). Roads that bisect high quality habitat have higher levels of mortality than those that bisect lower quality habitat (Shepard, et al., 2008, p. 357). Snake populations could experience especially high levels of road mortality during periods where high traffic volumes and species' seasonal movements coincide (Ashley, et al., 2007, p. 141).

Figure 3-1. Dead on Road (DOR) southern hognose snake, in North Carolina. Photo by J. Beane, North Carolina Museum of Natural Sciences.

Due to the secretive nature of the southern hognose snake and the difficulty in surveying for them, many records of this species are from encounters on roads; additionally many of those records are documented as Dead on Road (DOR; Figure 3-1). In North Carolina, during road surveys conducted between 1985–2012, 764 southern hognose snakes were detected; of those detections, 643 (84%) were observed DOR, 110 were observed Alive on Road (AOR), and 11 were encountered incidentally, not on a road (Beane, et al., 2014, p. 170). Observations in Florida between 1998-2001 detected 39 southern hognose snakes, all of which were DOR, and 62% of those observations were juveniles (Enge & Wood, 2002, p. 369; Enge & Wood, 2003, p. 192). The majority of southern hognose snakes encountered on North Carolina roads tend to be juveniles (Beane, et al., 2014, pp. 170-171).

Their cryptic coloration; small size; and aspects of their behavior such as slow movement, remaining motionless, and death feigning, lend this species to be particularly susceptible to road mortality compared to other snake species. Behavioral observations for a subset of southern hognose snakes found AOR in North Carolina support this idea. Many individuals encountered on roads would ‘‘freeze’’ and remain motionless when approached, whereas others would continue crawling very slowly, often in a characteristic hesitant, jerky fashion, and only a few individuals, mostly juveniles, would attempt to crawl away rather rapidly (Beane, et al., 2014, p. 173). It was also estimated that it takes the southern hognose snake 7.69 minutes to cross a typical two-lane road (Willson, et al., 2018, p. 451). We do not know the full impact that road mortality may play on this species, but the high number of observed DOR provides evidence that road mortality is occurring at a rate that is likely having population level effects and contributing to population declines in parts of the species' range.

3.3 Invasive Species

3.3.1 Red Imported Fire Ants

Introduction of non-native species are increasingly common, but the long-term consequences of these introductions are still poorly known (Langkilde, 2009, p. 208). The red imported fire ant (RIFA; *Solenopsis invicta*), originating from South America, was first introduced as early as 1918 to the United States at the port of Mobile, Alabama, and subsequently spread from there (Wilson, 1951, p. 68). The range of the red imported fire ant across the United States is shown in Figure 3-2 (United States Department of Agriculture, 2017, unpaginated).

Red imported fire ants can multiply rapidly and infiltrate disturbed and early-successional habitats (Todd, et al., 2008, p. 540). Reptiles are particularly susceptible to red imported fire ants. Many species of reptiles are oviparous (egg-laying) and their eggs can be depredated by red imported fire ants, both pre- and post-hatching. In addition, many reptile species inhabit disturbed areas, which red import fire ants prefer, and excavate nests, creating disturbance and providing scent that attracts red imported fire ants (Darracq, et al., 2017, p. 2). Species that nest under or on the ground and in or near open habitat may be more negatively affected by red imported fire ants (Todd, et al., 2008, p. 544). Red imported fire ants are aggressive and their stings can result in direct mortality, as well as reduced survival by preventing weight gain, altering behavior, changing foraging patterns, reductions in food availability, and altered habitat (Wilcox & Giuliano, 2014, pp. 3-4).

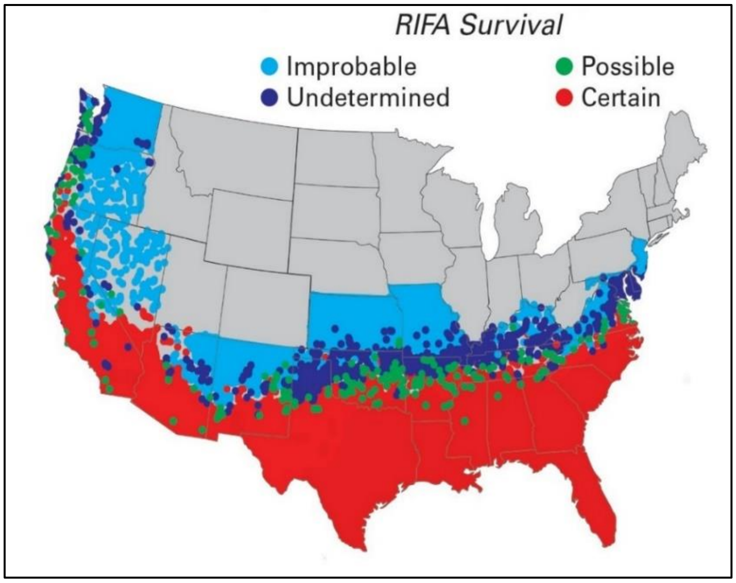

Figure 3-2. Current range and predicted range expansion of the red imported fire ant (RIFA; *Solenopsis invicta*) across the contiguous United States. Survival of RIFA is certain in the red area, possible in the green, undetermined in the dark blue, and improbable in the light blue area. Source: United States Department of Agriculture, 2017, unpaginated.

Red imported fire ants have been linked to population declines of several native species, including the Houston toad, (*Bufo houstonensis*; Brown, et al., 2012, entire), bobwhite quail (*Colinus virginianus*; Allen, et al., 2000, entire), Texas horned lizard (*Phrynosoma cornutum*; Price, 1990, p. 469.4), and have been proposed as contributing to the decline of the southern hognose snake (Tuberville, et al., 2000, pp. 33-34).

The apparent declines and extirpations of the southern hognose snake are concurrent with the range expansion of red imported fire ants in the Southeast. Portions of the snake's range within the Coastal Plains of Mississippi, Alabama, and the Florida Panhandle had become infested with red imported fire ants by 1958 and would be the first to experience the full impact of red imported fire ant predation (Callcott & Collins, 1996, p. 245; Mount, 1981, p. 75). The last detections for southern hognose snakes in Mississippi were 1981 and 1975 for Alabama. There is some speculation that a time lag occurs from when an area becomes heavily infested with red imported fire ants and the impacts become obvious (Mount, 1981, p. 77). It should be noted that red imported fire ants have difficulty establishing colonies in excessively sandy soils; in such habitat, the impact would be less severe than in those capable of supporting dense populations of red imported fire ants (Mount, 1981, p. 75). This may help explain why southern hognose snakes were extirpated from Mississippi and Alabama. Besides always being rare in that portion of their range, the soils are generally wetter west of the Mobile basin and are not as deep as the sandy soils in other portions of the range. Wetter soils are more readily colonized by red imported fire ants (LeBrun, et al., 2012, p. 888). Thus, in that portion of the range red imported fire ants were possibly one of the main factors leading to their extirpation. This also might help explain why southern hognose snakes continue to occupy areas like the Florida Ridge that have the deep sandy soils.

The southern hognose snake may be particularly susceptible to red imported fire ants because of its small size, slow speed, use of open, disturbed habitats, and the fact that it is a burrowing species. Southern hognose snakes also rely heavily on crypsis and immobility as an antipredatory defense, which in the case of red imported fire ants does not work to fend off the attack (Beane, et al., 2014, p. 174). There are examples of other reptiles exhibiting immobility when exposed to fire ants, as was the case in fence lizards (*Sceloporus undulatus*) where those lizards that had longer history with red imported fire ants were more likely to exhibit defensive behavior and quickly flee from them (Langkilde, 2009, p. 213). It is possible that the slow, cryptic behavior of the southern hognose snake has become maladaptive in the presence of red imported fire ants, creating an evolutionary trap that has contributed to its decline (Beane, et al., 2014, p. 174).

3.3.2 Feral Hogs

Feral hogs (*Sus scrofa*) negatively affect almost all aspects of ecosystem structure and function (Jolley, et al., 2010, p. 519) and are known to have significant impacts to native animal and plant communities through direct consumption and indirectly through rooting and soil disturbance (Barrios-Garcia & Ballari, 2012, pp. 2284-2293). Reptile species are particularly susceptible to impacts from feral hogs (Taylor & Hellgren, 1997, p. 38). In addition to causing direct mortality to reptiles and amphibians, feral hogs also have indirect effects on populations through rooting and habitat alteration (Jolley, et al., 2010, p. 520). Their rooting disturbs soil layers and natural decomposition cycles, which can lead to changes in nutrient cycling (Bratton, 1975, pp. 1358-1359).

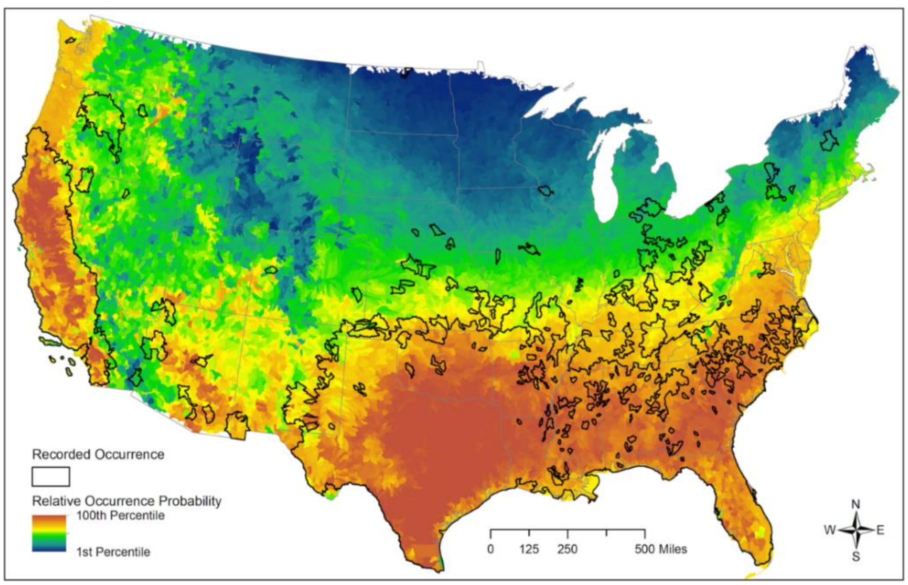

Figure 3-3. Current and predicted range expansion of feral hogs across the contiguous United States. Current range (recorded occurrence) of feral hogs from 1982 to 2012 is outlined in black. Predicted feral hog occurrence is displayed in color based on probability. Source: McClure, et al., 2015, p. 11.

A study at Fort Benning, Georgia found that an entire population of feral hogs (i.e., estimated to be 3,196 individuals) could consume 3.16 million reptiles and amphibians per year (Jolley, et al., 2010, p. 521). For southern hognose snakes, feral hogs could be a predator, particularly while foraging around wetland edges where snakes are searching for anuran prey (Enge, et al., 2016, p. 22). Feral hogs could also be impacting frogs and toads, a critical prey base of the southern hognose snake. For example, the eastern spadefoot toad remains underground for most of the year, but emerges on warm, rainy nights to breed during the spring and summer months in the southeastern United States (Hansen, 1958, p. 57). During these periods of breeding, eastern spadefoot toads are found at extremely high densities, and it is possible that feral hogs respond to this concentrated food source and focus their hunting on these spadefoot toads (Jolley, et al., 2010, p. 522). There are concerns that this selective foraging by feral hogs could threaten not only spadefoot toad populations but also other species that have a similar life history (Jolley, et al., 2010, p. 522) and impact other species further up the food chain, such as southern hognose snakes. The range and abundance of feral hogs in the contiguous United States is shown in Figure 3-3 (McClure, et al., 2015, pp. 11, 17); there is substantial overlap between feral hog occurrence and the range of the southern hognose snake.

3.4 Climate Change

In the southeastern United States, climate change is expected to result in more frequent drought, more extreme heat (resulting in increases in air and water temperatures), increased heavy precipitation events (e.g., flooding), more intense storms (e.g., frequency of major hurricanes increases), and rising sea level and accompanying storm surge (IPCC, 2013, entire). Warming in the Southeast is expected to be greatest in the summer, which is predicted to increase drought frequency, while annual mean precipitation is expected to increase slightly, leading to increased flooding events (IPCC, 2013, entire; Alder & Hostetler, 2013, unpaginated). Changes in climate may affect ecosystem processes and communities by altering the abiotic conditions experienced by biotic assemblages resulting in potential effects on community composition and individual species interactions (DeWan, et al., 2010, p. 7). These changes have the potential to impact southern hognose snakes and/or its habitat.

Despite the recognition of climate effects on ecosystem processes, there is uncertainty about what the exact climate future for the southeastern United States will be and how the ecosystems and species in this region will respond. It should be recognized that the greatest threat to many species from climate change may come from synergistic effects. That is, factors associated with a changing climate may act as risk multipliers by increasing the risk and severity of more imminent threats.

Terrestrial ectotherms, such as the southern hognose snake, may be at particularly high risk from climate change because they are less effective at buffering body temperature against ambient temperature using physiological mechanisms, and instead rely heavily on ambient thermal heterogeneity to regulate their temperature behaviorally, resulting in their growth, locomotion and reproduction being strongly dependent on their body temperature (Deutsch, et al., 2008, p. 6668; Kearney, et al., 2009, entire; Aubret & Shine, 2010, p. 246). For example, southern hognose snake reproduction is tied to seasons with suitable temperature and moisture regimes, and altered weather conditions during these seasons may result in frequently recurring "bust" years of reproductive failure, and ultimately population declines. Also, it has been shown that high temperatures that restrict foraging activity by reptiles can lead to energy shortfalls, and ultimately reduced population growth (Gibbons, et al., 2000, p. 660; Sinervo, et al., 2010, entire; Huey, et al., 2010, p. 833). Reptile species with specialized diets, such as the southern hognose snake, could be particularly vulnerable to changes in climate that affect their prey base. Populations of southern hognose snakes could decline in response to drought-induced population declines of frogs and toads, their primary prey.

The most substantial impacts from climate change on the southern hognose snake are likely habitat based. Current and continued projected warming will increase the risk of wildfire, insect, wind, and disease damage to southeastern forests, and limit the number of suitable days to implement prescribed fire. For example, predicted longer growing seasons will likely increase the risk of insect outbreak and very likely will expand the northern range of some species, such as the southern pine beetle (*Dendroctonus frontalis*) (McNulty, et al., 2013, p. 175).

The Southeast leads the nation in number of wildfires per year, and climate change will likely increase the frequency and intensity of wildfires (McNulty, et al., 2013, p. 173; Blate, et al., 2009, p. 58). The projected temperature increase across the Southeast will likely contribute to increased fire frequency and intensity, total burned area, change in fuel conditions, and longer fire seasons (McNulty, et al., 2013, p. 174).

Alternatively, constraints to managing southern hognose snake habitat with prescribed fire is likely the most substantial risk factor associated with climate change for this species. Predicted changes in temperature and precipitation due to climate change will limit the number of days with suitable conditions for controlled burns, and combined with issues associated with WUIs discussed earlier, will further constrain the ability to manage habitat with prescribed burning. As the ability to implement prescribed fire becomes further constrained, the ability to reduce woody vegetation and maintain an open under- and mid-story will be severely limited, and southern hognose snake habitat will likely degrade.

Additionally, there is risk to coastal populations of the southern hognose snake due to sea level rise (SLR) under climate change. Global mean sea level has risen about 7-8 inches (16-21 cm) since 1900, with about half of that rise occurring since 1993 (Hayhoe, et al., 2018, p. 85). In areas of the Southeast, tide gauge analysis reveals as much as 1 to 3 feet (0.30 to 0.91 meters) of local relative SLR in the past 100 years (Carter, et al., 2018, p. 757). The future estimated amount that sea level will rise depends on the response of the climate system to warming, as well as on the future scenarios of human-caused emissions (Hayhoe, et al., 2018, p. 85).

Coastal populations of southern hognose snakes are predicted to be directly impacted by inundation of upland habitat directly along the coast by rising sea levels, resulting in loss of habitat. Although the amount of habitat predicted to be lost within a given population due to SLR varies considerably depending on the location of the population, 50 southern hognose snake populations are considered to be vulnerable to SLR (i.e., population is anticipated to lose some amount of suitable habitat under all SLR scenarios). Loss of suitable habitat within a population will result in a decreased probability that a given population will persist.

3.5 Persecution, Harassment, and the Pet Trade

Humans have a long history of fearing snakes. Whether a snake is venomous or not, all snakes tend to be viewed as vile and loathsome creatures (Burghardt, et al., 2009, p. 262). Fear of snakes, called ophiophobia, has made snake conservation more difficult than other vertebrate groups (Burghardt, et al., 2009, p. 262). The negative perception of snakes ranges from low interest, to harassment, to persecution resulting in the deliberate killing of them. Unfortunately, many human-snake encounters result in the death of the snake (Whitaker & Shine, 2000, p. 121). Due to the hognose snake's defensive behavior of flattening their head like a cobra, opening their mouth, and hissing loudly, they tend to be viewed as a threat to humans and thus when encountered in the wild they may be killed by people who do not know they are harmless (Kelley, 2011, p. 19).

There has also been an increase in recreational herpetology by enthusiasts actively looking for the southern hognose snake because it is considered an uncommon species and they want to add this species to their life list. With the rise of social media there has been an increase of public knowledge of roads where it is easy to spot these animals. September and October, the most common months the species can be found, has become known as "Hogtober". These hobbyists may not be collecting individuals, rather just photographing and releasing, but this increased harassment may cause individuals increased stress that could be detrimental to them. Additionally, the increase in traffic on the roads from hobbyists leads to increased road mortality for the species (Martin, 2018, pers. comm.).

Hognose snakes have been in the North American pet trade dating back to the late 1980s and into the 1990s, but within the last several decades their numbers in the pet trade have expanded (Kelley, 2011, p. 18). Many view hognose snakes as desirable pets due to their upturned snout and coloration making them aesthetically attractive, as well as their tendency to seldom bite, unless a hand or finger is mistaken for food (Kelley, 2011, p. 18). Endearing nicknames such as "hoggies" and the fact that they are rear fanged, carry mild venom, and will play dead, add to their mystique as pets (Kelley, 2011, pp. 18-19). Western hognose snakes comprise most of the pet trade, with eastern and southern hognose snakes having a smaller commercial role (Kelley, 2011, p. 21). This may be because both the eastern and southern hognose snakes eat predominantly frogs and toads, and breeding in captivity can be more problematic for the southern hognose snake (Kelley, 2011, p. 19).

However, there is evidence that collection for the pet trade is a threat to this species. From 1990−1994, 135 wild-caught southern hognose snakes were reportedly sold in Florida, collected on primarily four areas of Florida roads where they were relatively abundant (Enge, 2005, pp. 208-209). Although there is some potential that some of these snakes were misidentified and were actually eastern hognose snakes, this shows that there is a demand for the southern hognose snake in the pet trade (Enge, et al., 2016, p. 22). Since the 1990s, the demand for this species continues to remain in the pet trade and hatchlings often sell for more than $200 at reptile shows (Enge, et al., 2016, p. 22; Kelley, 2011, p. 19). In Florida, two areas of Madison and Suwannee counties are well known to snake hunters for sometimes producing red-colored individuals that are worth up to $500 (Enge, et al., 2016, p. 22). Though the population impact of collecting southern hognose snakes from roads is unknown, social media has allowed rapid dissemination of locations of prime or new collecting areas, and commercial or recreational snake hunters may come from hundreds of miles away to look for this species (Enge, et al., 2016, pp. 22-23).

3.6 Disease

In wild populations of reptiles, debilitating diseases are most likely secondary expressions in individuals with impaired resistance caused by one or more primary environmental stressors, such as habitat degradation, invasive species, or pollution (Gibbons, et al., 2000, p. 658). These primary environmental stressors can lead to immune suppression, which can further lead to an increase in morbidity and mortality from infectious disease (Allender, et al., 2006, p. 107). Over the past several decades, the number of emerging fungal diseases and the number of species extinctions and extirpations caused by those diseases has increased (Lorch, et al., 2015, p. 1). For example, recent literature suggests that chytrid fungus (*Batrachochytrium dendrobatidis*) has played a role in the decline of at least 501 amphibian species over the past half century and potentially caused 90 extinctions (Scheele, et al., 2019, p. 1459)

Snake fungal disease (*Ophidiomyces ophiodiicola*) is a serious emerging fungal pathogen of endemic North American snakes and can persist in soil as well as colonize living hosts (Allender, et al., 2015, p. 187). First noted in 2006 as a severe skin infection associated with a precipitous decline in timber rattlesnakes (*Crotalus horridus*) in the northeastern United States, snake fungal disease has since been implicated in widespread morbidity and mortality across the eastern United States (Lorch, et al., 2016, p. 1; Allender, et al., 2015, p. 188). Infected wild snakes have several distinct lesions on various parts of the body, head, or tail, and often the animal will die from complications from the infection rather than from direct fungal damage (Lorch, et al., 2016, pp. 4-5).

Snake fungal disease has been most often observed in pit vipers; however, the disease has been detected on the skin of captive and free-ranging snake species representing 12 genera within two families, including colubrid snakes (Allender, et al., 2015, p. 188; Thompson, et al., 2018, p. 3). Snake fungal disease has been detected in at least 23 states and one Canadian province, though there is some speculation that it may be more widely distributed than the documented cases suggest because the efforts to monitor the health of many snake populations are limited (Thompson, et al., 2018, p. 1).

To date, there have been no documented cases of snake fungal disease in southern hognose snakes; however, the disease has been detected in every State within the species' current range. The impact of snake fungal disease on snake populations is currently unknown, but the effects of infectious diseases on wildlife populations are an increasing concern, especially for species persisting at small population sizes (Allender, et al., 2015, p. 194).

3.7 Conservation Measures

3.7.1 Conservation Lands

Suitable habitat for southern hognose snakes can be found within National Wildlife Refuges, National Forests, State Lands, and other conservation areas across the species' range (Table 3-1). Habitat improvements, including ecosystem restoration, enhancement, protection, prescribed burning, and mechanical upland habitat restoration conducted across the species' range have likely provided some benefits to the southern hognose snake. Most conservation lands owned by Federal and State agencies are expected to remain protected and managed for conservation purposes in the near future, which would eliminate the risk of direct loss of habitat to urbanization in these areas.

Many of these conservation lands in which southern hognose snakes occur, manage habitat for other longleaf-associated species, such as red-cockaded woodpeckers (*Picoides borealis*) and gopher tortoises. This habitat management likely has some benefits to the southern hognose snake when the managed habitat results in an open canopy system with more diverse groundcover.

Thirty-one percent of all occurrence records for the southern hognose snake occur on protected lands. The percentage increases to 77% of all occurrence records when including records that occur within a kilometer of protected lands also. This percentage may not reflect the proportion of individual snakes on protected lands because opportunities to detect the species on public lands are better. However, it may indicate that habitat suitable for the species is more prevalent on protected lands, or it could be a combination of the two. Still, based on the best available information, protected lands play an important role for this species.

Table 3-1. Protected lands within the current southern hognose snake range that continue to provide suitable habitat and have occurrence records. This is not a comprehensive list of all protected lands for the species.

STATE	Manager	Property
NORTH CAROLINA	Dept. of Defense	Fort Bragg
		Camp Lejeune
	State	Sandhills Game Land
SOUTH CAROLINA	U.S. Fish and Wildlife	Carolina Sandhills National Wildlife Refuge
	U.S. Forest Service	Francis Marion National Forest
	Dept. of Defense	Shaw Air Force Base/Poinsett Electronic Combat Range
		Fort Jackson/McCrady Training Center
	Dept. of Energy	Savannah River Site
	State	Sandhills State Forest
		Santee Coastal Reserve
		Tillman Sand Ridge Wildlife Management Area
		Webb Wildlife Center
GEORGIA	U.S. Fish and Wildlife	Eufaula National Wildlife Refuge
	Dept. of Defense	Fort Benning
		Fort Gordon
		Fort Stewart
	State	Big Hammock Wildlife Management Area
		Chattahoochee Fall Line Wildlife Management Area
		Sandhills Wildlife Management Area
		Yuchi Wildlife Management Area
FLORIDA	U.S. Fish and Wildlife	Lower Suwannee National Wildlife Refuge
	U.S. Forest Service	Apalachicola National Forest
	Dept. of Defense	Eglin Air Force Base
		Navy Air Station Pensacola
	State	Ashton Biological Preserve
		Choctawhatchee River Water Management Area
		Dade Battlefield State Historic Site
		Goethe State Forest
		Little River Conservation Area
		Marjorie Harris Carr Cross Florida Greenway State Recreation Area
		Palatlakaha Environmental and Agricultural Reserve Park
		Perry Oldenburg Wildlife and Environmental Area
		Rainbow Springs State Park
		River Rise Preserve State Park
		Roy L. Hyatt Environmental Center
		Subtropical Agricultural Research Station
		Suwannee Ridge Wildlife and Environmental Area
		Torreya State Park
		Troy Spring Conservation Area
		Twin Rivers State Forest
		Watermelon Pond Wildlife and Environmental Area
		Withlacoochee State Forest
		Withlacoochee State Trail
		Wood Ferry Conservation Area
		Yellow Jacket Conservation Area
		Yellow River Water Management Area
		Yulee Sugar Mill Ruins Historic State Park

Source: Enge, et al., 2016, pp. 64-65; Georgia Department of Natural Resources (GADNR), 2015, pp. D15-D16; South Carolina Department of Natural Resources, 2015, p. 8; Petersen, et al., 2017, pp. 3-20; North Carolina Wildlife Resources Commission, 2015, p. 128

3.7.2 Department of Defense

Throughout the Southeast, 10 military installations have records of southern hognose snakes, and an additional 26 installations could potentially have them (Petersen, et al., 2017, pp. 3-20). Active prescribed burning programs are implemented on most military installations to manage for longleaf pine ecosystems, which can benefit conservation of the southern hognose snake. As part of implementation of the Sikes Improvement Act (1997), the Secretaries of the military departments are required to prepare and implement integrated natural resource management plans (INRMP) for each military installation in the United States. No installations specifically include southern hognose snake habitat and population management prescriptions and goals within their Integrated Natural Resource Management Plans (INRMPs); however, most of the INRMPs do include specific management for other longleaf species such as the red-cockaded woodpecker and gopher tortoise, which would provide some benefit to southern hognose snakes. The Department of Defense's Readiness and Environmental Protection Integration (DoD REPI) program also offers opportunities to expand land conservation beyond installation boundaries to improve military training flexibility by defending against incompatible development and reducing regulatory restrictions that inhibit military activities. Working through landscape partnerships, the DoD REPI program has helped protect, restore, and maintain longleaf pine habitat across the Southeast.

3.7.3 Longleaf Ecosystem Conservation and Restoration

Department of Defense, U.S. Forest Service, USFWS, and multiple state agencies are all active partners in America's Longleaf Restoration Initiative. This is a collaborative effort of multiple public and private sector partners that actively supports range-wide efforts to restore and conserve longleaf pine ecosystems with a 15 year goal to increase longleaf from 3.4 to 8.0 million acres (America's Longleaf Restoration Initiative, 2018, unpaginated). These efforts are focused within 16 "significant landscapes" (Figure 3-4). Within these significant landscapes, Local Implementation Teams (LITs) are leading conservation efforts by coordinating partners, developing priorities, and

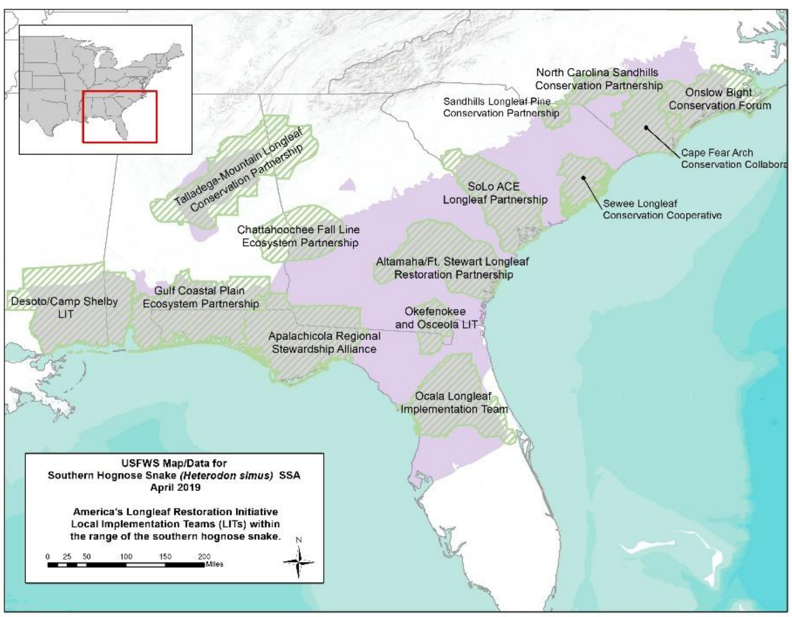

Figure 3-4. Locations of the Local Implementation Teams (LITs) within the range of the southern hognose snake.

fundraising to implement on-the-ground conservation. The majority of LITs are working within the range of the southern hognose snake, and each of these LITs has components of their conservation plans that support restoration of longleaf habitat and play an important role in southern hognose snake habitat restoration and management.

Throughout the range of the southern hognose snake, several Candidate Conservation Agreement with Assurances (CCAA) have been or are in different stages of being developed. Candidate Conservation Agreements with Assurances are voluntary commitments made by non-Federal partners to undertake actions that will remove or reduce threats to candidate or other at-risk species. The goal of any CCAA is to provide a net conservation benefit to the covered species and to preclude the need to list species under the ESA. As an incentive to the non-Federal property owner who engages in voluntary conservation actions for a particular species or group of species, landowners are given regulatory assurances if the species is listed under the ESA. Three such agreements we are currently aware of that could provide potential benefits to the southern hognose snake are described below.

Camp Blanding Joint Training Center, in Florida, signed a Candidate Conservation Agreement with Assurances (CCAA) with the USFWS and the Florida Fish and Wildlife Conservation Commission to manage enrolled lands in the agreement to benefit multiple species, including the southern hognose snake (USFWS, et al., 2017, entire). There are no records of southern hognose snakes at Camp Blanding; however, there is suitable habitat on the installation and surrounding area.

The Quail County Programmatic CCAA for North Florida and Southwest Georgia, not currently finalized, is an agreement between the USFWS, Florida Fish and Wildlife Conservation Commission, and Georgia Department of Natural Resources, in cooperation with Tall Timbers Research Station. This programmatic CCAA aims to enroll landowners to manage lands to the benefit of the covered species, including the southern hognose snake (USFWS, et al., 2018, entire).

In South Carolina, the USFWS and the South Carolina Department of Natural Resources are developing the South Carolina's Southern Pinelands Programmatic CCAA to benefit multiple priority pineland species, including the southern hognose snake. If implemented this programmatic CCAA would allow enrolled landowners to manage lands in a way that will benefit the southern hognose snake and provide them with regulatory assurances if the species is listed under the ESA (USFWS & South Carolina Department of Natural Resources, 2019, entire). This agreement is still in the planning stages.

3.7.4 State Protections

The southern hognose snake is listed as State threatened in North Carolina, South Carolina and Georgia, State endangered in Alabama and Mississippi, and not listed in Florida (Table 3-2). In

Florida, the species is ranked as a species of greatest conservation need (Florida Fish and Wildlife Conservation Commission, 2012, p. 60).

Table 3-2. Southern hognose snake listing status and rank by state (north to south) within the species' range.

State	State Listing	State Rank/Priority
North Carolina	Threatened	S2-Imperiled
South Carolina	Threatened	Highest Priority
Georgia	Threatened	S1/S2 - High Priority
Florida	Not Listed	Species of Greatest Conservation Need
Alabama	Endangered	Highest Conservation Concern
Mississippi	Endangered	SX- Believed to be Extirpated from the State

3.8 Summary of Factors Influencing Viability

We reviewed the potential factors that could be affecting the viability of the southern hognose snake (Figure 3-5). Concerns about the species' status revolved around the following factors: (1) habitat loss, conversion, and fragmentation resulting in the loss of longleaf pine savanna habitat across the range of the southern hognose snake; (2) road mortality based on the number and age classes of DOR individuals that could result in altered population structures; (3) invasive species, such as the red imported fire ant and feral hogs; (4) effects of climate change resulting in increased temperatures, decreased precipitation, increased severe weather such as drought, flooding, or storms, changes in wildfire frequency and intensity, decreased ability to conduct prescribed burns, and SLR; (5) the collection of individual snakes for the pet trade and persecution by humans; and (6) impacts that a potential disease outbreak, such as snake fungal disease may have on existing populations.

The primary concerns for the southern hognose snake's status are habitat based. Habitat loss is due to a number of factors including fire suppression, timber harvesting, SLR, conversion of land to agriculture, and urbanization. The current constraints on the ability to manage longleaf pine habitat through prescribed fire are further exacerbated by urbanization and climate change.

It is likely that several of these factors are acting synergistically to impact the southern hognose snake, and the combination of multiple stressors may be more harmful than a single factor alone. Although there is some inherent uncertainty surrounding the stressors we evaluated and their synergistic effects, this does not prevent us from making a credible assessment of the likely direction and magnitude of those impacts, even though it may not be possible to make such predictions of impacts with precision.

Projections of habitat loss due to urban development and climate change are carried forward in our assessment of southern hognose snake populations and the overall viability of the species. We were not able to assess impacts from invasive species, such as red imported fire ants and feral hogs, persecution, over-collection for the pet trade and increased harassment, and disease because datasets and or other information sources do not exist that capture the extent and degree of impact of these stressors to southern hognose snake populations across the species' range.

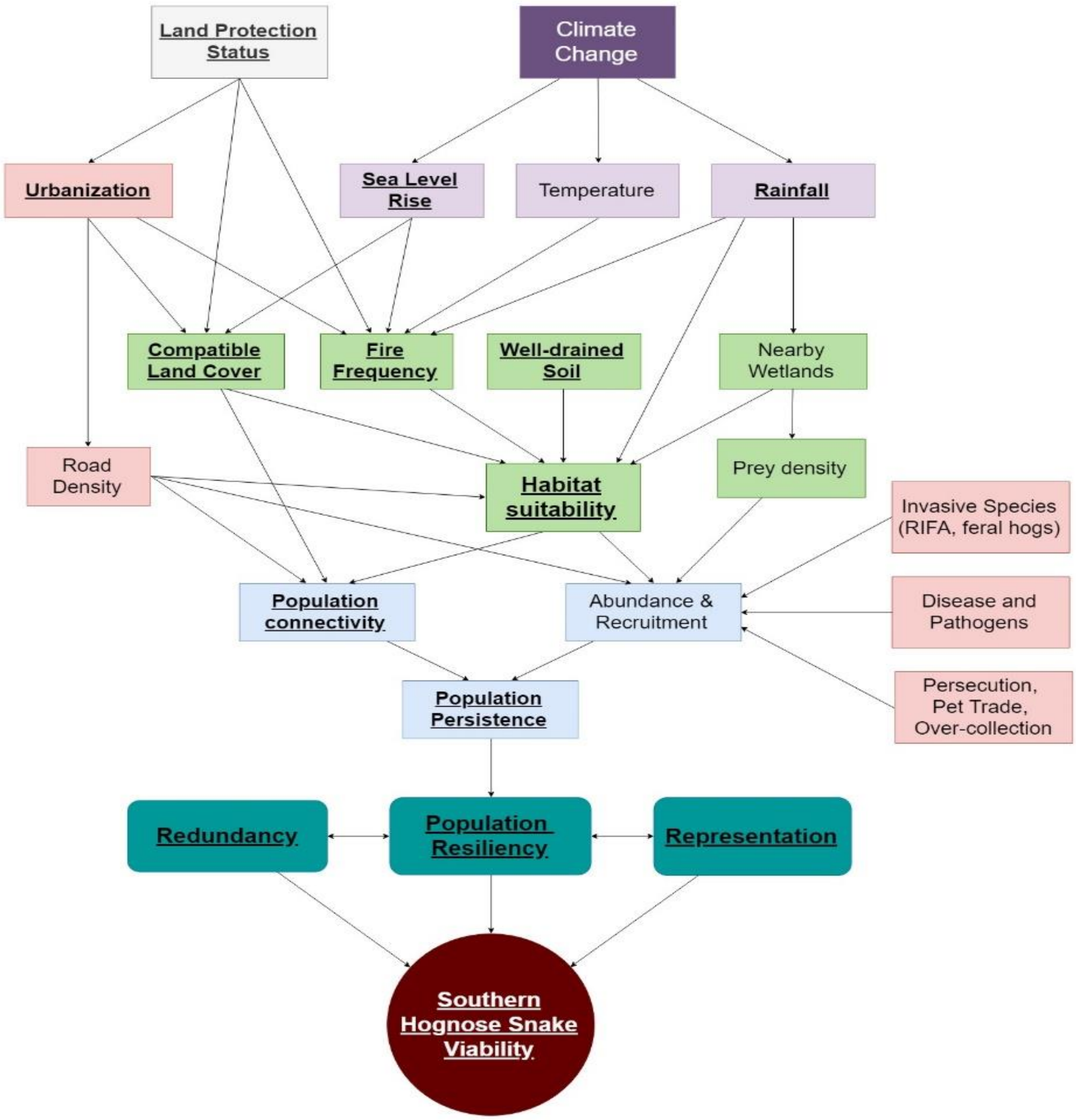

Figure 3-5. Influence diagram for the southern hognose snake, showing relationships between factors and species' viability. Color meanings: Grey – land ownership and protection status; Light red – stressors; Purple – climate-based factors; Green – habitat-based factors; Light blue – population metrics; Teal – components of viability (3Rs); Dark red – species viability. The factors that we were able to move forward in our analysis are bold/highlighted.

CHAPTER 4 – POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

In this chapter, we consider the southern hognose snake's historical distribution, its current distribution, and what the species needs for viability. We first define populations of the species. Next, we characterize the needs of the species in terms of population resiliency and species' representation and redundancy (the 3Rs). Finally, we estimate the current condition of the southern hognose snake using population and habitat metrics used to characterize the 3Rs.

4.1 Methods for Estimating Current Condition

For the purpose of this assessment, we defined ***viability*** as the ability of the southern hognose snake to sustain populations in the wild over time. Using the SSA framework, we describe viability of the southern hognose snake by first defining our populations, estimating current condition, and then in Chapter 5 predicting the future condition using the metrics of the 3Rs.

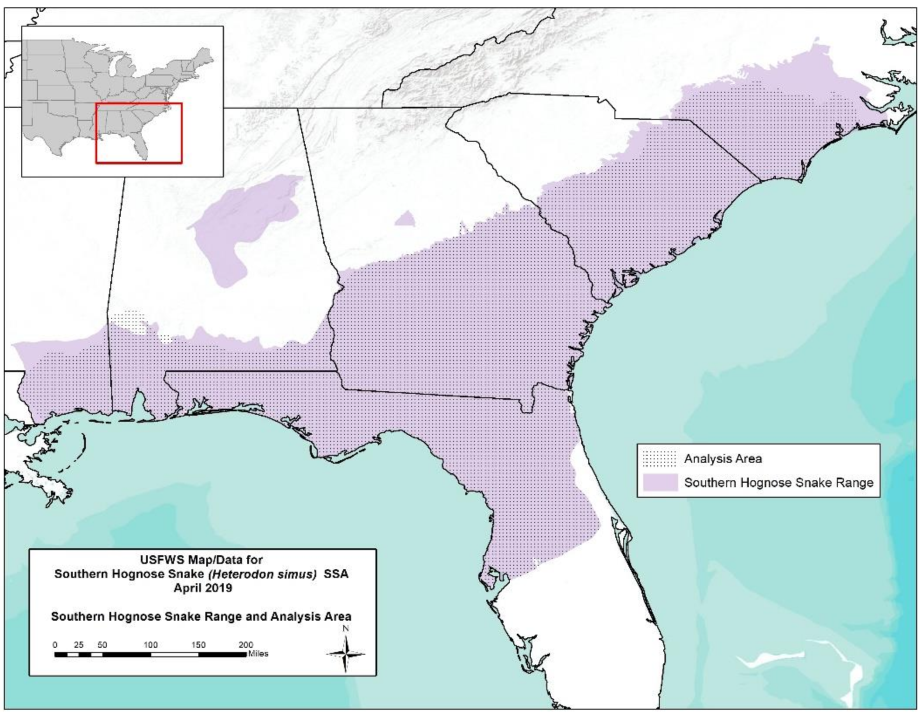

Figure 4-1. Comparison of the southern hognose snake range (purple) and analysis area used in the habitat and persistence modeling in the SSA (dotted area).

To characterize the 3Rs for the southern hognose snake, we estimated habitat suitability and population persistence across a portion of the species' range, which we refer to as the analysis area (Figure 4-1). We then used the patterns found in these analyses to perform a qualitative assessment of conditions for areas outside of the analysis area. The analysis area boundary was created during a habitat modeling study that began prior to developing the SSA (see below). This boundary encompasses all species records since 1980, and it does not extend to disjunct portions of the species' range in central Alabama and the Georgia Piedmont as well as contiguous areas in Alabama, Mississippi, and eastern North Carolina that contain only historical records and are included in the full species' range. Because habitat suitability metrics were also used to estimate population persistence, we used the same analysis area boundary for all quantitative analyses.

4.1.1 Habitat Analysis

Prior to developing this SSA, a habitat suitability model was developed for the southern hognose snake (detailed write-up found in Appendix A). We compiled a geospatial database of occurrence records in a Geographic Information System (GIS). The compiled dataset included records maintained by Natural Heritage Programs, USFWS, U.S. Forest Service, DoD, State agencies, academic researchers, and HerpMapper (HerpMapper, 2018, unpaginated), which include opportunistic sightings and observations during research and monitoring studies. Southern hognose snake records and available habitat/landscape data layers were used to identify habitat features that best predict species presence and the amount and distribution of potential suitable habitat across the species' range. Since the analysis focused on modeling current habitat suitability and not historical conditions, we used only species records since 1980 and habitat/landscape data layers showing conditions between 2000 and 2016. These decisions were made prior to the SSA with the support of species experts for capturing current habitat suitability. Model results showed habitat suitability, as measured by habitat suitability index (HSI) ranging from 0 (unsuitable) to 1 (most suitable), was strongly influenced by soil characteristics, land cover, and fire interval (Appendix A). These relationships agree with previous studies and expert opinion that the species generally favors fire-dependent, xeric habitat that is locally elevated (e.g., longleaf pine sandhills).

To aid map users in interpreting patterns of suitable habitat, HSI was converted to classes of Unsuitable (HSI = 0 – 0.24), Low (HSI = 0.25 – 0.39), Moderate (HSI = 0.4 – 0.59), and High Suitability (HSI = 0.6 – 1). Range-wide, there is an estimated 2.5 and 1.3 million ha of moderately and highly suitable habitat, respectively (Figure 4-2). Habitat was further summarized by its current protection status to inform partners of the degree of conservation assurances and potential opportunities. We classified habitat as "protected" if it occurred on publicly-owned land or on privately-owned land designated for conservation uses in protected area databases. We note that these methods classified habitat on DoD and other multi-use lands as protected. Although these lands are often actively managed for habitats and wildlife species, there is the potential that land use changes have/could result in the loss or degradation of suitable habitat. Predicted areas of higher habitat suitability tended to accurately highlight known species strongholds, such as National Forests, DoD lands, and other conservation lands; 28% and 36% of moderately and highly suitable habitat, respectively, currently exists in patches larger than 100 ha on public and protected lands.

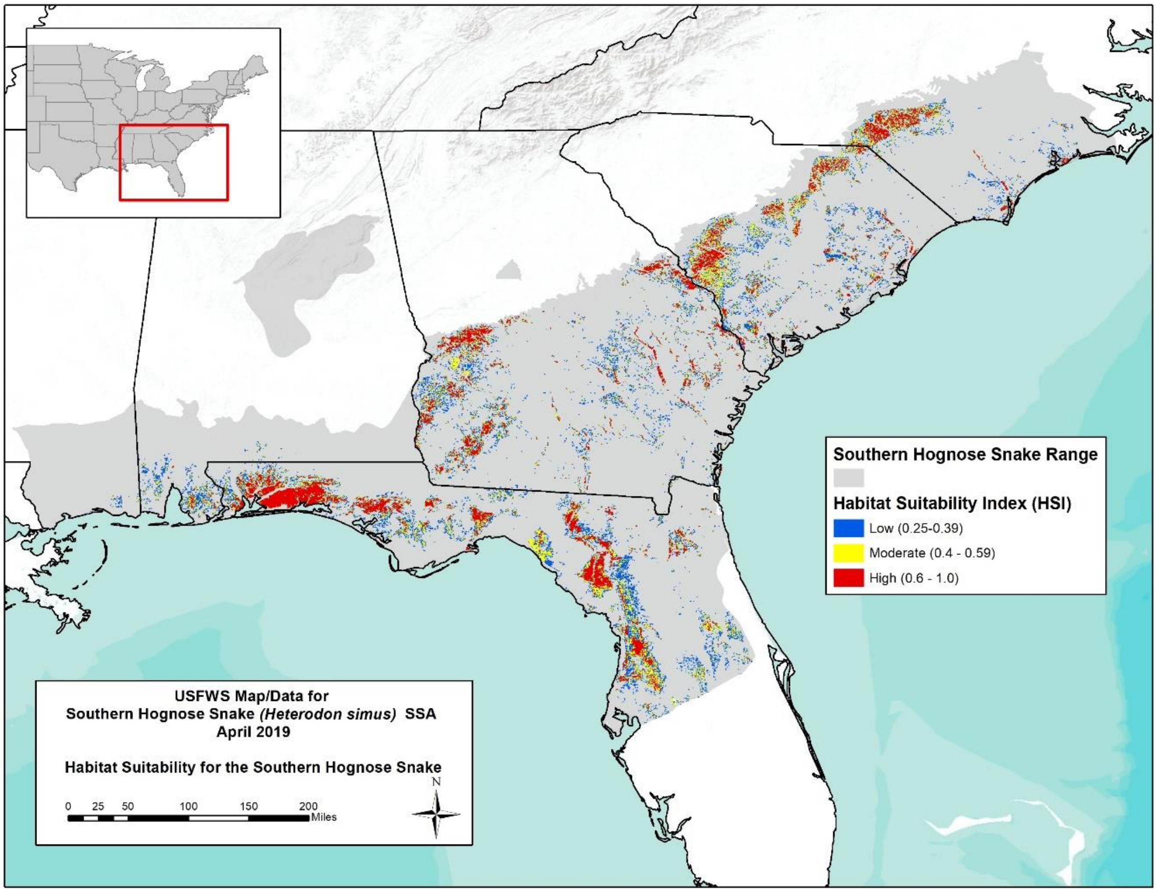

Figure 4-2. Spatial distribution of suitable habitat for the southern hognose snake across its range in the Southeast. The southern hognose snake range is shown in grey in the background.

4.1.2 Defining Populations

For this assessment, we defined populations for the species as contiguous areas surrounding known southern hognose snake occurrences with habitat conducive to survival, movement, and inter-breeding among individuals within the area. We compiled all species records gathered for the habitat analysis in GIS and included every record regardless of year of observation. To delineate populations, we used records with available latitude and longitude information. County records (n=27) that were lacking coordinates were placed at the county's centroid and included as populations, assuming that at some point in time southern hognose snakes occurred within that county somewhere on the landscape. Then we buffered the species occurrence records by 5 kilometers (km) (3.1 miles) and divided contiguous areas by large rivers and interstate roads that likely prevent movement and interbreeding among individuals on opposite sides of the barrier (Figure 4-3).

The choice of buffer distance was informed by expert input and protocols used by NatureServe (NatureServe, 2018, unpaginated). Ideally, we would have selected a buffer distance using a

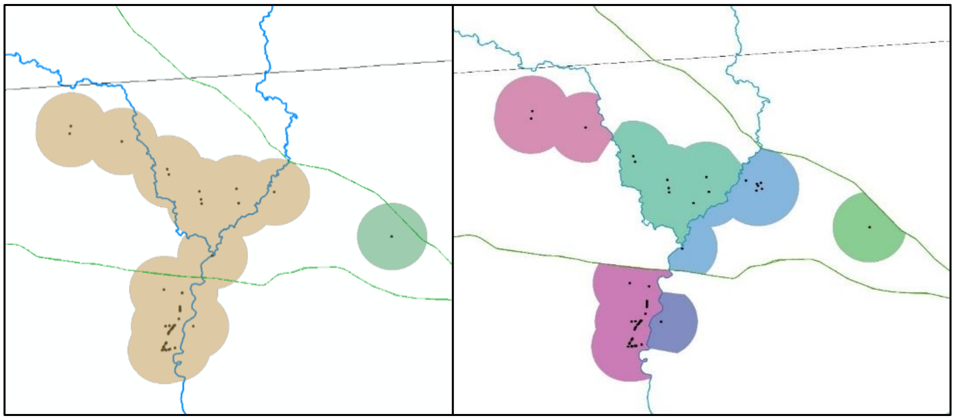

Figure 4-3. Example of delineating populations. Left panel: southern hognose snake location records buffer by 5 km then group together by population, with different colors depicting different populations. Right panel: populations were then divided by ecologically-relevant barriers, such as major rivers and major highways, to derive our final populations, with different colors again depicting different populations.

reported maximum annual movement or dispersal distance metric. For the southern hognose snake, these values have not been reported, nor could we find these values reported for a surrogate species. NatureServe suggests a separation distance for colubrid snakes of 10 km (6.2 miles) for suitable habitat and 1 km (0.62 miles) for unsuitable habitat. This recommendation was based on a limited number of studies of movement and range in colubrid snakes and was selected by NatureServe for the colubrid group because it seems generally unlikely that two locations separated by less than 10 km of suitable habitat would represent distinct occurrences (NatureServe, 2018, unpaginated).

Data reported for a limited sample of southern hognose snakes seems to indicate a 10 km buffer may be too large for purposes of delineating populations. Southern hognose snakes have relatively small home range sizes, between 8-30 hectare (19.7-74.1 acres), and these home ranges are smaller than those reported for eastern hognose snakes (Beane, 2018; Tuberville, 2018, pers. comm.). One female southern hognose snake was reported to have moved 1.44 km (0.9 mi) in one day (Beane, 2018, pers. comm.). Taking the NatureServe recommendation into account, using expert opinion, species size and cryptic nature, and other species biology, 5 km was determined to be an acceptable buffer distance. This distance represents the potential maximum extent an individual could occupy. By using a maximum extent, our intent is to capture the majority of the area potentially used by an individual; this is likely an overestimate of the area actually used by an individual.

Once the 5 km buffers were created, any buffers that overlapped each other were merged, which created contiguous areas (populations) where any points within 5 km of each other were part of the same population. We then divided populations by two ecologically relevant barriers: (1) large rivers of the 6^{th} order or higher, accessed from the National Hydrography Dataset (U.S. Geological Survey, 2016, unpaginated), and (2) interstates (primary roads) classified in the TIGER roads dataset (U.S. Census Bureau, 2017). Based on expert opinion, movement of individual snakes across these barriers is extremely unlikely, thus areas on either side of the barrier are considered separate populations in our analysis.

4.1.3 Population Resiliency

To characterize resiliency, we developed a model that estimates the likelihood that a site is currently (in 2018) occupied by southern hognose snakes for each defined population in the species' range. We define this metric estimated from the model as the "current persistence probability." In other words, current persistence represents the probability that there is at least one southern hognose snake that has survived through a time period and is still remaining within the population boundary. The complement (1 – current persistence) can be interpreted as the probability a population has become extirpated. Current persistence is not a direct measure of population size or growth rates, which are population-level metrics we could not estimate with available data. Estimating population sizes or growth rates usually relies on first estimating demographic rates, such as individual survival, with mark-recapture and other data. We were not able to use mark-recapture for this species, as existing datasets contain low numbers of recaptures that prevent any traditional analyses (Smith, 2018, pers. comm.). However, we can make reasonable inferences about resiliency based on persistence. We can assume large populations with sufficiently high survival and recruitment rates will have a higher probability of persisting over time. We can also assume that more resilient populations are those that have continued to persist on the landscape over time, tend to occupy higher quality habitat, are more likely on protected lands, and have some level of connectivity to other populations.

How does the persistence model work? The population persistence model took information about southern hognose snake detections, search effort, and site conditions to estimate the probability each population has persisted from one year to the next, as well as the probability the population currently persists in 2018. More specifically, the model used three types of information to estimate persistence for each population. First, it used a history of when southern hognose snakes were or were not seen in a population area. We would expect populations where southern hognose snakes have been detected often and recently to have a higher probability of currently persisting. Second, it used a history of search effort in the area, captured by records of southern hognose snakes and 13 other snake species that share similar habitats. Search effort helped the model estimate when southern hognose snakes may be persisting in an area but have gone undetected. Third, it used three attributes of a population's conditions that may influence persistence probability: (1) mean habitat suitability inside a population boundary, (2) the proportion of the population boundary on protected land, and (3) the number of nearby populations within 10 km.

We ran the model 50,000 times. In each run, the model estimated each population's probability of persisting one year to the next, based on data inputs, and used that probability to randomly draw an outcome for each population in the next year. We can think of this as a coin flip determining whether a population persisted or has become extirpated. Because of this randomness (stochasticity), estimates varied between model runs.

We calculated each population's current persistence probability as the proportion of model runs where the population was still persisting in 2018. Additionally, we summed the number of populations still persisting in 2018 within each representative unit and range-wide in each model run, and we used these to calculate the mean number of populations persisting at these scales.

We structured our persistence model similar to the Cormack-Jolly-Seber model (Lebreton, et al., 1992, entire; Brooks, et al., 2000, entire), which was designed to estimate survival of individual animals based on mark-recapture data, to analogously estimate persistence ("survival") of populations based on observation histories. We used the delineated populations created from the comprehensive dataset of southern hognose snake occurrence records to create a time series of when snakes were or were not observed within each population boundary.

Models using a similar approach rely on absence information (i.e., when searches for the target species occurred, but the species was not observed) to estimate survival, occupancy, and persistence (MacKenzie, et al., 2002, entire; Kéry, et al., 2009, entire). However, robust search effort and absence data do not exist for the southern hognose snake. Therefore, we developed a search effort dataset from occurrence records of other snake species (non-target species) commonly observed in southern hognose snake habitats obtained from HerpMapper and other State and Federal partners. We used the search effort dataset to account for imperfect detection of the southern hognose snake and improve the precision of persistence estimates. We assumed that records of other, non-target snake species that fall within a given population boundary indicate that the area was searched by a person in a given year and provide information about the chance a population is persisting. For example, consider two populations (A and B), in which southern hognose snakes have not been observed in either population since 1990. Population A has been frequently searched since then, and other species of common snakes continue to be reported in the area. Population B, however, has only been searched once since then. Assuming everything else is equal, there is more evidence that the southern hognose snake has become extirpated in Population A, while Population B is more uncertain. In using non-target species data, we made the following assumptions: (1) non-target records indicate an event when an area known to have been occupied by southern hognose snakes at some time was searched, and the search was performed in a way that southern hognose snakes could be observed (e.g., road surveys), and (2) that southern hognose snake records would have been reported if found when a person submitted non-target records to Herpmapper. For more information on which non-target species we used and how we queried the data, see Appendix B.

Next, we summarized population-specific metrics for several spatial variables that likely influence persistence and incorporated them into the model. For each population, we calculated three metrics to be used as predictors of persistence: (1) the average HSI estimated in the habitat analysis (Appendix A), within each population boundary, (2) the proportion of the population that is currently on protected land, and (3) the number of populations within a 10 km radius of the population (Table 4-1). For protected lands, we used areas that are currently publicly owned and managed, as well as private lands that are registered in State or Federal programs where natural resource conservation is the goal.

Table 4-1. List of predictors used to model southern hognose snake population persistence, the hypothesized relationships to population resilience, and the average and range of predictors across 204 populations within the analysis area.

Site condition predictor	Biological justification	Mean (range)
Habitat Suitability Index (HSI)	Higher habitat suitability represents areas of higher quality (well-drained, sandy soils, compatible forest/grassland landcover, frequent fires) that should increase southern hognose snake survival, recruitment, and persistence. The average HSI within a population boundary is highly correlated to the amount of suitable habitat.	22% (0 – 83.2%)
Proportion on protected land	Higher proportions of a population that occur on protected land should increase habitat quality through regular management practices and may limit direct threats such as road mortality and collection.	21.1% (0 – 100%)
No. of populations within 10 km	Populations close to other populations may have a higher chance of long-term persistence. Nearby populations may provide opportunities for "rescue" where recolonization can occur after a catastrophe and provide for some genetic exchange; alternatively, nearby populations could provide a signal that there are localized conditions (e.g., geological, climatic) that promote population persistence that have not been otherwise captured in our analyses.	1.8 (0 – 7)

Once we had time series of southern hognose snake observations, search effort indices, and spatial predictor metrics for each population, we fit the persistence model using a state-space formulation in a Bayesian framework (Kéry & Schaub, 2012, pp. 171-239). State-space models explicitly model how the state of a system (what is truly happening in a system) changes over time (e.g., population persistence and extirpation) as well as the process of observing an individual (what we actually see), given the population has not become extirpated (Figure 4-4). Thus, they are helpful in separating real biological signals from error in observation data.

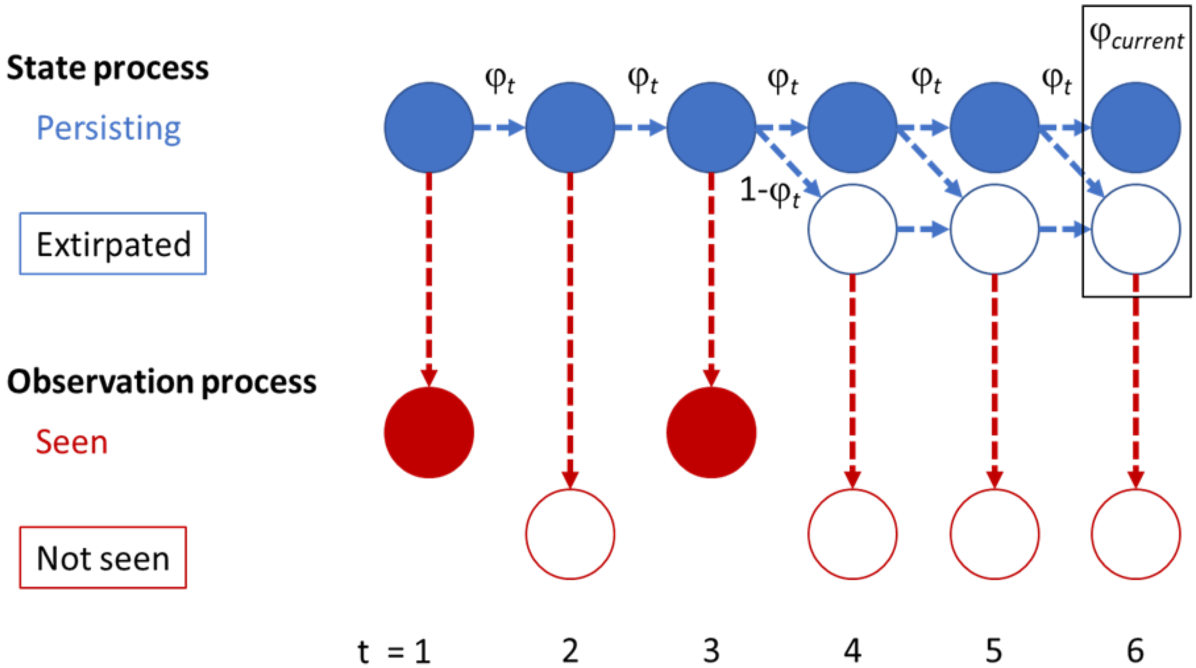

Figure 4-4. Example of the state process (true state of the system) and observation process (what we observe) of a population over time for the persistence model. The population persists or becomes extirpated each year based on the annual persistence probability (φ_t), which is estimated in the model. This probability is used to derive the current persistence probability ($\varphi_{current}$) – i.e., the probability a site has survived over the entire time period modeled and is currently occupied in 2018. Its complement ($1 - \varphi_{current}$) is interpreted as the probability a population has become extirpated. In this figure, imperfect detection is represented in time period 2 when individuals were not observed but the population was still known to be persisting (because individuals were seen in time 3). Since time 3 was the last year individuals were observed, the model estimates the probability the population persists or becomes extirpated each year after that. If the population became extirpated in time period 4, then the sequence of the true state process would be z = [1, 1, 1, 0, 0, 0]. The observed capture history (when individuals were seen in this population) would be y = [1, 0, 1, 0, 0, 0]. Source: Kéry & Schaub, 2012, p. 176.

We modeled the probability of populations persisting or becoming extirpated each year over the period from 1950 to 2018. We used 1950 as a historical starting year in the model for the following reasons: (1) using the full time period of records (1880 – 2018) would have been computationally difficult and (2) only 55 southern hognose snakes records (2.5% of total records in dataset) were from between 1880 and 1950. We modeled state histories ($z_{i,t:}$) of populations each year through this time period, where a population could either persist ($z_{i,t} = 1$) or become extirpated ($z_{i,t} = 0$), given that it still persisted the year before ($z_{i,t-1} = 1$). The state of a population was a function of an annual population-specific persistence probability (φ_t). We assigned each population a state of z = 1 in the first year of the model timeframe (1950). By doing so, we assumed that any area where southern hognose snakes have been observed had a population persisting at that location in 1950 and that populations not discovered until after 1950 were actually there before, but not detected, rather than the area being recently colonized by dispersing individuals. We provided the model with information about the known state of populations, which improved parameter estimation. For example, a population where southern hognose snakes were detected in 2000 but not after indicates that it persisted at least between 1950 and 2000, and we would supply known states (z = 1) for the population between these years. The model would estimate the annual persistence probability that led to that state history and would predict z states each year after 2000 (see Figure 4-4 for a graphical example). In order to characterize current condition, we derived the probability that each population still persisted in 2018 ($\varphi_{current}$) by calculating the proportion of model iterations where a $z_{i,2018} = 1$. We interpret this value as the probability a population has persisted through the entire time period modeled and still exists currently, and again, we refer to this as current persistence. Note that this value differs from annual population-specific persistence (φ_t) estimated in the model that reflects the probability a population will persist from one year into the next year (which we refer to as annual persistence). For more information on our methods, see Appendix B.

We measured southern hognose snake population resiliency by using current persistence probabilities (between 0 and 100%) and we summarized results by grouping populations into categories representing ranges of persistence probabilities. The categories we chose were unlikely or extirpated (< 50%), more likely than not on landscape (50 – 79%), very likely on landscape (80 – 94%), and extremely likely on landscape or extant (95 – 100%). For a population to be highly resilient, it must have a relatively high current persistence probability.

4.1.4 Species Representation and Redundancy

Representation reflects the ability of a species to adapt to changing environmental conditions and can be measured by the breadth of genetic or environmental diversity within and among populations. For the southern hognose snake, we do not have information related to genetic diversity. In the absence of species-specific genetic and ecological diversity information, representation can be assessed based on the extent and variability of habitat characteristics across the geographical range. Ecoregions are a system of classification based on physiography, where areas with similar characteristics of land formation, dominant soil and vegetation types, climate, air and sea currents, and distribution of flora and fauna are grouped into a single ecoregion (Bailey, 1983, entire; Bailey, et al., 1994, entire). Ecoregions have been used to reflect broad areas within which local adaptations and genetic coadaptation have likely occurred. Therefore, we used ecoregions to act as an appropriate proxy for factors likely to influence the adaptive capacity of southern hognose snakes across the landscape. We broke the southern hognose snake range into nine representative units based on grouping EPA IV ecoregions by similar ecological characteristics (e.g., soil, geology) and dividing them by the Savannah, Chattahoochee, and Mobile-Tombigbee Rivers where appropriate (Figure 4-5).

In addition to maintaining its breadth of genetic and environmental diversity, the southern hognose snake needs to exhibit some degree of redundancy to maintain viability. Species-level redundancy reflects the ability of a species to withstand catastrophic events and remain extant, and is best achieved by having multiple, widely distributed populations relative to the spatial occurrence of catastrophic events. Species that are well-distributed across their historical range are considered less susceptible to extinction and more likely to be viable than species confined to a small portion of their range (Carroll, et al., 2010, entire; Redford, et al., 2011, entire). In addition to guarding against a single or series of catastrophic events, redundancy is important to protect against losing irreplaceable sources of adaptive diversity.

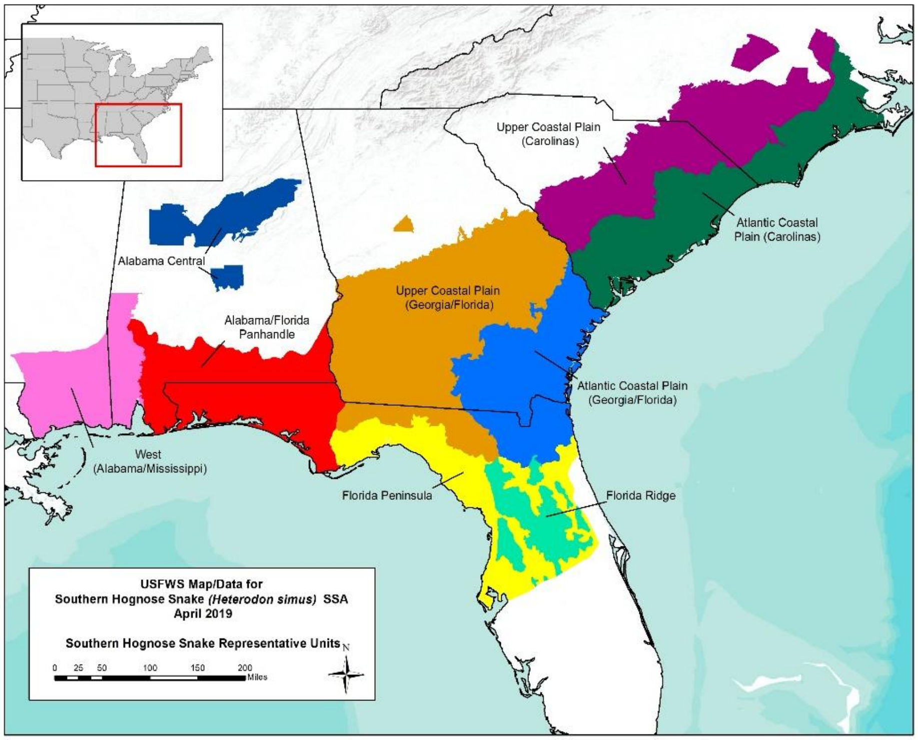

Figure 4-5. Representative units for the southern hognose snake. Nine units were selected based on ecoregion groups.

When investigating redundancy for southern hognose snakes, we consider a catastrophe to be any destructive event or episode that involves population-level impacts with the potential to negatively influence population resiliency outside of normal environmental and demographic stochasticity. Catastrophes that have the potential to occur in the southern hognose snakes' range include large-scale drought, wildfires, and hurricanes. Although we do not have data on the direct effects that these catastrophic events have on populations of southern hognose snakes, these catastrophes have the potential to negatively impact populations outside of the normal environmental and demographic stochasticity they experience. Additionally, drought, wildfires, and hurricanes occurring across the range of the species are predicted to increase under climate change.

To characterize representation and redundancy, we captured predictions of the number of resilient populations within a representative unit and range-wide in two ways. First, we summed the number of populations within a unit and range-wide with current persistence probabilities at or above each category (threshold), as described for characterizing population resiliency (Section 4.1.3). Second, we recorded the number of populations predicted to persist in 2018 within each unit and range-wide, using direct outputs from the model. Each model iteration recorded the number of populations persisting in 2018 in each representative unit and range-wide, and we used all model iterations to calculate the mean (the most likely prediction) and 95% confidence intervals for the predicted number of persisting populations in 2018.

One can think of the difference between a specific population's probability of persistence and the mean number of populations persisting within a representative unit by considering a set of four fair coins. Each has a 50% probability of getting a heads – this is a population's persistence probability. If we flip all four coins many times, the most likely outcome, on average, is getting two heads and two tails – this is the mean number of persisting populations predicted in a model iteration. The specific coins that yield a heads may change each trial, but we still expect two out of four heads most commonly. Therefore, when assessing representation and redundancy at the scale of a representative unit and range-wide, it may be helpful to consider the two types of results alongside each other. One can interpret the mean number of persisting populations as the most likely outcome then further assess the current resiliency of populations within a representative unit and range-wide, using the number of populations above a certain persistence threshold (e.g., 80%). We also note that the laws of probability make it so this mean number of persisting populations approximately equals the number of populations with a 50% or greater persistence probability. For more information on our methods, see Appendix B.

We measured representation using the number and distribution of resilient populations (i.e., those above a certain persistence probability threshold) across representative units in the species' range, as well as assessing the spatial distribution (latitudinal and longitudinal variability) of resilient populations. To have high representation, the species must have highly resilient populations located in each of the representative units, and resilient populations should span the latitudinal and longitudinal extent of historical populations.

We measured redundancy using the current number and distribution of resilient populations within representative units and across the range of the species. To have high redundancy, the southern hognose snake would need to have multiple resilient populations within a representative unit and throughout its range.

4.2 Current Condition Results

4.2.1 Populations

For our population analysis, we obtained 2,227 southern hognose snake records, from years 1880-2018. Many of the early occurrence records were for the county only without available coordinates. The occurrence records were spread throughout the species' range, but a majority of the records came from the Upper Coastal Plain (Carolinas) representative unit (Table 4-2). From these records, we identified a total of 222 populations of southern hognose snakes (Figure 4-6).

Table 4-2. Summary of number of occurrence records for the southern hognose snake, with number of populations for representative units and range-wide.		
Representative unit	**No. of records**	**No. of populations**
Upper Coastal Plain (Carolinas)	1438	30
Upper Coastal Plain (GA/FL)	285	58
Atl. Coastal Plain (Carolinas)	117	34
Atl. Coastal Plain (GA/FL)	32	14
FL Peninsula	76	33
FL Ridge	194	16
AL/FL Panhandle	54	26
West (AL/MS)	18	7
AL Central	13	4
Range-wide	2227	222

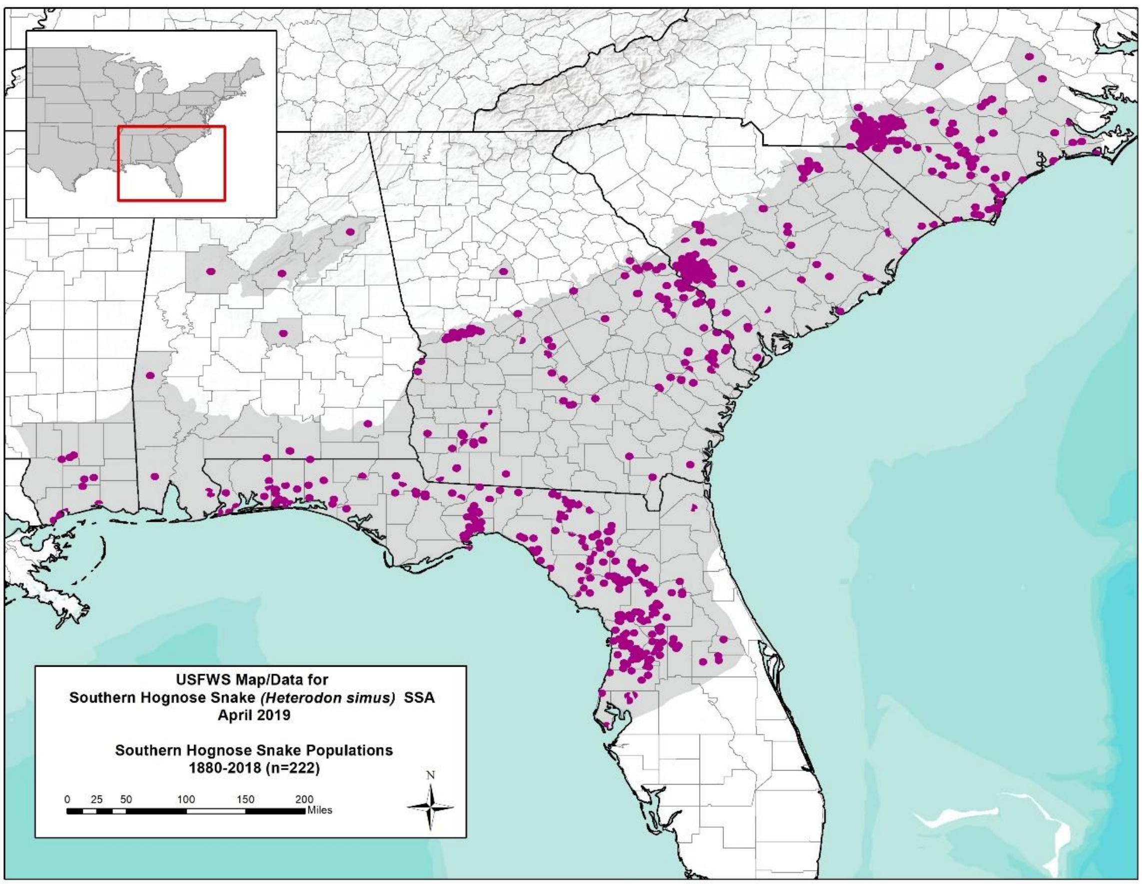

Figure 4-6. Distribution of 222 southern hognose snake populations across the species' range (shaded background).

4.2.2 Current Population Resiliency

To assess the current condition of the southern hognose snake, we modeled persistence using 2,196 occurrence records grouped into 204 populations that occurred within the analysis area. The remaining 31 occurrence records that fell outside of the analysis area were grouped into 18 populations. All of these records were found prior to 1975 and likely represent extirpated populations, and thus are included in our resiliency analysis as extirpated. Out of the 69 years we modeled (1950-2018), the mean number of years southern hognose snakes were found in a population was 2.67 (range = 1 to 45). From the search effort dataset, the number of observer-days per year per population ranged from 0 to 82 (mean = 0.167), and records of non-target species came from 124 of 204 (60.8%) populations. The persistence model showed adequate convergence and fit to the data. The baseline detection rate, the probability of detecting at least one southern hognose snake in a population in a given year, was low but the model showed that detection rates have increased gradually over time (see Appendix B).

We present the number of populations (out of 222) in each persistence category, as well as the cumulative number of populations at or above each persistence category, in Table 4-3; Figure 4-7. Range-wide, we have likely lost 60% (133/222) of southern hognose snake populations (i.e., populations with a less than 50% probability of current persistence). Conversely, 30.6% of populations had a greater than 80% probability of current persistence and 22.1% had a greater than 95% probability of current persistence. Note that we categorized populations into persistence threshold using mean estimates of persistence, and there is uncertainty around these estimates. We report mean persistence estimates and 95% confidence intervals for each population in Appendix B.

Table 4-3. Number and percentage of southern hognose snake populations in each persistence category and cumulative number of populations at or above each threshold.

Population persistence	Number of populations in each category	% of total	Cumulative number of populations at or above each threshold	% of Total
Extremely Likely on Landscape (Extant) 95-100%	49	22.1%	49	22.1%
Very Likely on Landscape 80-94.9%	19	8.6%	68	30.6%
More Likely than Not 50-79.9%	21	9.5%	89	40.1%
Unlikely < 50% (Extirpated)	133	59.9%	-	-
Total	222	100%		

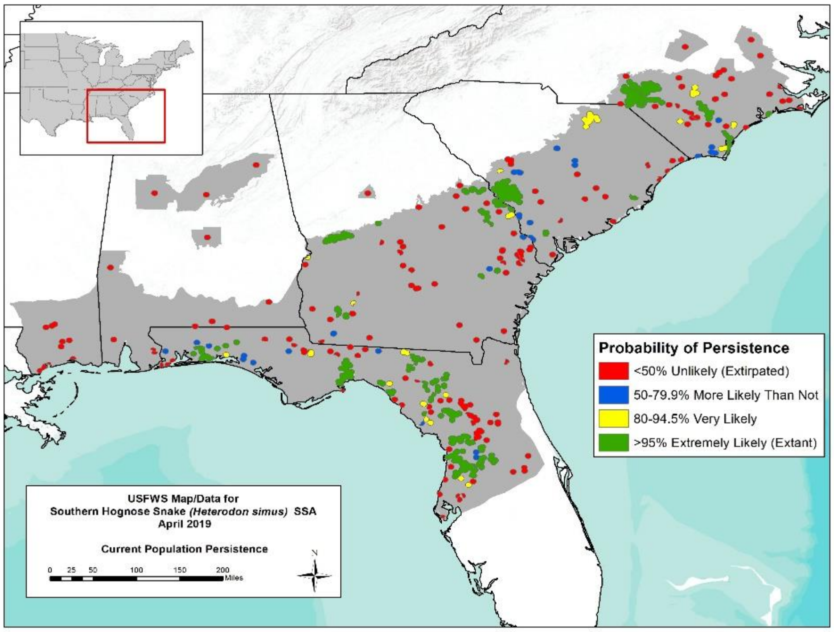

Figure 4-7. Populations of southern hognose snakes by category of current persistence probability.

Current persistence was equal to 1 for populations where southern hognose snakes were observed in 2018 and generally decreased with years since the last observation (Figure 4-8). Not surprisingly, population resiliency, as measured by current persistence probability, increased with habitat suitability, proportion of protected land, and number of populations within 10 km. A few populations have not been observed since 1972 but had higher than average current persistence probabilities (Figure 4-8). These populations had suitable habitat, but no known search effort in years following the last observation, according to our records. Because of these conditions, the model predicted these populations had a higher chance of persistence compared to other populations not observed since the early 1970s. While conducting additional searches at any site would improve the accuracy of model estimates, additional surveys of populations that have had many years pass since an animal was observed and have not been searched since may change estimates of current persistence.

The relationship between persistence and site predictors agreed with expert judgment that the species generally uses and survives best in fire-dependent, xeric habitat (e.g., longleaf pine sandhills). It is also reasonable to assume that populations on protected lands likely have a reduced risk of habitat loss, especially if protected lands have been established and managed for conservation over longer periods, which would cause higher population persistence probabilities. The strong relationship between number of populations within 10 km and persistence could support the idea that nearby populations may provide opportunities for “rescue” where recolonization can occur after a catastrophe, that there may be some level of genetic exchange taking place, or that there are localized conditions (e.g., geological, climatic) that promote long-term population persistence that have not been otherwise captured in our analyses. However, we caution that this relationship is somewhat phenomenological without further research into dispersal capabilities of the species to inform the degree that populations within 10 km of each other could interact.

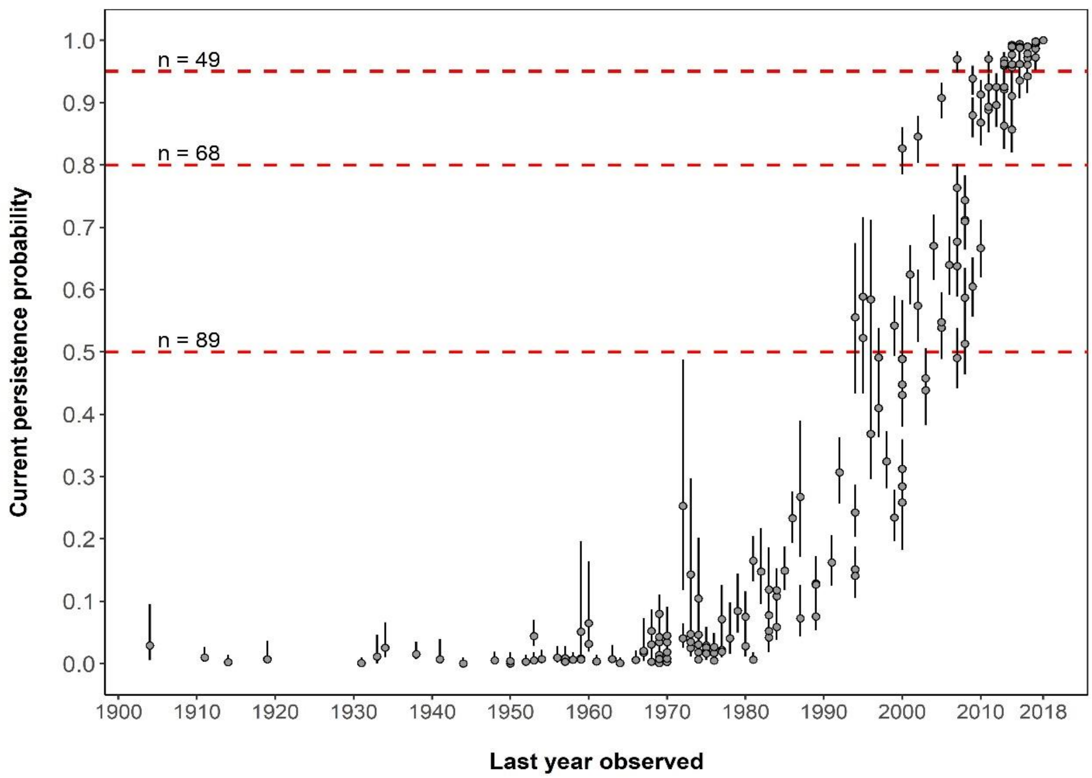

Figure 4-8. Probability of persistence in the current year (2018) for southern hognose snake populations (n = 204) related to the last year an individual was observed in a population. Horizontal red dashed lines indicate persistence thresholds of 50, 80, and 95%, and n values indicate the number of populations above each threshold. Each point represents a population with the exception that the point with 100% persistence probability in 2018 represents 18 populations where snakes were observed that year.

4.2.3 Current Species Representation and Redundancy

We summarized trends in southern hognose snake representation and redundancy by summarizing the number and spatial distribution of populations by reporting both persistence probability thresholds, in each of the nine representative units across its range, as well as the mean number of populations predicted to persist with 95% confidence intervals (Table 4-4; Figure 4-9). Additionally, we describe changes in representation and redundancy that have occurred over time by reporting the percentage of populations currently persisting (at or above a threshold) relative to the total number of populations ever documented in each unit (Table 4-4).

All southern hognose snake populations have likely become extirpated from two representative units: the West (AL/MS) and Alabama Central units (Table 4-4). The Atlantic Coastal Plain (GA/FL) unit was predicted to have only 2 populations above a 50% probability of current persistence and only 1 population above an 80% probability. Therefore, this unit is also at a higher risk of unit-wide extirpation and indicates the potential for further loss of representation. The southern hognose snake has likely experienced a decrease in latitudinal and longitudinal variability (i.e., a range contraction), relative to its historic range extent. Specifically, all populations in the western portion of its range – the West (AL/MS) and Alabama Central representative units – and in the northeastern edge of the range are more likely than not to be extirpated. Because the Alabama Central unit represents a distinct ecoregion (Ridge and Valley) and associated habitats not existing in any other unit, extirpation of the southern hognose snake from this unit has decreased the species' representation in terms of ecological variability.

There has been a reduction in redundancy for the southern hognose snake within each representative unit, highlighted by the loss of the western units and that only two representative units (Florida Ridge and Alabama/Florida Panhandle) had at least 50% of their total populations currently existing at a level of 50% probability of persistence. In other words, each of the 9 representative units has likely lost at least 50% of its populations. Furthermore, all representative units have seen a reduction in the number of highly resilient populations, and many of those remaining populations exhibit a degree of spatial clustering within the unit (they tend to be clumped near each other), which has left portions of the unit no longer occupied. Range-wide redundancy for the southern hognose snake has been reduced from historic levels. Out of 222 populations, only 89 are more likely than not to be currently persisting (>50% probability) and even fewer populations are at or above the 80 and 95% persistence thresholds. Within the occupied portion of the range, populations with higher persistence probabilities are spread throughout the range but exhibit a degree of clustering, which has left large areas lacking resilient populations (e.g., southern Alabama, middle Georgia, eastern Florida Peninsula, and coastal South Carolina). Below, we report results for each of the representative units relevant to representation and redundancy.

Table 4-4. Southern hognose snake summary statistics of number of occurrence records, number of populations (pops), mean persistence probability, and cumulative number of populations at each current persistence probability thresholds within representative units.

				No. of pops at or above persistence threshold (as percentage of no. pops/unit)			
Representative unit	**No. of records**	**No. of pops total**	**Mean (±95% CIs) no. of pops predicted to persist**	**Unlikely < 50% (Extirpated)**	**More Likely than Not ≥ 50%**	**Very Likely on Landscape ≥ 80%**	**Extremely Likely on Landscape (Extant) ≥ 95%**
Upper Coastal Plain (Carolinas)	1438	30	11 (8, 13)	19 (63.3%)	11 (36.7%)	7 (13.3%)	3 (10%)
Upper Coastal Plain (GA/FL)	285	58	28 (26, 33)	30 (51.7%)	28 (48.3%)	25 (39.7%)	20 (34.5%)
Atl. Coastal Plain (Carolinas)	117	34	14 (11, 16)	21 (61.8%)	13 (38.2%)	8 (23.5%)	6 (17.6%)
Atl. Coastal Plain (GA/FL)	32	14	2 (2, 5)	12 (85.7%)	2 (14.3%)	1 (7.1%)	1 (7.1%)
FL Peninsula	76	33	14 (12, 17)	19 (57.6%)	14 (42.4%)	12 (27.3%)	6 (23%)
FL Ridge	194	16	8 (7, 9)	8 (50%)	8 (50%)	8 (50%)	7 (43.8%)
AL/FL Panhandle	54	26	13 (8, 14)	13 (50%)	13 (50%)	7 (27%)	6 (23%)
West (AL/MS)	18	7	0 (0, 0)	7 (100%)	0 (0%)	0 (0%)	0 (0%)
AL Central	13	4	0 (0, 0)	4 (100%)	0 (0%)	0 (0%)	0 (0%)
Range-wide	2227	222	89 (74, 107)	133 (60.0%)	89 (40.1%)	68 (30.6%)	49 (22.1%)

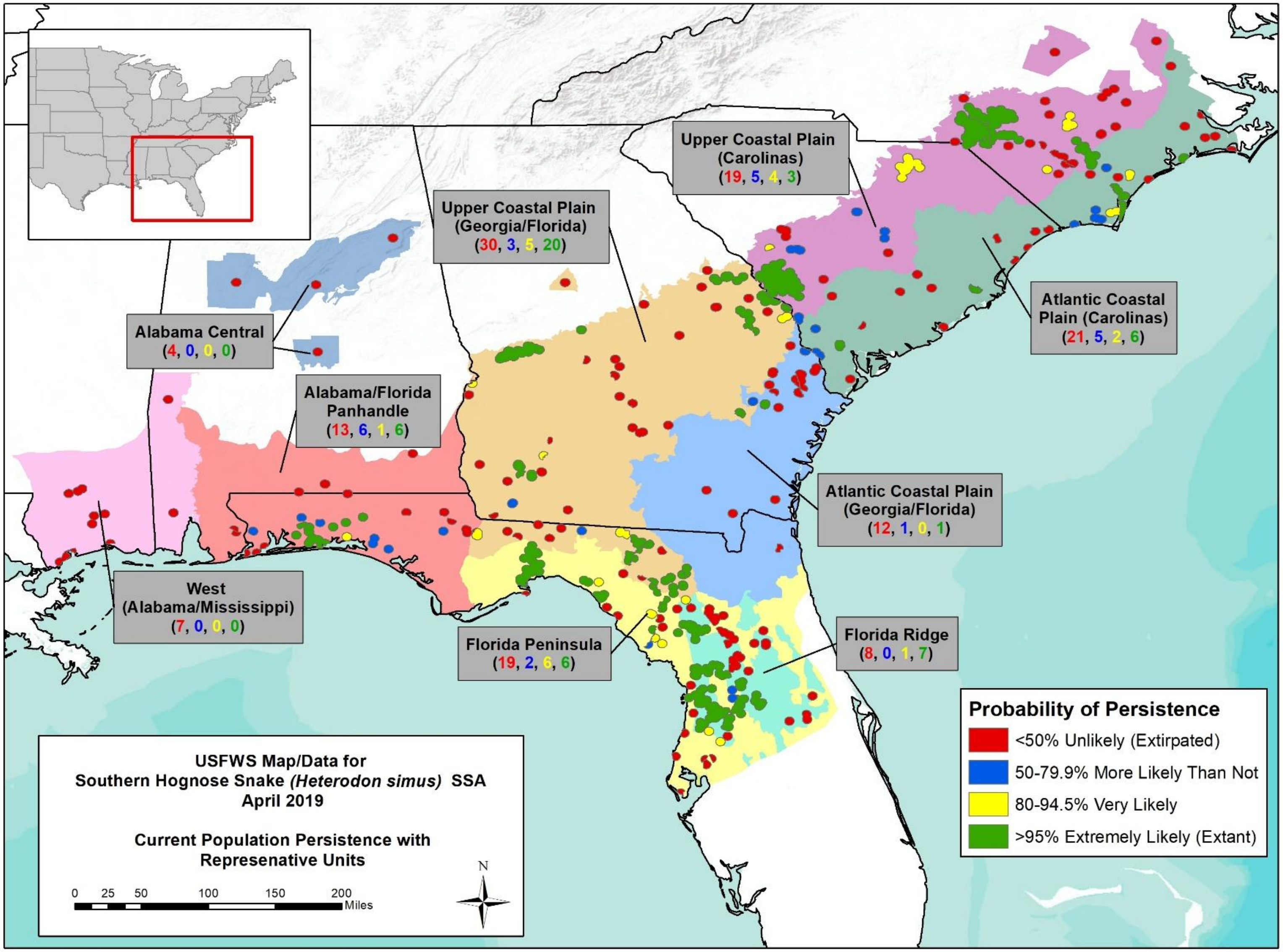

Figure 4-9. Southern hognose snake populations across representative units based on probability of persistence. Green populations are extremely likely to currently occur on the landscape, or be extant; yellow populations are very likely; blue more likely than not; and red populations are unlikely to currently exist (i.e., considered extirpated).

Upper Coastal Plain (Carolinas)

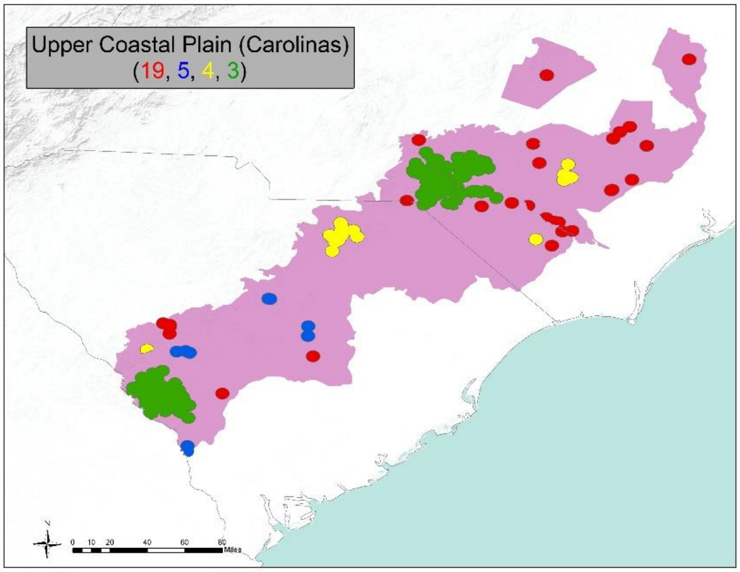

Figure 4-10. Populations of southern hognose snakes by category of current persistence probability in the Upper Coastal Plain (Carolinas) representative unit.

This unit only has 3 populations (10% of total populations in unit) that are extremely likely on the landscape (≥95%); however these populations cover the largest area and consist of the highest number of records relative to other populations across the range of the southern hognose snake. These three large populations appear to be highly resilient, as snakes continue to be commonly observed. There appears to be a range contraction in the northeastern portion of this unit, as most populations in that area are likely extirpated (<50% probability of persistence). This representative unit has likely lost 63.3% (19/30) of its populations.

Upper Coastal Plain (GA/FL)

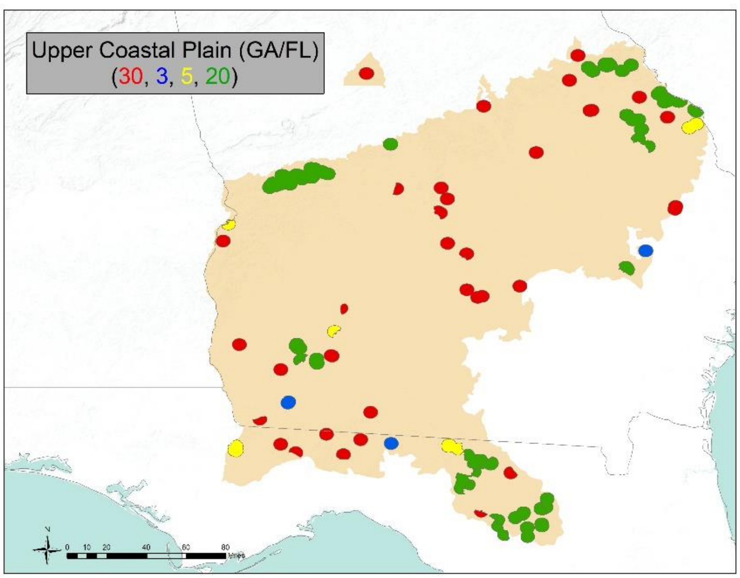

Figure 4-11. Populations of southern hognose snakes by category of current persistence probability in the Upper Coastal Plain (GA/FL) representative unit.

The Upper Coastal Plain (GA/FL) unit has the most populations (58) delineated, although the total number of records is relatively low (285) compared to the other units. Out of all units, this unit has the highest number of populations (20) that are extremely likely to be persisting (≥95%), but it has also likely lost the highest number of populations (28). Resilient populations are clustered at the periphery of the unit, leaving the central portion devoid of resilient populations. This representative unit has likely lost 51.7% (30/58) of its populations.

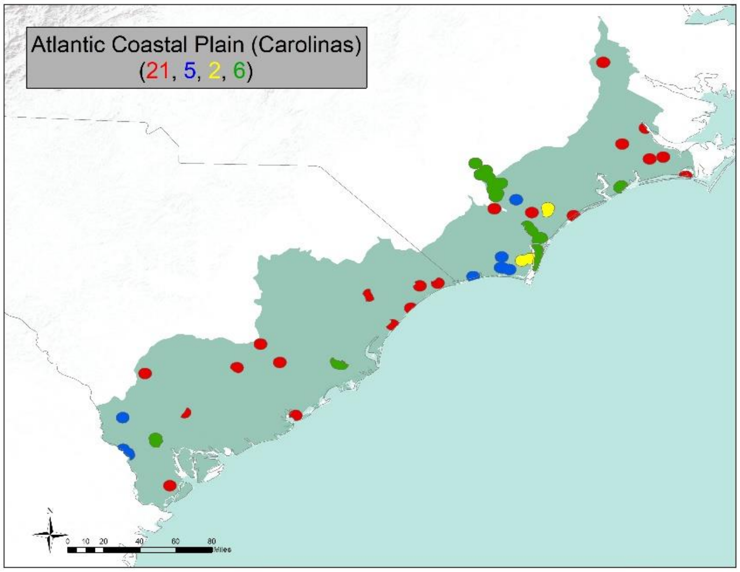

Figure 4-12. Populations of southern hognose snakes by category of current persistence probability in the Atlantic Coastal Plain (Carolinas) representative unit.

Atlantic Coastal Plain (Carolinas)

This unit has 6 populations (17.6%) that are extremely likely to be persisting (>95%), and these resilient populations tend to be located along the coast, making them more susceptible to habitat loss from future SLR. There appears to be a range contraction in the northeastern portion of this unit, as most populations in that area are likely extirpated (<50%). This representative unit has likely lost 61.8% (21/34) of its populations.

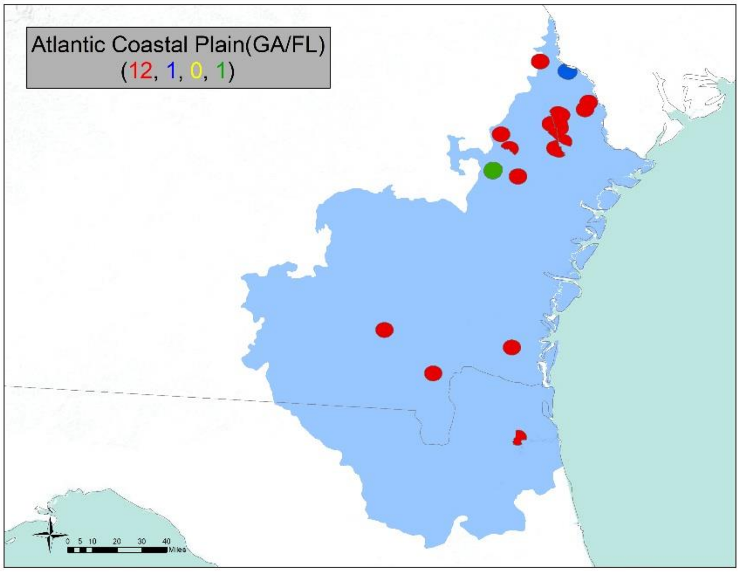

Figure 4-13. Populations of southern hognose snakes by category of current persistence probability in the Atlantic Coastal Plain (GA/FL) representative unit.

Atlantic Coastal Plain (GA/FL)

Other than the West and Alabama Central units, the Atlantic Coastal Plain (GA/FL) unit has the lowest percentage of resilient populations. This unit has seen an extreme reduction in redundancy, as there is currently only one population that is very likely to be persisting (>80%), and one additional population that is more likely than not to be persisting (>50%). Both of these populations are clustered in the northern portion of the unit, leaving a significant gap within the unit, and when combined with the loss of distribution in the Upper Coastal units, a significant range-wide gap. This representative unit has likely lost 85.7% (12/14) of its populations.

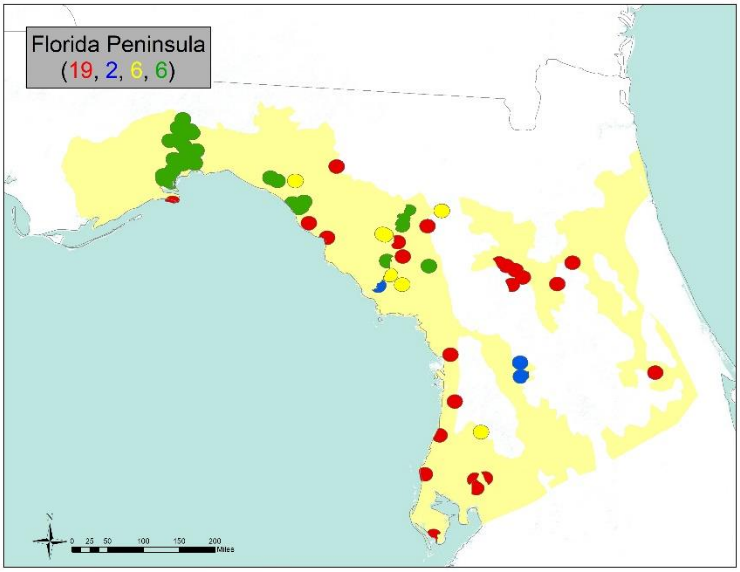

Figure 4-14. Populations of southern hognose snakes by category of current persistence probability in the Florida Peninsula representative unit.

Florida Peninsula

This unit has 6 populations that are extremely likely to be persisting (>95%), all are distributed throughout the western portion of the unit, with no populations likely remaining in the eastern portion of the unit. This representative unit has likely lost 57.6% (19/33) of its populations.

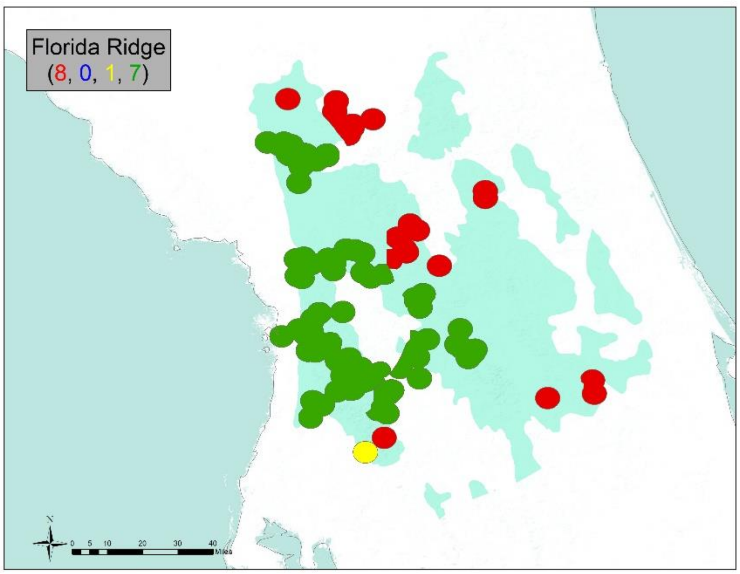

Figure 4-15. Populations of southern hognose snakes by category of current persistence probability in the Florida Ridge representative unit.

Florida Ridge

Although the Florida Ridge unit has relatively few populations (16), it has the highest percentage (43.8%) of populations that are extremely likely to persist (>95%). Similar to the Florida Peninsula unit, the resilient populations in this unit are distributed throughout the western portion, with no populations likely remaining in the eastern portion. The unit's redundancy of resilient populations can be attributed to the land protection, management practices, and habitat suitability of this unit. This representative unit has likely lost 50% (8/16) of its populations.

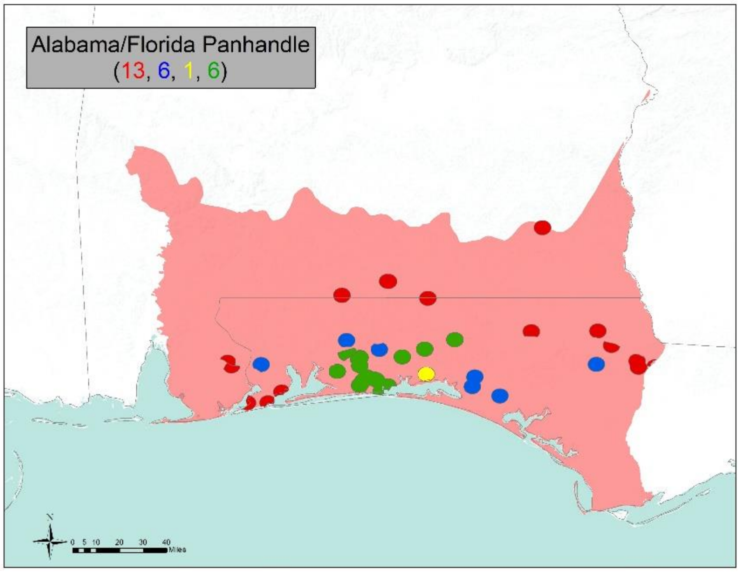

Figure 4-16. Populations of southern hognose snakes by category of current persistence probability in the AL/FL Panhandle representative unit.

Alabama/Florida Panhandle

This unit has 6 populations that are extremely likely to be persisting (>95%), all clustered along the coast. These resilient coastal populations are found on Eglin Air Force Base, an area that has the highest predicted habitat suitability found within the range of the southern hognose snake. There has been a significant range contraction within this unit, exemplified by the fact that there are no populations in Alabama that are likely to be persisting. This representative unit has likely lost 50% (13/26) of its populations.

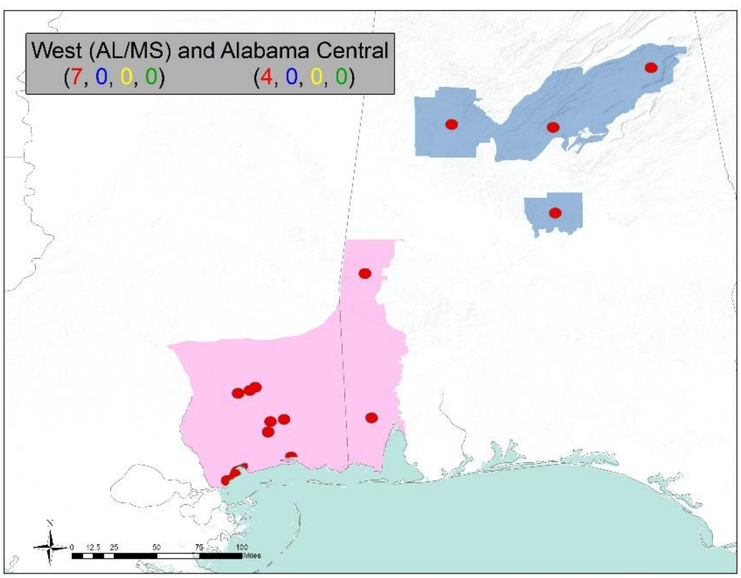

Figure 4-17. Populations of southern hognose snakes by category of current persistence probability in the West (AL/MS) and Alabama Central representative units.

West (AL/MS) and Alabama Central Units

These units currently have zero populations with a probability of current persistence greater than 50%. In fact, the last detection of the southern hognose snake was in 1981 in the West unit, and 1965 in the Alabama Central unit. It is very likely that neither of these representative units are occupied, and thus represent a significant reduction in the western extent of the species' range.

4.3 Summary of Current Conditions

Current resiliency, as measured by population persistence probabilities, for the southern hognose snake has decreased from historical conditions. We considered a population to be highly resilient if it had a relatively high current persistence probability. The southern hognose snake only has 22.1% of its total populations exhibiting the highest degree of resiliency and has likely experienced a loss of 60% of its total populations. The remaining populations have varying degrees of resiliency.

Current representation, as measured by the number and distribution of resilient populations (i.e., those above a certain persistence probability threshold) across representative units in the species' range has also decreased from historical conditions. To have high representation the species must have highly resilient populations located in each of the representative units, and those occupied units should span the latitudinal and longitudinal extent of historical populations. The southern hognose snake has experienced a complete loss of two representative units, one additional representative unit is at risk of becoming extirpated, and all the remaining units are showing declines in the number of resilient populations. There has been a loss of latitudinal and longitudinal variability within the range as all of the populations at the northeastern and western extent of its range have been extirpated.

Current redundancy, as measured by using the current number and distribution of resilient populations within representative units and across the range of the species has been reduced from historical conditions. To have high redundancy the species needs to have multiple resilient populations within representative units and throughout its range. Each of the 9 representative units has likely lost at least 50% of its populations. Range-wide, the number of populations more likely than not to currently persist has decreased by 60%, relative to the historical number of populations. The southern hognose snake has experienced a decline in the number of resilient populations within each of the representative units and across its entire range. Additionally, the distribution of resilient populations within each unit and across the range has become clustered, leaving portions of each representative unit and overall range-wide lacking resilient populations.

CHAPTER 5 – FUTURE CONDITIONS AND VIABILITY

In the previous chapters, we have considered the southern hognose snake's ecological needs, factors influencing viability, and the current condition of the species. We now consider what the species' future condition is likely to be. We apply our future scenarios to the concepts of resiliency, representation, and redundancy to describe the future viability of the southern hognose snake.

5.1 Methods for Estimating Future Condition

In evaluating future conditions for the southern hognose snake, we considered several stressors that may influence future viability of the species and developed seven plausible scenarios representing the potential effects of these stressors along with potential effects of different management efforts over time. Using the results from the habitat analysis, we performed spatial analyses to predict changes in land cover and fire frequency under various levels of urbanization, sea level rise (SLR), and management effort. Then, using the model framework developed for the current condition analysis described in Chapter 4, we created a stochastic simulation model that allowed us to project population persistence into the future as influenced by changes in habitat suitability and land protection (Figure 5-1), and summarized predicted patterns of population persistence at 2040, 2060, and 2080.

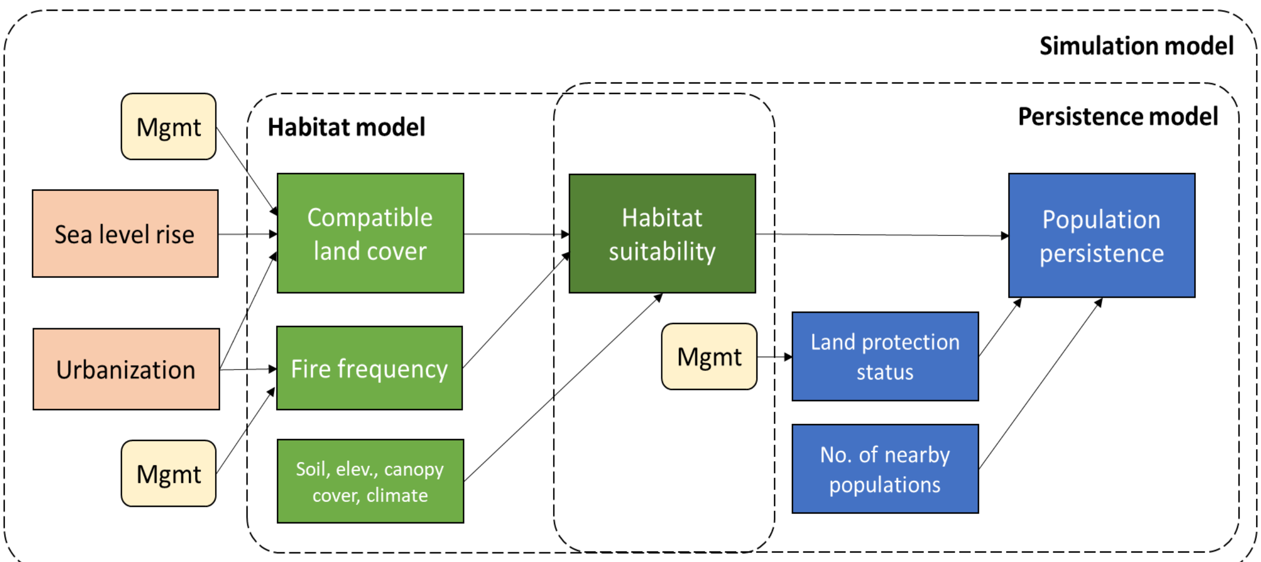

Figure 5-1. Conceptual model linking components included in the habitat suitability model (green), current persistence model (blue), and impacts of stressors (orange) and management (yellow) in the simulation model for future conditions of the southern hognose snake.

How does the simulation model work? The simulation model took each southern hognose snake population's probability of persistence at the present (2018) and predicted the probability it will persist or become extirpated in the future, given varying levels of stressors and management effort that were captured in seven different scenarios. Specifically, we selected the level of future urbanization, SLR, and management effort (e.g., prescribed fire, restoration, land protection) associated with each scenario. Next, we modeled the effects of these conditions on the amount of compatible land cover and fire frequency within each population's boundary. Next, we calculated future habitat suitability based on these changing conditions. Finally, we used the persistence model described in Chapter 4 to estimate the probability each population would persist from one year to the next, through the year 2080, given changes in habitat suitability and proportion of protected land. We would expect populations that retain high levels of habitat suitability and land protection to have higher probabilities of persisting in the future; conversely, we would expect populations experiencing reductions in habitat suitability due to stressors to have lower future persistence probabilities.

We ran the model 10,000 times per scenario. In each run, the model estimated each population's probability of persisting one year to the next, based on changing conditions, and used that probability to randomly draw an outcome for each population in the next year. We can think of this as a coin flip determining whether a population persists or becomes extirpated. Because of this randomness (stochasticity), predictions varied between model runs.

We calculated each population's future persistence probability as the proportion of model runs where the population was still persisting each year through 2080. Additionally, we summed the number of populations still persisting each year within each representative unit and range-wide in each model run, and we used these to calculate the mean number of populations persisting at these scales in the future.

5.1.1 Stressors and Effects on Habitat Conditions

In predicting future conditions, we selected stressors that will continue to have an impact on southern hognose snake populations in the future. These stressors were based on the discussed factors influencing viability (Chapter 3; Figure 3-5) and availability of data that could be incorporated into the model. We selected urbanization and SLR as the stressors that have predicted effects on land cover and fire frequency. Changes in land cover and fire frequency subsequently influenced future habitat suitability, as predicted by the habitat suitability model (Section 4.1.1; Appendix A), and ultimately population persistence, as predicted by the stochastic simulation model (Section 5.1.3; Figure 5-1; Appendix B). There are other stressors potentially affecting southern hognose snake populations that will continue into the future, but the availability of data and our understanding of these stressors' effects are limited and made it difficult to include in our model. Below we describe the data sources we used for capturing stressors and spatial analysis methods used in ArcGIS to model the effects of stressors on habitat conditions.

We captured the extent and rate of urbanization using the Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade (SLEUTH) model, which simulates patterns of urban expansion across the Southeast based on observations of past urban growth and transportation networks, including the sprawling, fragmented, "leapfrog" development, which has been the dominant form of development in the Southeast (Terando, et al., 2014, entire). The SLEUTH model predicts the probability of urbanization ranging from 0-100%, with higher probabilities indicating areas more likely to be developed. The model specifies a 0% probability of urbanization for protected areas (e.g., National Forests, State-owned conservation lands); however, new conservation lands have been created by government agencies and other partners since the model was developed. Therefore, we set the probability of urbanization to 0 for any cell that overlapped our raster of currently protected areas. We used SLEUTH projections from 2040, 2060, and 2080, and interpolated the annual extent of urbanization between those periods. We modeled the effect of habitat loss from urbanization by a given year by removing any area currently classified as compatible land cover that overlapped areas likely to be urbanized above a certain probability threshold (see scenario descriptions in Section 5.1.2). We then recalculated the proportion of compatible land cover for each population that subsequently affected overall habitat suitability.

We also wanted to capture the effects of urbanization on fire frequency to account for fire exclusion/suppression that often occurs in areas adjacent to developed lands. Studies have found evidence of fire exclusion/suppression in habitats within 600 m to 5 km (0.4 to 3.1 miles) of urban areas (Theobald & Romme, 2007, entire; Pickens, et al., 2017, p. 105). Therefore, we chose a moderate value of 3.2 km (2 miles) to capture the interaction between urbanization and fire frequency. Using the predicted urbanized areas at each time period and urbanization probability level, we identified areas within 3.2 km of urban boundaries. We then projected future reductions in fire frequency by applying a distance-weighted reduction to any cell within 3.2 km of urban areas. Using this approach, fire frequency for any cell overlapping future urban areas was reduced by 100% (equaled 0) and any cell more than 3.2 km away from urban areas was reduced by 0% (unchanged). Any cell between 0 and 3.2 km away from urban areas was reduced by a percentage proportional to its distance; for example, a cell 1.6 km (1 mile) from an urban area was reduced by 50%. We recalculated the mean fire frequency for each population, which subsequently affected overall habitat suitability.

Similarly, we captured potential habitat loss due to inundation from SLR. We used National Oceanic and Atmospheric Administration (NOAA) SLR projections, which provide a range of inundation levels from low to extreme through the year 2100 (NOAA, 2018, unpaginated). We reviewed local scenarios for locations in the Southeast, selected multiple inundation heights representing a range of threat levels (see scenario descriptions in Section 5.1.2), and created rasters showing inundated areas, given each height, at 2040, 2060, and 2080. Similar to modeling urbanization, we interpolated the annual extent of inundation due to SLR between those periods. We reduced the amount of compatible land cover for populations if currently compatible land cover was predicted to be inundated by SLR, given a certain inundation level and year.

5.1.2 Scenario development

We developed seven plausible scenarios to simulate future conditions (Table 5-1). The first three scenarios predicted future conditions under varying levels of urbanization and SLR with status quo management. For the last four scenarios, we used the same rates of urbanization and SLR, using the most likely level for each of these stressors, and varied levels of management effort. For status quo management we assumed: (1) the amount of protected area for each population will remain constant through time (e.g., protected land will not be sold or urbanized); (2) compatible land cover will not increase (e.g., that would otherwise be due to habitat restoration efforts); and (3) fire frequency will remain at the same level it was between 2001 and 2016 (i.e., the period used to calculate fire frequency in the habitat suitability analysis [see Appendix A]), unless the area was urbanized or adjacent (within 3.2 km) to future urban areas.

Low Stressors – In this scenario, we considered a future where management remains at the status quo and evaluated the future condition of the southern hognose snake under a low rate of urbanization by selecting areas with a greater than 90% probability of being urbanized (only includes areas with high certainty of development) and a low level of SLR (1 ft. at year 2080).

Medium Stressors – In this scenario, we considered a future where management remains at the status quo and evaluated the future condition of the southern hognose snake under a medium rate of urbanization by selecting areas with a greater than 50% probability of being urbanized and a medium level of SLR (3 ft. at year 2080).

High Stressors – In this scenario, we considered a future where management remains at the status quo and evaluated the future condition of the southern hognose snake under a high rate of urbanization by selecting areas with a greater than 10% probability of being urbanized (includes areas with a low probability of development) and a high level of SLR (6 ft. at year 2080).

Decreased Management – In this scenario, we considered a future where it is difficult to continue to manage habitat for the southern hognose snake. In this scenario, we simulated decreased management effort where habitat suitability declines for populations that are currently on protected lands. We decreased fire frequency on protected lands by simulating the equivalent of applying one less prescribed burn every five years in these areas, and we used the updated mean fire frequency for each population to predict habitat suitability and population persistence in the future. We also used the medium rate of urbanization (50 % probability) and a medium level of SLR (3 ft. at year 2080), since these are considered the most likely levels for these stressors.

Improved Management – In this scenario, we considered a future in which we improve the management for the southern hognose snake. In this scenario, we simulated additional management effort that focused on improving habitat suitability for populations that are currently on protected lands. We increased the fire frequency by simulating the equivalent of applying 1 additional prescribed burn every 5 years to populations that occur on protected lands, and we used the updated mean fire frequency for each population to predict habitat suitability and population persistence in the future. We also used the medium rate of urbanization (50 % probability) and a medium level of SLR (3 ft. at year 2080), since these are considered the most likely levels for these stressors.

Protect More Populations – In this scenario, we considered a future where additional populations were permanently protected. In this scenario, we considered acquiring, protecting, and improving additional land within population boundaries for those populations that are very likely to currently persist (≥ 80% current persistence probability) but are not currently protected (< 0.1 proportion of protected land). We assigned a new proportion of protected land of 0.9 on these populations to simulate protecting the majority (90%) of land within the population boundary. We also increased the proportion of compatible land cover by 0.1 to simulate restoring habitat in 10% of the population area. As in the improved management scenario, we also simulated additional management effort for the newly protected lands, as well as the lands already protected by increasing the fire frequency to simulate 1 additional prescribed burn every 5 years in these areas. We used the medium rate of urbanization (50% probability) and a medium level of SLR (3 ft. at year 2080), since these are considered the most likely levels for these stressors.

Protect Even More Populations – In this scenario, we considered a future where all populations that are currently more likely than not to persist, are permanently protected. We followed the same steps as in the previous scenario, except that we considered acquiring, protecting, and improving additional land within population boundaries for those populations that are more likely than not to persist (> 50% current persistence probability), but are not currently protected (< 0.1 proportion of protected land). As in the previous scenario, we simulated protecting the majority of land within these populations' boundaries, increasing compatible land cover, and increasing fire frequency by 1 additional prescribed burn every 5 years. We used the medium rate of urbanization (50% probability) and a medium level of SLR (3 ft. at year 2080), since these are considered the most likely levels for these stressors.

Table 5-1. List of scenarios used to predict future conditions for the southern hognose snake, showing levels of urbanization, sea level rise (SLR), and management conditions considered in each scenario. Note: SLR represents inundation levels at 2080.

Scenario Name	Urbanization	SLR	Management Level
Low Stressors	Low (90%)	Low (1ft)	Status Quo
Medium Stressors	Medium (50%) (most likely)	Medium (3ft) (most likely)	Status Quo
High Stressors	High (10%)	High (6ft)	Status Quo
Decreased Management	Medium (50%) (most likely)	Medium (3ft) (most likely)	Decreased management effort on protected lands by decreasing fire frequency by 20% (One less burn every 5 years).
Improved Management	Medium (50%) (most likely)	Medium (3ft) (most likely)	Increased management on protected lands by increasing fire frequency by 20% (One extra burn every 5 years).
Protect More Populations	Medium (50%) (most likely)	Medium (3ft) (most likely)	Acquire, protect, and improve additional land within population boundaries for those populations that are very likely to currently persist (> 80% current persistence probability), but are not currently protected and improve mgmt. on all protected lands by increasing fire frequency by one extra burn every 5 years.
Protect Even More Populations	Medium (50%) (most likely)	Medium (3ft) (most likely)	Acquire, protect, and improve additional land within population boundaries for those populations that are more likely than not to persist (> 50% current persistence probability), but are not currently protected and improve mgmt. on all protected lands by increasing fire frequency by one extra burn every 5 years.

5.1.3 Stochastic simulation model

To predict the probability of persistence for each population in the future, we developed a stochastic simulation model that was based on the current probability of persistence and future predicted changes in habitat suitability and land protection (introduced in Box above; Figure 5-1).

We built a multi-loop simulation model (McGowan, et al., 2014, entire) that allowed us to simulate thousands of replicates of each population under the seven different scenarios. This approach accounted for random year-to-year stochasticity as well as uncertainty around rates (i.e., annual persistence probability) estimated from the current persistence model. The model looped through 10,000 iterations for each of the scenarios. In each iteration, it looped through each of the 204 southern hognose snake populations within the analysis area and simulated persistence from the present (2018) to 2080.

The core of the simulation model was the persistence model used to estimate current conditions (see 4.1.3). For each population, the model selected its probability of currently persisting and randomly simulated it persisting or becoming extirpated in the next year (2019). From 2020 to 2080, the probability a population persisted from one year to the next was a function of its habitat suitability, proportion of land protected, and number of nearby populations, given the conditions of each scenario. For each year in a model iteration, it selected the annual values of land cover and fire frequency that were influenced by rates of urbanization, SLR, and management efforts associated with a particular scenario. It then used these conditions, along with all other predictors used in the habitat suitability model (e.g., soil drainage, local elevation) that did not change in any scenario, to calculate mean habitat suitability for each population and year. Finally, it used the new values of a population's habitat suitability, along with the proportion of protected land and number of nearby populations, to estimate the probability a population persists each year in the future through 2080.

For this model, the primary output was the probability a population persists at a given year in the future through 2080, which we call "future persistence probability." We calculated the future persistence probability for each population as the proportion of model iterations where the population was persisting at a given year. The complement of future persistence probability can be interpreted as the probability a population has become extirpated by a given year. These future persistence probabilities for populations are directly comparable to the current persistence probabilities estimated in Chapter 4. We characterized future conditions similarly to current conditions by summarizing the number of populations at or above certain persistence probability thresholds (50, 80, and 95%) in each representative unit and range-wide, given each of the seven scenarios. Like in the current conditions analysis, in addition to a specific population's persistence probability, each model iteration recorded the number of populations persisting at each time step in each representative unit and range-wide. We used all model iterations to calculate the mean (the most likely prediction) and 95% confidence intervals for the number of persisting populations, in each representative unit and range-wide, each year. Similar to results for current conditions, the mean number of persisting populations approximately equals the number of populations with a 50% or greater persistence probability. We summarized these outputs for three future time horizons: 2040, 2060, and 2080. For more details on methods used in the future conditions analysis, see Appendix B.

5.2 Future Condition Results

5.2.1 Summary of analysis

Habitat conditions used to predict future persistence varied slightly between scenarios (Table 5-2). Specifically, there were similar reductions of land cover, fire frequency, and HSI due to projected urbanization and SLR across the low, medium, and high stressor scenarios. The projected urbanization and SLR across the Southeast for the year 2080 is shown in Figure 5-2. Across the stressor scenarios, the average population lost from 12% of its compatible land cover (under low stressor levels) to 16% (under high stressor levels). While some populations

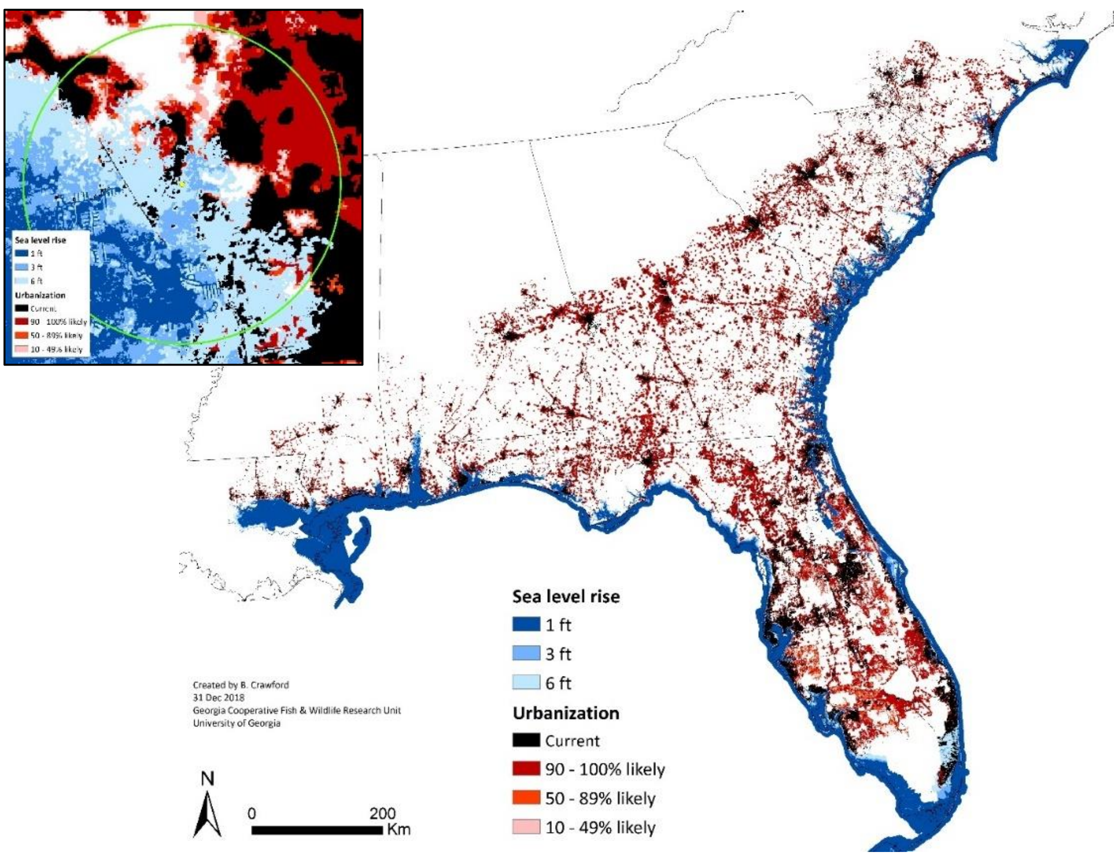

Figure 5-2. Projected urbanization (black and red) and sea level rise (blue) for the year 2080 in the Southeast, United States. Certain southern hognose snake populations (green circle in inset) were predicted to experience substantial habitat loss due to urbanization and sea level rise.

experienced no loss of land cover, others were predicted to lose the majority of compatible land cover due to urbanization and SLR. A few coastal populations experienced a “squeezing” effect where there is a loss of land cover from SLR on one side and loss due to urbanization on another (see inset in Figure 5-2 for an example). Among the four management scenarios, the percent change in land cover, fire frequency, and HSI increased from the decreased management scenario to the protect even more populations scenario. We note that populations were still predicted to experience some degree of compatible land cover loss for all management scenarios; however, the two scenarios where more populations were protected resulted in an increase in HSI for populations, on average.

Table 5-2. Predicted changes in habitat variables (compatible land cover, fire frequency, and Habitat Suitability Index [HSI]) between the present and 2080. All values represent the percent change (losses or gains) in habitat variables under each scenario in the future conditions analysis. Means (top value in each cell) represent the average change across populations, and minimums and maximums (bottom values in each cell) represent the lowest and highest changes, respectively, predicted for a single population.

Habitat variable	**Scenario**						
	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
Compatible land cover	-12.2 (-74.5, 0.0)	-13.7 (-76, 0.0)	-15.8 (-77.7, 0.0)	-13.7 (-76.0, 0.0)	-13.7 (-76, 0.0)	-9.6 (-76, 8.7)	-7.5 (-57.6, 9.0)
Fire frequency	-1.9 (-16.1, 0.0)	-1.9 (-16.4, 0.0)	-2.1 (-16.6, 0.0)	-6.1 (-22.2, 0.0)	2.3 (-10.9, 20.0)	4.8 (-10.9, 20.0)	6.3 (-10.9, 20.0)
HSI	-3.9 (-51.4, 0.0)	-4.3 (-53.9, 0.0)	-4.9 (-56.5, 0.0)	-7.5 (-53.9, 0.0)	-0.1 (-53.9, 51.6)	2.8 (-53.9, 51.6)	4.9 (-34.1, 51.6)

5.2.2 Future Population Resiliency

Using the simulation model, we predicted the future persistence probability for each of the 204 populations in the analysis area through the year 2080. We assumed that the 18 populations outside of the analysis area will remain unlikely to persist (i.e., extirpated) on the landscape. We followed similar steps as in the current condition analysis to summarize population resiliency by reporting the number of populations at each persistence threshold under the seven future scenarios in years 2040, 2060, and 2080 (Table 5-3). In Figure 5-3, we display the distribution of populations by category of persistence probability across the species’ range under current conditions, the medium stressor scenario in 2080, and the protect even more populations scenario in 2080.

For all scenarios, future population persistence decreased from current conditions. The degree of the decrease depended on the scenario. For all scenarios, many populations that fell within the extremely likely on landscape (≥95%) and very likely on landscape (≥80%) threshold under current conditions were predicted to have lower persistence probabilities in the future and, thus, dropped to lower categories. The number and percentage of resilient populations (those in the higher persistence categories) decreased the most in the decreased management scenario and decreased least (but still decreased) in the protect even more populations scenarios, relative to current conditions. The three stressor scenarios (low, medium, and high), yielded nearly identical predictions of the number and percentage of resilient populations. These patterns were seen across all future time horizons (2040, 2060, and 2080). Concurrently, we predicted the number and percentage of populations likely to be extirpated (<50%) to increase for all scenarios and future time horizons, relative to current conditions. These trends reflected the process of populations currently in higher persistence categories transitioning to lower categories as their probabilities of persistence decreased over time. For example, the percentage of total populations likely to be extirpated (<50%) currently is 60%. Under the medium stressor scenario, by 2040 that percentage has increased to 65.3%, by 2060 it has increase to 72.1%, and by 2080 to 74.3%. In other words, under the medium stressor scenario, the most likely scenario, we estimated 12 additional populations will likely become extirpated by 2040, an additional 27 populations by 2060, and an additional 32 by 2080, for a total of 74.3% of populations estimated to be extirpated by 2080.

Patterns of resiliency between the scenarios were not surprising. Population persistence probabilities were likely similar between the three stressor scenarios because there were only minimal differences between the three scenarios in the amount of land cover loss, reduction in fire frequency, and habitat suitability for populations (Table 5-2). The similarity in results between all stressor scenarios highlights the fact that while SLR and urbanization result in declines in persistence probabilities, the magnitude of the declines are not closely correlated with the magnitude of the stressor level. For the decreased management scenario, persistence probabilities were consistently lower than all other scenarios. This is not surprising given that reductions in prescribed fire led to further reductions in predicted habitat suitability, ultimately leading to reduced persistence probabilities. The improve management scenario yielded only slightly more persisting populations compared to the three stressor scenarios. However, the two scenarios that included protecting more populations predicted higher numbers of persisting populations, relative to all other scenarios. These scenarios simulated investing resources in protection of populations that are likely persisting currently, acquiring land within the population boundary, and managing habitat adequately with prescribed fire. This highlights the importance of increased management effort in reducing the rate of population loss relative to other scenarios. However, it is important to note that although management scenarios yielded higher numbers of persisting populations compared to the other scenarios, these scenarios still predicted the number of persisting populations to decrease from current conditions, even with these higher levels of management.

Because we predicted the number of populations to decline at the upper persistence thresholds (>95% and >80%), resiliency for this species was reduced in all scenarios we tested. Habitat suitability was reduced under the three stressor scenarios, and although there was some improvement of habitat predicted from the management scenarios, the improvement was not substantial enough to overcome the habitat suitability reductions resulting from the influence of

SLR and urbanization. As habitat suitability is reduced and populations are predicted to become extirpated, connectivity of habitats and those remaining populations will decrease, which is another factor that can potentially reduce future resilience for the southern hognose snake.

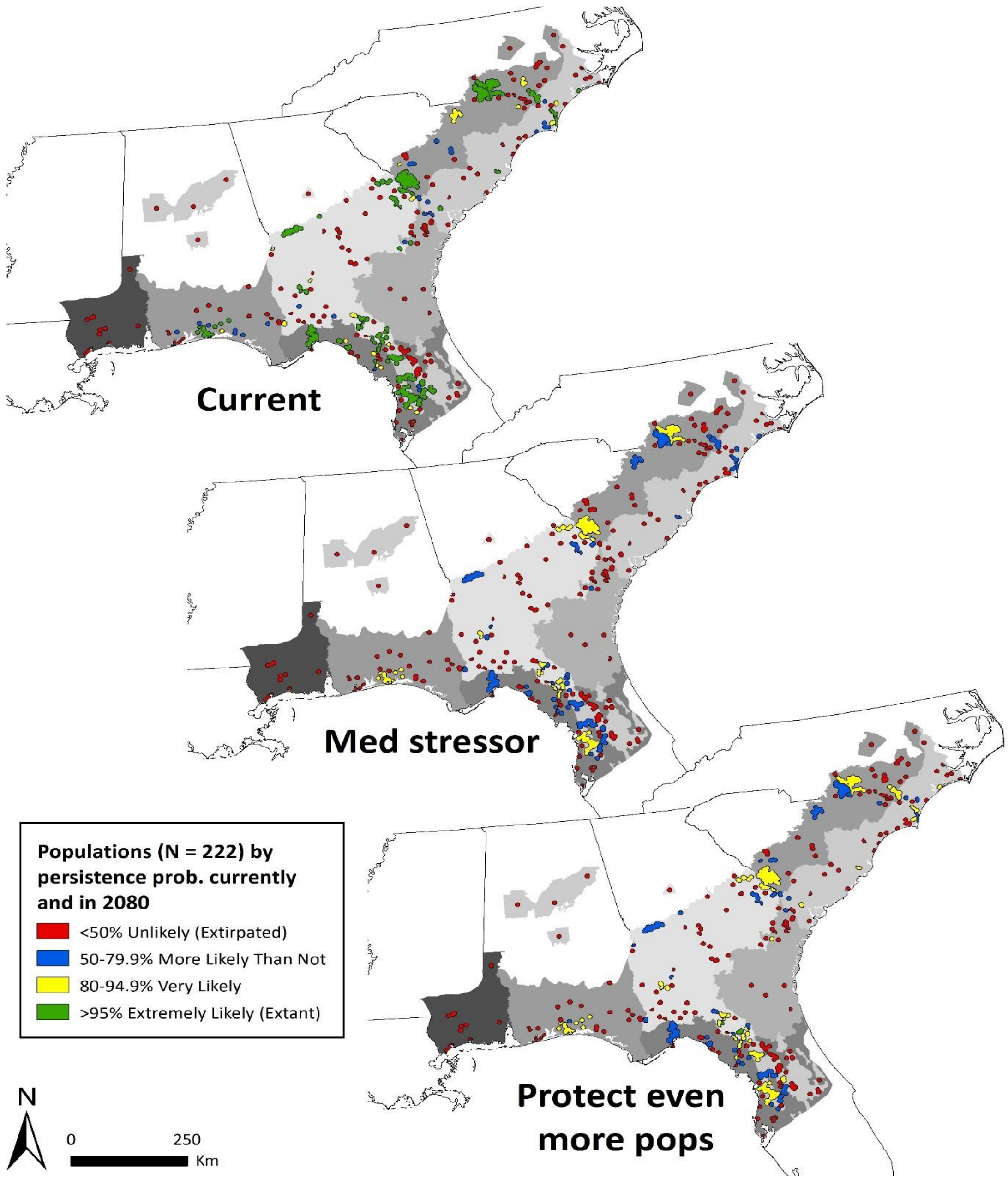

Figure 5-3. Spatial distribution of southern hognose snake populations by category of persistence probability across the species' range under current conditions, the medium stressor scenario in 2080, and the protect even more populations scenario in 2080.

Table 5-3. Distribution of southern hognose snake populations (N = 222) in each category of population persistence in 2040, 2060, and 2080, for the seven scenarios. *Indicates the numbers are reported at cumulative totals and percentage.

Year - 2040	Scenario							
Population persistence category	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
*Extremely Likely on Landscape (Extant) 95-100%	49 (22.1%)	8 (3.6%)	8 (3.6%)	8 (3.6%)	5 (2.3%)	10 (4.5%)	15 (6.8%)	16 (7.2%)
*Very Likely on Landscape 80-94.9%	68 (30.6%)	44 (19.8%)	45 (20.3%)	45 (20.3%)	43 (19.4%)	46 (20.7%)	54 (24.3%)	54 (24.3%)
*More Likely than Not 50-79.9%	89 (40.1%)	76 (34.2%)	77 (34.7%)	77 (34.7%)	74 (33.3%)	77 (34.7%)	78 (35.1%)	82 (36.9%)
Unlikely (Extirpated) < 50%	133 (59.9%)	146 (65.8%)	145 (65.3%)	145 (65.3%)	148 (66.7%)	145 (65.3%)	144 (64.9%)	140 (63.1%)
Year - 2060	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
*Extremely Likely on Landscape (Extant) 95-100%	49 (22.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.5%)	4 (1.8%)	4 (1.8%)
*Very Likely on Landscape 80-94.9%	68 (30.6%)	27 (12.2%)	28 (12.6%)	27 (12.2%)	24 (10.8%)	31 (14.0%)	41 (18.5%)	42 (18.9%)
*More Likely than Not 50-79.9%	89 (40.1%)	63 (28.4%)	62 (27.9%)	62 (27.9%)	62 (27.9%)	64 (28.8%)	74 (33.3%)	75 (33.8%)
Unlikely (Extirpated) < 50%	133 (59.9%)	159 (71.6%)	160 (72.1%)	160 (72.1%)	160 (72.1%)	158 (71.2%)	148 (66.7%)	147 (66.2%)
Year - 2080	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
*Extremely Likely on Landscape (Extant) 95-100%	49 (22.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.5%)	2 (0.9%)
*Very Likely on Landscape 80-94.9%	68 (30.6%)	20 (9.0%)	20 (9.0%)	20 (9.0%)	14 (6.3%)	14 (6.3%)	35 (15.8%)	36 (16.2%)
*More Likely than Not 50-79.9%	89 (40.1%)	57 (25.7%)	57 (25.7%)	57 (25.7%)	56 (25.2%)	58 (26.1%)	66 (29.7%)	70 (31.5%)
Unlikely (Extirpated) < 50%	133 (59.9%)	165 (74.3%)	165 (74.3%)	165 (74.3%)	166 (74.8%)	164 (73.9%)	156 (70.3%)	152 (68.5%)

5.2.3 Future Species Representation and Redundancy

We summarized trends in the future condition of the southern hognose snake for representation and redundancy using the number of populations likely to persist and their spatial distribution. Specifically, we report both the persistence probability thresholds, in each of the 9 representative units and across its range, in 2040, 2060, and 2080 (Table 5-4; Figure 5-4 and 5-5), as well as the mean number of populations predicted to persist with 95% confidence intervals (Tables 5-5). The mean numbers of populations persisting, as predicted directly from the simulation model, are relatively close (± 2 populations) to the number of populations above a 50% persistence probability for all of the representative units.

We can assume that the risk of an entire representative unit becoming extirpated increases as the number of populations predicted to persist within that unit decreases. Therefore, we interpret a higher risk of loss of representation when a representative unit has zero populations above a certain persistence threshold, moderate risk when a unit has one or two populations above a certain threshold, and lower risk when a unit has three or more populations above a certain threshold. We discuss the risk for particular units in relative terms to other units.

Overall, we predicted future representation and redundancy to decrease from current conditions, but the degree of decrease depended on the scenario. The number of resilient populations and the number of representative units with resilient populations decreased the most under the decreased management scenario and least under the protect even more populations scenario. In our current condition analysis, we determined that the southern hognose snake has become extirpated in 2 of 9 representative units. Each of the other 7 representative units had at least 1 population extremely likely to be on the landscape (persistence probability ≥ 95%). In 2040, between 4 and 6 of 9 representative units were predicted to be occupied by at least one population at the ≥95% threshold, depending on the scenario. By 2060, between 0 and 2 of 9 representative units were predicted to be occupied by at least one population at the ≥95% threshold. By 2080, no representative unit has a population that is in the ≥95% threshold, except for the Upper Coastal Plain (GA/FL) under the protect more populations and protect even more populations scenarios.

One representative unit, Atlantic Coastal Plain (GA/FL), was predicted to have only 1 remaining population more likely than not to persist (≥50%) by 2080, in all scenarios except for the protect even more populations scenario, in which only 1 additional population is more likely than not to persist (Table 5-4; Figure 5-4). Thus, the Atlantic Coastal Plain (GA/FL) was predicted to be at the highest risk of extirpation, relative to the other units, and indicates a high potential for losing representation of the species in this unit in the future.

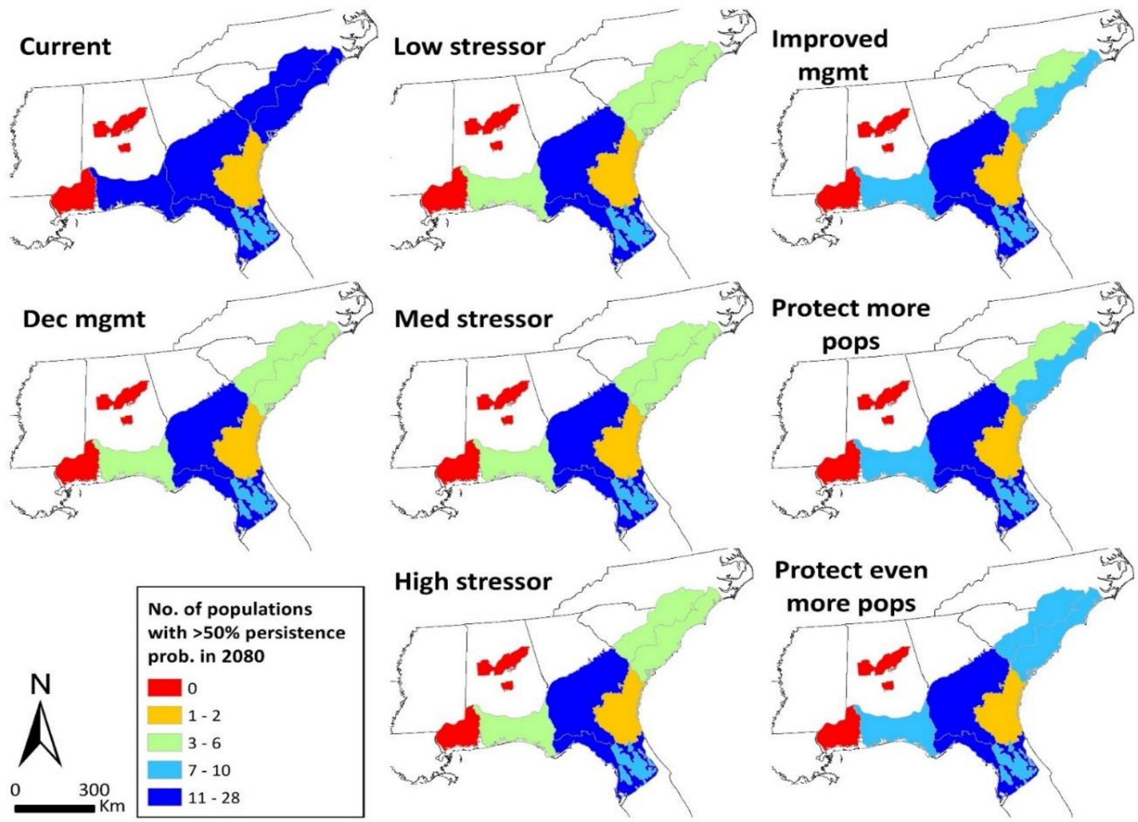

Figure 5-4. Redundancy, measured by the number of populations above the 50% persistence probability threshold, within representative units for the southern hognose snake, currently and in the year 2080, under the seven scenarios.

In addition to summarizing future conditions using the number of populations meeting a certain persistence probability threshold, we present the mean number of populations still persisting (and 95% confidence intervals), as predicted directly from the simulation model (Table 5-5). We used cell shadings in Table 5-5 to highlight relative risks to losing representation within a unit. As discussed above, we again see that the Atlantic Coastal Plain (GA/FL) was the representative unit with a higher risk of losing representation, relative to other units, since the 95% confidence interval included 0 populations persisting in 2080. The Florida Ridge unit had a moderate risk of losing representation as the mean number of populations was 5 but the lower 95% confidence interval included only 2 populations persisting in 2080. All other units (besides the two units that are presumed to be currently extirpated) were predicted to have a lower risk of losing representation, since all units had lower confidence intervals that included 3 or more populations predicted to persist in 2080 under all threat scenarios.

We had previously predicted that the southern hognose snake has likely experienced a decrease in latitudinal and longitudinal variability (i.e., a range contraction) from its historical to current range extent. Future predictions showed that populations at or above the 50% and 80% persistence threshold will likely be distributed throughout the species' range that is currently occupied under all scenarios (Figure 5-3). However, these more resilient populations will continue to exhibit a degree of clustering, which will likely leave large areas lacking resilient populations (e.g., southern Alabama, middle Georgia, eastern Florida Peninsula, and coastal South Carolina).

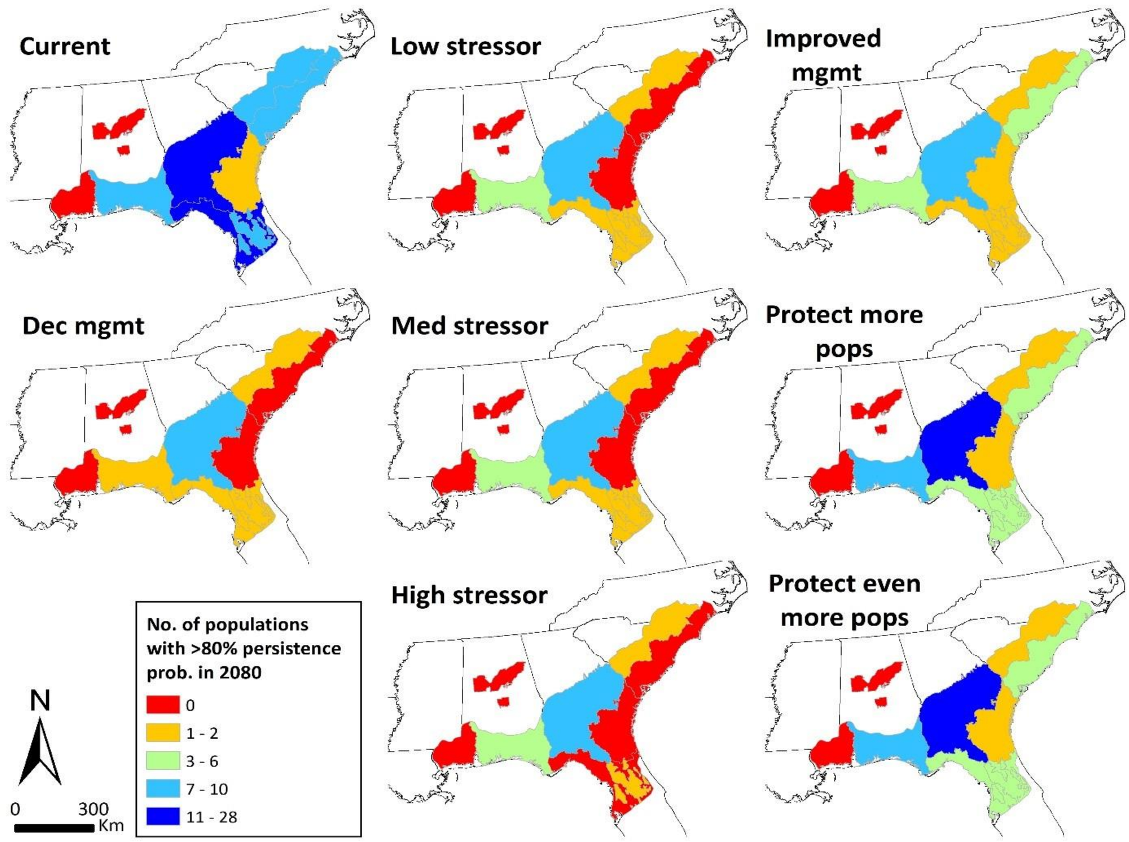

Figure 5-5. Redundancy, measured by the number of populations above the 80% persistence probability threshold, within representative units for the southern hognose snake, currently and in the year 2080, under the seven scenarios.

Redundancy, as measured by the number of populations above the 50, 80, and 95% persistence threshold (Table 5-4) and by the mean number of populations persisting (Table 5-5; Figure 5-6), decreased in all scenarios, time periods, and representative units, relative to current conditions. By examining patterns in Figure 5-6, several takeaways emerged that are reflected throughout the results. First, there was substantial overlap in the confidence intervals around predictions for each scenario. This is expected since the simulation model accounted for uncertainty around parameter estimates from the current analysis, as well as random year-to-year stochasticity. Still, conclusions can be drawn by comparing mean predictions relative to one another. Second, the three stressor scenarios yielded nearly identical predictions of the number of persisting populations. This is not surprising since there were only minimal differences between the low and high stressor scenarios in the amount of land cover loss, reduction in fire frequency, and HSI for populations, on average. Third, the decreased management scenario and improved management scenario only marginally reduced and increased, respectively, the mean number of persisting populations relative to the stressor scenarios. These two scenarios included the effects of stressors at their medium level as well as small adjustments to habitat management (a decrease or increase of 1 prescribed fire every 5 years) on lands that are currently protected. Fourth, the two scenarios representing highest management effort (the protect more populations and protect even more populations scenarios) yielded a greater number of persisting populations, on average. Comparing the outcomes of the improved management scenario vs. the two higher management effort scenarios highlights the value of protecting additional populations, rather than solely managing populations on currently protected lands, if one's goal is to increase the number of persisting southern hognose snake populations in the future. However, the fundamental take-away is that under all scenarios, including those with the most intensive conservation efforts, all led to reductions in the number of populations over time. Range-wide, 11 additional populations are predicted to persist at an 80% threshold under the protect even more populations management scenario compared to the improved management scenario. It is interesting to note that only 1 additional population is predicted to persist at an 80% threshold when comparing the protect more populations scenario and the protect even more populations scenario, and that one population is in the Upper Coastal Plain, where representation is highest amongst all of the units.

Looking at redundancy within the representative units, we see that two representative units (Upper Coastal Plain (GA/FL), and the Alabama/Florida Panhandle) were predicted to have at least 1 population above the 80% persistence probability threshold and at least 6 populations above the 50% threshold in 2080 under the three stressor scenarios (Table 5-4). These units have higher redundancy relative to the other units. The Upper Coastal Plain (GA/FL) currently has the highest number of populations and was predicted in the future to maintain the highest level of redundancy in the future, relative to the other units. The Alabama/Florida Panhandle unit currently has fewer populations, but many of them were clustered on Eglin Air Force Base – a protected area with the highest HSI in the species' range. Despite currently having fewer populations, multiple populations in this unit were predicted to persist over time due to these favorable conditions. All other units had reduced redundancy but were predicted to have a lower risk, since all units had lower confidence intervals that included 3 or more populations predicted to persist in 2080 under all threat scenarios. Lastly, we note that it is very likely that the two Western representative units (West and Alabama Central) are no longer occupied by the species, and these units will continue to be unoccupied by the species under all scenarios.

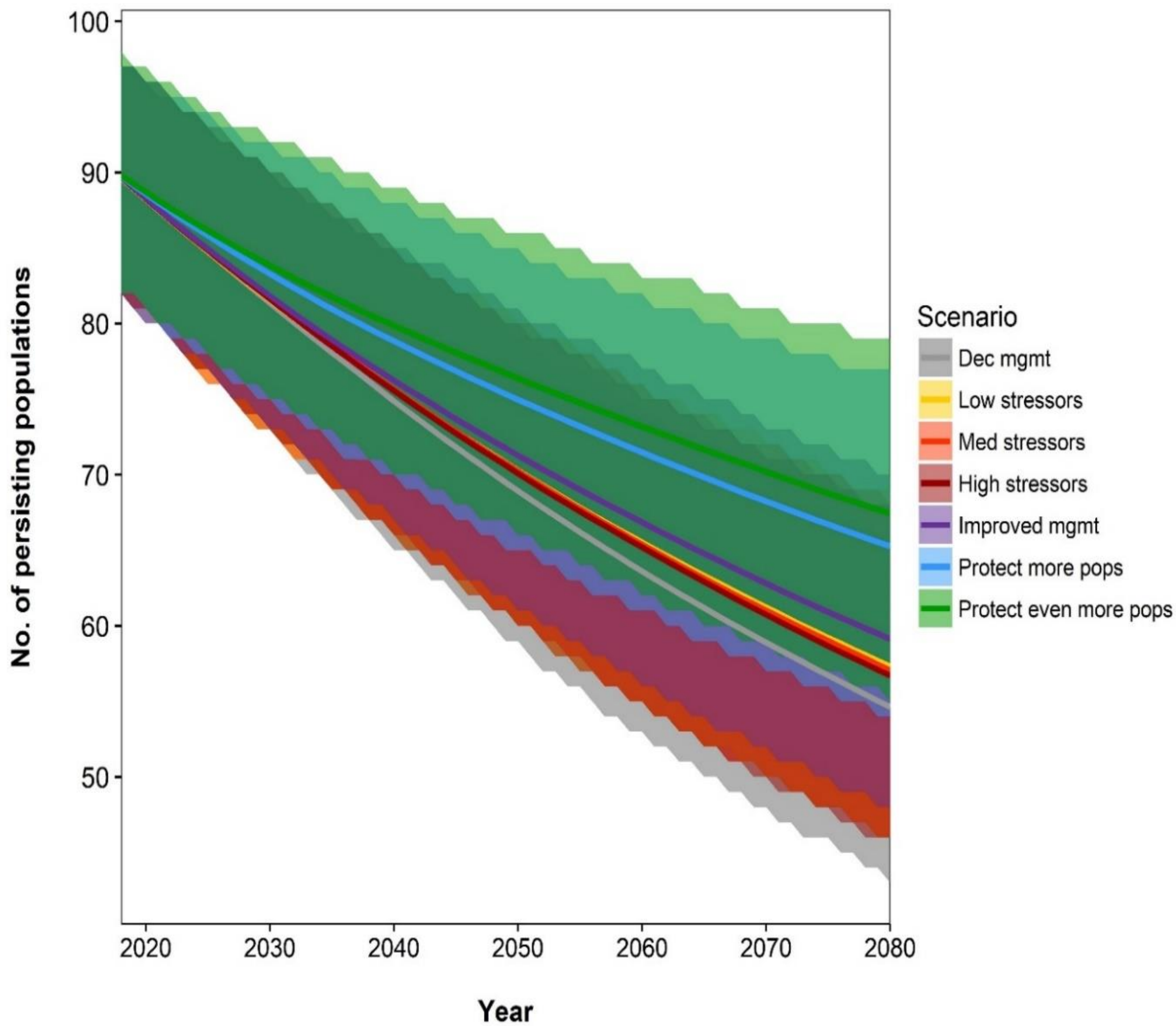

Figure 5-6. Predicted mean (± 95% confidence intervals) number of persisting southern hognose snake populations between the present year (2018) and 2080, given seven scenarios of stressors and management efforts.

Table 5-4. Number of southern hognose snake populations at or above the 50, 80, and 95% threshold of persistence probability in 2040, 2060, and 2080, for the seven scenarios, within each representative unit and range-wide. Cell shadings: Red – 0 populations meeting the persistence probability threshold; Orange – 1 or 2 populations within the persistence probability threshold.

Year - 2040	Scenario																							
	Current			Low Stressor			Med Stressor			High Stressor			Decreased Mgmt			Improved Mgmt			Protect More Pops.			Protect Even More Pops.		
Rep unit	50	80	95	50	80	95	50	80	95	50	80	95	50	80	95	50	80	95	50	80	95	50	80	95
Upper Coastal Plain (Carolinas)	11	7	3	7	3	1	7	3	1	7	3	1	7	3	1	7	3	1	8	3	1	9	3	1
Upper Coastal Plain (GA/FL)	28	25	20	25	18	4	25	18	4	25	18	4	25	17	3	25	18	4	25	19	7	26	19	7
Atl. Coastal Plain (Carolinas)	13	8	6	10	6	0	10	6	0	10	6	0	10	5	0	10	6	0	10	7	2	11	7	1
Atl. Coastal Plain (GA/FL)	2	1	1	2	1	0	2	1	0	2	1	0	2	1	0	2	1	0	2	1	0	2	1	0
FL Peninsula	14	12	6	14	5	0	14	6	0	14	6	0	14	6	0	14	6	0	14	10	1	14	10	1
FL Ridge	8	8	7	8	5	1	8	5	1	8	5	1	8	5	1	8	6	1	8	7	1	8	7	2
AL/FL Panhandle	13	7	6	10	6	2	11	6	2	11	6	2	8	6	0	11	6	4	11	7	3	12	7	4
West (AL/MS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AL Central	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Range-wide	89	68	49	76	44	8	77	45	8	77	45	8	74	43	5	77	46	10	78	54	15	82	54	16
Year - 2060	Current			Low Stressor			Med Stressor			High Stressor			Decreased Mgmt			Improved Mgmt			Protect More Pops.			Protect Even More Pops.		
Upper Coastal Plain (Carolinas)	11	7	3	4	3	0	4	3	0	4	3	0	4	3	0	4	3	0	8	3	0	9	3	0
Upper Coastal Plain (GA/FL)	28	25	20	22	12	0	22	12	0	22	12	0	22	12	0	22	13	0	24	16	2	25	17	2
Atl. Coastal Plain (Carolinas)	13	8	6	9	2	0	9	2	0	9	2	0	9	1	0	9	4	0	10	6	0	10	6	0
Atl. Coastal Plain (GA/FL)	2	1	1	1	0	0	1	1	0	1	0	0	1	0	0	1	1	0	2	1	0	2	1	0
FL Peninsula	14	12	6	12	2	0	11	2	0	11	2	0	12	2	0	12	2	0	12	3	1	12	4	1
FL Ridge	8	8	7	7	2	0	7	2	0	7	2	0	7	2	0	7	2	0	8	5	0	8	4	0
AL/FL Panhandle	13	7	6	8	6	0	8	6	0	8	6	0	7	4	0	9	6	1	9	7	1	9	7	1

	Current			Low Stressor			Med Stressor			High Stressor			Decreased Mgmt			Improved Mgmt			Protect More Pops.			Protect Even More Pops.		
West (AL/MS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AL Central	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Range-wide	89	68	49	63	27	0	62	28	0	62	27	0	62	24	0	64	31	1	74	41	4	75	42	4
Year - 2080	Current			Low Stressor			Med Stressor			High Stressor			Decreased Mgmt			Improved Mgmt			Protect More Pops.			Protect Even More Pops.		
Upper Coastal Plain (Carolinas)	11	7	3	4	2	0	4	2	0	4	2	0	4	2	0	4	2	0	6	2	0	8	2	0
Upper Coastal Plain (GA/FL)	28	25	20	21	10	0	21	10	0	21	10	0	21	8	0	21	10	0	24	13	1	24	14	2
Atl. Coastal Plain (Carolinas)	13	8	6	7	0	0	7	0	0	7	0	0	6	0	0	7	3	0	8	6	0	10	6	0
Atl. Coastal Plain (GA/FL)	2	1	1	1	0	0	1	0	0	1	0	0	1	0	0	1	1	0	1	1	0	2	1	0
FL Peninsula	14	12	6	11	1	0	11	1	0	11	0	0	11	1	0	11	1	0	11	3	0	11	3	0
FL Ridge	8	8	7	7	1	0	7	1	0	7	1	0	7	1	0	7	1	0	8	3	0	7	3	0
AL/FL Panhandle	13	7	6	6	6	0	6	6	0	6	6	0	6	2	0	7	6	0	8	7	0	8	7	0
West (AL/MS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AL Central	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Range-wide	89	68	49	57	20	0	57	20	0	57	19	0	56	14	0	58	24	0	66	35	1	70	36	2

Table 5-5. Mean number of southern hognose snake populations (Lower, Upper 95% confidence intervals) predicted to persist in 2040, 2060, and 2080, given seven scenarios of stressors and management actions, across each representative unit and range-wide.

Year - 2040					Scenario			
Rep unit	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
Upper Coastal Plain (Carolinas)	11 (8, 13)	8 (5, 11)	8 (5, 11)	8 (5, 11)	8 (5, 11)	8 (5, 11)	8 (6, 11)	9 (6, 12)
Upper Coastal Plain (GA/FL)	28 (26, 33)	25 (21, 29)	25 (21, 29)	25 (21, 29)	25 (21, 29)	25 (21, 29)	26 (22, 30)	26 (22, 30)
Atl. Coastal Plain (Carolinas)	13 (10, 15)	10 (7, 13)	10 (7, 13)	10 (7, 13)	10 (7, 13)	10 (7, 13)	11 (10, 14)	11 (8, 14)
Atl. Coastal Plain (GA/FL)	2 (2, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)
FL Peninsula	14 (12, 17)	12 (9, 16)	12 (9, 15)	12 (9, 16)	12 (9, 15)	12 (9, 16)	13 (10, 16)	13 (10, 16)
FL Ridge	8 (7, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)
AL/FL Panhandle	13 (8, 14)	9 (7, 12)	9 (7, 12)	9 (7, 12)	9 (6, 11)	9 (7, 12)	10 (7, 12)	10 (7, 12)
West (AL/MS)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
AL Central	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Range-wide	89 (73, 106)	75 (55, 95)	75 (55, 94)	75 (55, 95)	74 (54, 93)	75 (55, 95)	77 (61, 97)	79 (59, 98)
Year - 2060	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
Upper Coastal Plain (Carolinas)	11 (8, 13)	7 (4, 10)	7 (4, 10)	7 (4, 10)	7 (4, 10)	7 (4, 10)	7 (4, 10)	8 (5, 11)
Upper Coastal Plain (GA/FL)	28 (26, 33)	22 (17, 27)	22 (17, 26)	22 (17, 26)	22 (17, 26)	22 (18, 27)	24 (19, 28)	24 (20, 28)
Atl. Coastal Plain (Carolinas)	13 (10, 15)	8 (5, 12)	8 (5, 12)	8 (5, 12)	8 (4, 11)	9 (6, 12)	9 (6, 13)	10 (7, 13)
Atl. Coastal Plain (GA/FL)	2 (2, 5)	2 (1, 4)	2 (1, 4)	2 (1, 4)	2 (0, 4)	3 (1, 5)	3 (1, 5)	3 (1, 5)
FL Peninsula	14 (12, 17)	11 (7, 14)	11 (7, 14)	11 (7, 14)	11 (7, 14)	11 (7, 14)	11 (8, 15)	11 (8, 15)
FL Ridge	8 (7, 9)	6 (3, 8)	6 (3, 8)	6 (3, 8)	6 (3, 8)	6 (3, 8)	7 (4, 8)	7 (4, 8)
AL/FL Panhandle	13 (8, 14)	8 (6, 11)	8 (6, 11)	8 (6, 11)	8 (5, 10)	9 (6, 11)	9 (6, 11)	9 (7, 12)
West (AL/MS)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
AL Central	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Range-wide	89 (73, 106)	65 (43, 86)	64 (43, 85)	64 (43, 85)	63 (40, 83)	66 (45, 87)	70 (49, 91)	72 (52, 92)
Year - 2080	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
Upper Coastal Plain (Carolinas)	11 (8, 13)	6 (3, 9)	6 (3, 9)	6 (3, 9)	6 (3, 9)	6 (3, 9)	6 (3, 9)	7 (4, 10)
Upper Coastal Plain (GA/FL)	28 (26, 33)	19 (14, 24)	19 (14, 24)	19 (14, 24)	19 (14, 24)	20 (15, 24)	22 (17, 26)	22 (18, 27)

Atl. Coastal Plain (Carolinas)	13 (10, 15)	7 (4, 11)	7 (4, 11)	7 (4, 11)	6 (3, 10)	8 (4, 11)	8 (5, 12)	9 (6, 12)
Atl. Coastal Plain (GA/FL)	2 (2, 5)	2 (0, 4)	2 (0, 4)	2 (0, 4)	2 (0, 4)	2 (1, 4)	2 (1, 4)	3 (1, 4)
FL Peninsula	14 (12, 17)	9 (5, 13)	9 (5, 13)	9 (5, 13)	9 (5, 13)	9 (5, 13)	10 (7, 14)	10 (7, 14)
FL Ridge	8 (7, 9)	5 (2, 7)	5 (2, 7)	5 (2, 7)	5 (2, 7)	5 (3, 7)	6 (4, 8)	6 (4, 8)
AL/FL Panhandle	13 (8, 14)	8 (5, 10)	8 (5, 10)	8 (5, 10)	6 (4, 9)	8 (6, 11)	8 (6, 11)	9 (6, 11)
West (AL/MS)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
AL Central	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Range-wide	89 (73, 106)	56 (33, 78)	56 (33, 78)	56 (33, 78)	54 (31, 76)	58 (37, 79)	64 (44, 85)	66 (46, 86)

Cell shadings: Red – lower 95% confidence interval includes 0 populations persisting in a unit; Orange – lower 95% confidence interval includes 1 or 2 populations persisting in a unit.

5.2.4 Limitations

In any species status assessment, the process of modeling current conditions and projecting those into the future requires making strategic simplifications of reality. We must account for multiple uncertainties and make informed assumptions when necessary. The level of uncertainty is especially high for a species that is difficult to detect and as data limited as the southern hognose snake. Still, this assessment addressed some of the key uncertainties and yielded useful predictions for characterizing the species' status. Through the use of predictive models and multiple scenarios, we captured a range of possible conditions in the future. We highlight and explain some of the key limitations and assumptions of the analyses below.

Quantitative models are essential tools for capturing the dynamics of complex, ecological systems, predicting species' outcomes, and informing conservation decisions for at-risk and listed species (Morris, et al., 2002, entire; McGowan, et al., 2017, entire). We developed three types of models in our analyses, (1) a habitat suitability model, (2) a current persistence model, and (3) a future persistence model. Each one, like all models, required simplifications and assumptions about the underlying ecological systems. Our models generated specific quantitative results, but these should be interpreted as estimates rather than precise predictions of reality. For example, the results of the habitat suitability model represented areas of relatively high and low suitability based on a set of predictors; however, a specific site may have additional factors, such as presence of non-native invasive species or a history of over-collection, which we were not able to incorporate into the model.

We were not able to include all the factors that may be influencing viability for the southern hognose snake (Chapter 3) because spatial data for these stressors were not available across the species' range or at all, such as impacts from invasive feral hogs and red imported fire ants. These limitations likely did not hinder the reliability of results from the habitat suitability model since we included several of the most influential factors identified in the literature and by expert judgment as predictors – specifically, soil drainage, compatible land cover, and fire frequency. Simplifications were also made in the persistence model where we only included three predictors even though an infinite number of factors could influence population persistence locally. However, we developed all models in this assessment using the best available data and expert judgment for the southern hognose snake and its ecological systems. Despite simplifications, our approach ensured that many of the inputs believed to be most important were included in persistence models, and the results of this assessment tended to agree with expert judgment and previous studies characterizing trends in southern hognose snake habitat use and population persistence. We also projected population outcomes under multiple scenarios using the same model structure, and although there was uncertainty around all model predictions, one can consider and compare the range of plausible future conditions predicted across scenarios to effectively evaluate relative risks to the species.

We delineated 222 populations that served as the primary units for analyses, but creating these population boundaries required a set of assumptions that are important to consider when interpreting the results. Most importantly, we assumed that our full database of species records, which came from datasets maintained by State and Federal agencies and other researchers, adequately represented the distribution of southern hognose snake populations in the Southeast. While the full dataset likely captured most of the areas where southern hognose snakes occurred, it likely did not capture all locations where they occur due to the cryptic nature of the species and the lower search effort and data availability from private lands. This results in some uncertainty around the actual number of populations. We employed a transparent and collaborative process to delineate populations and develop models, and while assumptions are unavoidable, they were based on best available scientific information.
Models used in current and future conditions hinged on a novel approach to estimate persistence of populations, but we had to make several assumptions about how persistence probability was related to population resiliency. First, we assumed if the population is currently on the landscape, then it must display some level of resiliency for it to have persisted over time. Secondly, most likely larger populations will have a higher current persistence probability than smaller populations. Third, we assumed the more resilient populations are more likely to occur in highly suitable habitat, on protected lands and in proximity to other populations. Since we were able to account for these factors in our model, populations that meet these factors most likely have higher current persistence probability and therefore more resiliency.

While persistence probability is a reasonable indicator of resilience, we did not explicitly account for further dynamics within the population (e.g., increases in recruitment, abundance) or between populations (e.g., colonization rates between neighboring populations) that could influence viability. More complex models (e.g., population viability analysis) exist that directly estimate these biological processes; however, they require basic life history and demographic information that have not been estimated for southern hognose snakes. It is possible that our models are under- or overestimating persistence for certain populations by not explicitly estimating other processes like recruitment or colonization. However, biological processes like recruitment and colonization are represented, at least to some degree, in the set of predictors of annual persistence. We can assume that the predictor of HSI, which was positively related to the annual persistence probability, is also positively related to recruitment and survival rates for a population as the habitat it occupies contains more compatible land cover and forage, and fewer anthropogenic threats. Similarly, we did not explicitly estimate colonization between populations, but this process was represented by including the number of nearby populations as a predictor of a population's annual persistence probability. We also acknowledge that many – or most – population boundaries include some proportion of unsuitable habitat that, in some cases, could be causing a single population defined in our study to be functioning as several isolated subpopulations. It is likely that smaller, isolated subpopulations would each have lower growth rates and persistence probabilities than a single large population. Directly accounting for fragmentation would require fine-scale information about southern hognose snake movement capabilities through different habitat types that is not currently available. However, we found in preliminary analysis for the habitat suitability models (Appendix A) that mean HSI was related to the amount and connectivity of suitable habitat in populations; thus, we can assume that including HSI as a predictor of persistence also partially accounted for the influence of fragmentation within a boundary. Even without explicitly estimating recruitment or colonization rates, the model structure allows for populations to be stable (i.e., persist and not become extirpated over time) over time, which is useful for assessing the degree and distribution of risk of extinction for populations across the species' range. Still, improving the quality and quantity of data for southern hognose snakes in the future will greatly improve predictions of population outcomes using additional types of models.

Finally, as previously stated, the habitat suitability model was based on a set of predictors, but there are likely other important climate-related factors that were not included in the model but are likely to affect habitat suitability and population persistence. Although we did include the projected impacts of SLR to habitat suitability, there are many other probable climate change-related impacts that we were not able to model. For example, projected increases in temperature and decreases in precipitation due to climate change are likely to further constrain the ability to implement prescribed fire, which would lower habitat suitability and consequently population persistence for most, if not all, populations of southern hognose snakes. Also, projected increases in mean temperature will result in increases in soil temperature, which has the potential to negatively impact burrowing species such as the southern hognose snake. Additionally, there is a great amount of uncertainty in how the longleaf pine ecosystem will respond to climate change (e.g., range contraction vs. shifting range), and any changes in the total acreage or distribution of longleaf pine will likely impact the southern hognose snake.

5.3 Summary of Future Conditions and Viability based on Resiliency, Representation, and Redundancy

For the southern hognose snake to maintain ***viability***, it needs to have resilient populations that are able to withstand stochastic events and maintain ecological and genetic diversity, which will help preserve the breadth of adaptive capacity, and hence, the evolutionary flexibility of the species. In addition, the populations need to be spread across its range in a way that reduces the chance that a catastrophic event is not likely to lead to the species extinction.

Our analysis shows that future resiliency, as measured by future population persistence, for the southern hognose snake is predicted to decline from current conditions under all our scenarios. We considered a population to be highly resilient if it had a relatively high future population persistence probability. By 2040, only 3.6% of populations exhibit the highest degree of resiliency under the medium stressor scenario, which is the most likely scenario. By 2060, there are no populations that exhibit the highest degree of resiliency for any of the scenarios besides the scenarios where management is improved for the species. By 2080, only 2 of 222 (0.9%) historical populations exhibit the highest degree of resiliency under the highest management effort scenario. The other persistence thresholds see some variability in the number of populations remaining; however, all categories see a decrease in the number of populations within them, and there is an increase in the number of populations that are likely to become extirpated.

Our analysis shows that future representation, as measured by the number and distribution of resilient populations (i.e., those above a certain persistence probability threshold) across representative units in the species' range, will also be reduced from current conditions. To have high representation the species must have multiple highly resilient populations located in each of the representative units, and those occupied units should span the latitudinal and longitudinal extent of historical populations. As described in the current conditions, the southern hognose snake has already been extirpated from two representative units. In the future, there is high risk of the species being extirpated from a third representative unit and moderate risk of reduced representation in a fourth unit. The remaining five representative units showed declines in the number of resilient populations, but the risk of the species becoming extirpated from any unit was low. There has been a loss of latitudinal and longitudinal variability within the range, as all of the populations at the northern and western extent of its range have been extirpated.

Our analysis shows that future redundancy, as measured by the number and distribution of resilient populations within representative units and across the range of the species, will be reduced from current conditions under all scenarios tested. To have high redundancy, the species needs to have multiple resilient populations within a representative unit and throughout its range. Under all scenarios we see a reduction in the number of resilient populations within each of the units, as well as across the range of the species. In the future, the number of resilient populations decreased the most under scenarios that included no additional management effort; however, scenarios including the protection and habitat management of additional populations were predicted to maintain more resilient populations on the landscape relative to other scenarios. Additionally, the distribution of resilient populations within each of the units and across the range will become increasingly clustered as additional populations become extirpated, leaving more portions of the range lacking resilient populations.

The purpose of this assessment was to assess viability of the southern hognose snake. Our assessment shows that there have been range-wide declines for this species from its historical to current conditions, which has previously been suggested in the literature (Tuberville, et al., 2000, entire). The number of resilient populations is expected to continue to decrease in the future due to the effects of urbanization and SLR. Certain management efforts (i.e., acquiring, protecting, and managing land currently occupied by the species) may lessen the rate of population declines, but the southern hognose snake's resiliency, representation, and redundancy is expected to continue to decrease in the future.

LITERATURE CITED

Alder, J. & Hostetler, S. W., 2013. *U.S. Geological Survey, National Climate Change Viewer.* [Online] Available at: https://www2.usgs.gov/climate_landuse/clu_rd/nccv.asp [Accessed October 2018].

Allen, C. R. et al., 2000. Impact of red imported fire ant infestation on northern bobwhite quail abundance trends in southeastern United States. *Journal of Agricultural and Urban Entomology,* 17(1), pp. 43-51.

Allender, M. C. et al., 2006. Hematology, plasma biochemistry, and antibodies to select viruses in wild-caught eastern massasauga rattlesnakes (*Sistrurus catenatus catenatus*) from Illinois. *Journal of Wildlife Disease,* 42(1), pp. 107-114.

Allender, M. C., Raudabaugh, D. B., Gleason, F. H. & Miller, A. N., 2015. The natural history, ecology, and epidemiology of *Ophidiomyces ophiodiicola* and its potential impact on free-ranging snake populations. *Fungal Ecology,* Volume 17, pp. 187-196.

America's Longleaf Restoration Initiative, 2018. *American's Longleaf.* [Online] Available at: http://www.americaslongleaf.org/ [Accessed 26 November 2018].

Andrews, K. M. & Gibbons, J. W., 2005. How do highways influence snake movement? Behavioral responses to roads and vehicles. *Copeia,* pp. 772-782.

Ashley, E. P., Kosloski, A. & Petrie, S. A., 2007. Incidence of intentional vehicle-reptile collisions. *Human Dimensions of Wildlife,* Volume 12, pp. 137-143.

Ashton & Ashton, 1981. *Handbook of Reptiles and Amphibians of Florida. Part 1: The Snakes.* Miami: Windward Publishing.

Aubret, F. & Shine, R., 2010. Thermal plasticity in young snakes: how will climate change affect the thermoregulatory tactics of ecotherms?. *The Journal of Experimental Biology,* Volume 213, pp. 242-248.

Averill-Murray, R. C., 2006. Natural history of the western hog-nosed snake (*Heterodon nasicus*) with notes on envenomation. *Sonoran Herpetologist,* 19(9), pp. 98-101.

Bailey, M. A., Holmes, J. N., Buhlmann, K. A. & Mitchell, J. C., 2006. *Habitat management guidelines for amphibian and reptiles of the Southeastern United States.* Montgomery: Partners in Amphibian and Reptile Conservation Technical Publication HMG-2.

Bailey, R. G., 1983. Delineation of ecosystem regions. *Environmental Management,* 7(4), pp. 365-373.

Bailey, R. G., Jensen, M. E., Cleland, D. T. & Bourgeron, P. S., 1994. Design and use of ecological mapping units. *Ecosystem management: principles and applications. United States Department of Agriculture, Forest Service General Technical Report.,* Volume 1, pp. 95-106.

Barbour, M. S. & Litvaitis, J. A., 1993. Niche dimensions of New England cottontails in relation to habitat patch size. *Oecologia,* Volume 95, pp. 321-327.

Barrios-Garcia, M. N. & Ballari, S. A., 2012. Impact of wild boar (*Sus scrofa*) in its introduced and native range: A review. *Biological Invasions,* Volume 14, pp. 2283-2300.

Bartolotti, G., 2018. *Project Simus Florida.* [Online] Available at: http://projectsimusflorida.synthasite.com/ [Accessed 18 September 2018].

Beane, J. C., 2018. *Personal communication* [Interview] (24 October 2018).

Beane, J. C., 2019. *Personal communication* [Email] (18 April 2019).

Beane, J. C., Graham, S. P., Thorp, T. J. & Pusser, L. T., 2014. Natural history of the southern hognose snake (*Heterodon simus*) in North Carolina. *Copeia,* pp. 168-175.

Beane, J. C. & Thorp, T. J., 2007. Size and longevity records for the southern hognose snake, *Heterodon simus*. *Bulletin of the Chicago Herpetological Society,* 42(12), p. 193.

Beane, J. C., Thorp, T. J. & Alford, S. L., 2007. *Heterodon simus* (Southern Hognose Snake) hibernacula. *Herpetological Review,* 38(4), p. 467.

Beane, J. C., Thorp, T. J. & Jackan, D. A., 1998. *Heterodon simus* (Southern Hognose Snake) diet. *Herpetological Review,* 29(1), pp. 44-45.

Blate, G. M. et al., 2009. Adapting to climate change in United States national forests. *Unasylva,* Volume 60, pp. 57-62.

Bonnet, X., Naulleau, G. & Shine, R., 1999. The dangers of leaving home: dispersal and mortality in snakes. *Biological Conservation,* 89(1), pp. 39-50.

Bratton, S. P., 1975. The effect of European wild boar (*Sus scrofa*) on Gray Beech Forest in the Great Smoky Mountains. *Ecology,* 56(6), pp. 1356-1366.

Breininger, D. R. et al., 2012. Habitat fragmentation effects on annual survival of the federally protected eastern indigo snake. *Animal Conservation,* Volume 15, pp. 361-368.

Brooks, S. P., Catchpole, E. A. & Morgan, B. J., 2000. Bayesian animal survival estimation. *Statistical Science,* 15(4), pp. 357-376.

Brown, D. J., DeVolld, B., Nowlin, W. H. & Forstner, M. R., 2012. Fire ants in Houston toad habitat: annual activity and responses to canopy cover and fire. *Journal of Fish and Wildlife Management,* 3(1), pp. 142-149.

Burghardt, G. M., Murphy, J. B., Chiszar, D. & Hutchins, M., 2009. Combating ophiophobia. In: S. J. Mullin & R. A. Seigel, eds. *Snakes: Ecology and Conservation.* Ithaca and London: Cornell University Press, pp. 262-280.

Callcott, A.-M. A. & Collins, H. L., 1996. Invasion and range expansion of imported fire ants (Hymenoptera: Formicidae) in North America from 1918-1995. *The Florida Entomologist,* 79(2), pp. 240-251.

Carr, A., 1940. *Heterodon simus* (Linnaeus) Southern Hog-nosed Snake. *A contribution to the herpetology of Florida,* pp. 79-80.

Carroll, C. et al., 2010. Geography and recovery under the U.S. Endangered Species Act. *Conservation Biology,* Volume 24, pp. 395-403.

Carter, L. et al., 2018. Southeast. In: D. R. Reidmiller, et al. eds. *Impacts, Risks, and Adaptation in the United Stations: Fourth National Climate Assessment, Volume II.* Washington, D.C.: U.S. Global Change Research Program, pp. 743-808.

Center for Biological Diversity, 2012. *Petition to List 53 Amphibians and Reptiles in the United States as Threatened or Endangered Species under the Endangered Species Act,* Tucson: Petition filed July 11, 2012.

Conant, R. & Collins, J. T., 1998. *A field guide to amphibians and reptiles of eastern and central North America.* Third ed. Boston, Massachusetts: Houghton Mifflin.

Crother, B. I. (ed.), 2017. *Scientific and standard English names of amphibians and reptiles of North America north of Mexico, with comments regarding confidence in our understanding.* 8 ed. Topeka: Society for the Study of Amphibians and Reptiles.

Darracq, A. K. et al., 2017. Invasive ants influence native lizard populations. *Ecosphere,* 8(1), pp. 1-11.

Deutsch, C. A. et al., 2008. Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences,* 105(18), pp. 6668-6672.

DeWan, A., Dubois, N., Theoharides, K. & Boshoven, J., 2010. *Understanding the impacts of climate change on fish and wildlife in North Carolina*, Washington D.C.: Defenders of Wildlife Report.

Edgren, R. A., 1953. On the identity of the snake *Coluber simus* Linnaeus. *Copeia,* pp. 64-65.

Edgren, R. A., 1955. The natural history of the hog-nosed snakes, genus *Heterodon*: a review. *Herpetologica,* Volume 11, pp. 105-117.

Enge, K. M., 1997. *A Standardized Protocol for Drift-fence Surveys. Technical Report No. 14,* Tallahassee: Florida Game and Fresh Water Fish Commission.

Enge, K. M., 2004. Record clutch size for the southern hognose snake (*Heterodon simus*). *Bulletin of the Maryland Herpetological Society*, 40(2), p. 76.

Enge, K. M., 2005. Commercial harvest of amphibians and reptiles in Florida for the pet trade. In: W. E. Meshaka & K. J. Babbitt, eds. *Amphibians and reptiles: Status and conservation in Florida.* Malabar: Krieger Publishing Company, pp. 198-211.

Enge, K., Mays, J. D., Butryn, R. & Hill, E. P., 2016. *Status assessments of the southern hog-nosed snake, Florida pinesnake, short-tailed kingsnake, and eastern diamond-backed rattlesnake in Florida*, Gainesville: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute.

Enge, K. M. & Marion, W. R., 1986. Effects of clearcutting and site preparation on herpetofauna of a North Florida flatwoods. *Forest Ecology and Management,* Volume 14, pp. 177-192.

Enge, K. M. & Wood, K. N., 2002. A pedestrian road survey of an upland snake community in Florida. *Southeastern Naturalist,* 1(4), pp. 365-380.

Enge, K. M. & Wood, K. N., 2003. A pedestrian road survey of the southern hognose snake (*Heterodon simus*) in Hernando County, Florida. *Florida Scientist,* 66(3), pp. 189-203.

Ernst , C. H. & Barbour, R. W., 1989. *Snakes of Eastern North America.* Fairfax: George Mason University Press.

Ernst, C. H. & Ernst, E. M., 2003. *Snakes of the United States and Canada.* Washington D.C.: Smithsonian Books.

Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics,* Volume 34, pp. 487-515.

Florida Fish and Wildlife Conservation Commission, 2012. *Florida's State Wildlife Action Plan,* Tallahassee: Florida Fish and Wildlife Conservation Commission.

Forman, R. T. & Alexander, L. E., 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics,* Volume 29, pp. 207-231.

Frost, C., 1993. Four centuries of changing landscape patterns in the longleaf pine ecosystem. In: S. M. Herman, ed. *The longleaf pine ecosystem: ecology, restoration, and management. Tall*

Timber Fire Ecology Conference Proceedings, No. 18. Tallahassee: Tall Timbers Fire Ecology Conference Proceedings.

Frost, C. C., 1998. Presettlement fire frequency regimes of the United States: a first approximation. In: T. L. Preden & L. A. Brennan, eds. *Fire in ecosystem management: shifting the paradigm from suppression to prescription. Tall Timbers Fire Ecology Conference Proceedings, No. 20.* Tallahassee: Tall Timbers Research Station, pp. 70-81.

Georgia Department of Natural Resources (GADNR), 2015. *Georgia State Wildlife Action Plan,* Social Circle, Georgia: Georgia Department of Natural Resources.

Gibbons, J. W. et al., 2000. The global decline of reptiles, Déjà Vu Amphibians: reptile species are declining on a global scale. *BioScience,* 50(8), pp. 653-666.

Gibbons, J. W. & Semlitsch, R. D., 1987. Activity Patterns. In: R. A. Seigel, J. T. Collins & S. S. Novak, eds. *Snakes: Ecology and Evolutionary Biology.* Caldwell: The Blackburn Press, pp. 396-421.

Gibbons, W. & Dorcas, M., 2005. *Snakes of the Southeast.* Athens: University of Georgia Press.

Gibbs, J. P. et al., 2007. *The amphibians and reptiles of New York State: identification, natural history, and conservation.* London: Oxford University Press.

Glitzenstein, J. S. & Wade, D. D., 2003. Fire frequency effects on longleaf pine (*Pinus palustris* P. Miller) vegetation in South Carolina and Northeast Florida, USA. *Natural Areas Journal,* 23(1), pp. 22-37.

Glor, R. E., Flecker, A. S., Benard, M. F. & Power, A. G., 2001. Lizard diversity and agricultural disturbance in a Caribbean forest landscape. *Biodiversity and Conservation,* Volume 10, pp. 711-723.

Goin, C. J., 1947. A note on the food of *Heterodon simus*. *Copeia,* p. 275.

Hansen, K. L., 1958. Breeding pattern of the eastern spadefoot toad. *Herpetologica,* 14(2), pp. 57-67.

Hayhoe, K. et al., 2018. Our Changing Climate. In: D. R. Reidmiller, et al. eds. *Impacts, Risks, and Adaptation in the United Stations: Fourth National Climate Assessment, Volume II.* Washington, D.C.: U.S. Global Change Research Program, pp. 72-144.

HerpMapper, 2018. *HerpMapper - A Global Herp Atlas and Data Hub.* [Online] Available at: http://www.herpmapper.org [Accessed November 2018].

Holbrook, J. E., 1842. *North American herpetology; or a description of the reptiles inhabiting the United States.* Philadelphia: J. Dobson.

Huey, R. B., Losos, J. B. & Moritz, C., 2010. Are lizards toast? *Science*, Volume 328, pp. 832-833.

Integrated Taxonomic Information System, 2017. *Heterodon Latreille in Sonnini and Latreille, 1801*. [Online] Available at: https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=174153#null [Accessed 30 November 2018].

IPCC, 2013. Summary for Policymakers. In: T. F. Stocker, et al. eds. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, pp. 3-29.

Jensen, J. B., 1996. *Heterodon simus* (southern hognose snake). Hatchling size. *Herpetological Review,* Volume 27, p. 25.

Jensen, J. B., Camp, C. D., Gibbons, J. W. & Elliot, M. J., 2008. *Amphibians and Reptiles of Georgia.* Athens: University of Georgia Press.

Jolley, D. B. et al., 2010. Estimate of herpetofauna depredation by a population of wild pigs. *Journal of Mammalogy,* 91(2), pp. 519-524.

Kanowski, J. J., Reis, T. M., Catterall, C. P. & Piper, S. D., 2006. Factors affecting the use of reforested sites by reptiles in cleared rainforest landscapes in tropical and subtropical Australia. *Restoration Ecology,* Volume 14, pp. 67-76.

Kearney, M. R., Porter, W. & Shine, R., 2009. The potential for behavioral thermoregulation to buffer 'cold-blooded' animals against climate warming. *Proceedings of the National Academy of Sciences*, 106(10), pp. 3835-3840.

Kelley, L. G., 2011. *The embeddedness of hog-nosed snakes (Heterodon spp.) in the wildlife pet trade and the relevance of assemblage geographies for reptile conservation. Master's thesis.* Tallahassee: Florida State University.

Kéry, M. et al., 2009. Trend estimation in populations with imperfect detection. *Journal of Applied Ecology*, 46(6), pp. 1163-1172.

Kéry, M. & Schaub, M., 2012. *Bayesian population analysis using WinBUGS: a hierarchical perspective.* San Diego: Academic Press.

Kjoss, V. A. & Litvaitis, J. A., 2001. Community structure of snakes in a human-dominated landscape. *Biological Conservation,* Volume 98, pp. 285-292.

Knapp, L. A., Estes, B. L. & Skinner, D. N., 2009. *Ecological Effects of Prescribed Fire Season: A Literature Review and Synthesis for Managers,* Albany: United States Department of Agriculture, Forest Service.

Landers, J. L., Van Lear, D. H. & Boyer, W. D., 1995. The longleaf pine forests of the Southeast: requiem or renaissance? *Journal of Forestry,* 93(11), pp. 39-44.

Langkilde, T., 2009. Invasive fire ants alter behavior and morphology of native lizards. *Ecology,* 90(1), pp. 208-217.

Lebreton, J.-D., Burnham, K. P., Clobert, J. & Anderson, D. R., 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. *Ecological Monograhps,* 62(1), pp. 67-118.

LeBrun, E. G., Plowes, R. M. & Gilbert, L. E., 2012. Imported fire ants near the edge of their range: distrubance and moisture determine prevalence and impact of an invasive social insect. *Journal of Animal Ecology,* Volume 81, pp. 884-895.

Lorch, J. M. et al., 2016. Snake fungal disease: an emerging threat to wild snakes. *Philosophical Transactions Royal Society B,* 371(1709), p. 20150457.

Lorch, J. M. et al., 2015. Experimental infection of snakes with *Ophidiomyces ophiodiicola* causes pathological changes that typify snake fungal disease. *mBio,* 6(6), pp. e01534-15.

MacKenzie, D. I. et al., 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology,* 82(8), pp. 2248-2255.

Martin, M., 2018. *Personal communication* [Interview] (29 October 2018).

McAlister, W. H., 1963. Evidence of mild toxicity in the saliva of the hognose snake (*Heterodon*). *Herpetologica,* 19(2), pp. 132-137.

McClure, M. L. et al., 2015. Modeling and mapping the probability of occurrence of invasive wild pigs across the contiguous United States. *PloS one,* 10(8), p. e0133771. doi:10.1371/.

McGowan, C. P. et al., 2017. Incorporating population viability models into species status assessment and listing decisions under the U.S. Endangered Species Act. *Global Ecology and Conservation,* Volume 12, pp. 119-130.

McGowan, C. P. et al., 2014. Establishing endangered species recovery criteria using predictive simulation modeling. *Biological Conservation,* Volume 177, pp. 220-229.

McKinney, M. L., 2002. Urbanization, biodiversity, and conservation. *Bioscience,* Volume 52, pp. 883-890.

McNulty, S. et al., 2013. Forests and Climate Change in the Southeast USA. In: K. T. Ingram, K. Dow, L. Carter & J. Anderson, eds. *Climate of the Southeast United States.* Washington D.C.: Island Press, pp. 165-189.

Means, D. B., 2005. Pine silviculture. In: M. Lannoo, ed. *Amphibian declines.* Berkeley: University of California Press, pp. 139-145.

Meylan, P. A., 1985. *Heterodon simus* (Linnaeus) Southern Hognose Snake. *Catalogue of American Amphibians and Reptiles,* pp. 375.1-375.2.

Morris, W. F. et al., 2002. Population viability analysis in endangered species recovery plans: Past use and future improvements. *Ecological Applications,* Volume 12, pp. 708-712.

Mount, R. H., 1981. The red imported fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae), as a possible serious predator on some native southeastern vertebrates: direct observation and subjective impressions [reptiles and birds]. *Journal of the Alabama Academy of Science,* 52(1), pp. 71-78.

National Oceanic and Atmospheric Administration (NOAA), 2018. *Sea Level Rise Viewer.* [Online] Available at: https://coast.noaa.gov/slr/ [Accessed 15 November 2018].

NatureServe, 2018. *NatureServe Explorer.* [Online] Available at: http://explorer.natureserve.org [Accessed 4 December 2018].

Noel, J. M., Platt, W. J. & Moser, E. B., 1998. Structural characteristics of old- and second-growth stands of longleaf pine (*Pinus palustris*) in the Gulf coastal region of the U.S.A. *Conservation Biology,* Volume 12, pp. 533-548.

North Carolina Wildlife Resources Commission, 2015. *North Carolina Wildlife Action Plan,* Raleigh: North Carolina Wildlife Resources commission.

Noss, R. F., 2013. *Forgotten grasslands of the South: natural history and conservation.* Washington D.C.: Island Press.

Palmer, W. M. & Braswell, A. L., 1995. *Reptiles of North Carolina.* Chapel Hill: The University of North Carolina Press.

Petersen, C. E., Lovich, R. E. & Stallings, S. A., 2017. *Amphibian and Reptile Biodiversity on United States Department of Defense Installations,* Washington D.C: Department of Defense Legacy Resource Management Program.

Pickens, B. A. et al., 2017. The effect of urban growth on landscape-scale restoration for a fire-dependent songbird. *Journal of Environmental Management,* Volume 191, pp. 105-115.

Platt, D. R., 1969. *Natural history of the hognose snakes Heterodon platyrhinos and Heterodon nasicus.* Lawrence: University of Kansas.

Prestemon, J. P. & Abt, R. C., 2002. Timber products supply and demand. In: D. N. Wear & J. G. Greis, eds. *Southern forest resource assessment. General technical report SRS-53.* Asheville: U.S. Department of Agriculture, Forest Service, Southern Research Station, pp. 299-325.

Price, A. H., 1990. *Phrynosoma cornutum* (Harlan) Texas Horned Lizard. *Catalogue of American Amphibians and Reptiles,* pp. 469.1- 469.7.

Price, W. H. & Carr, L. G., 1943. Eggs of *Heterodon simus*. *Copeia,* p. 193.

Redford, K. H. et al., 2011. What does it mean to successfully conserve a (vertebrate) species?. *Bioscience,* Volume 61, p. 39–48.

Reinert, H. K. et al., 2011. Response of timber rattlesnakes to commercial logging operations. *Journal of Wildlife Management*, 75(1), pp. 19-29.

Roe, J. H., Gibson, J. & Kingsbury, B. A., 2006. Beyond the wetland border: Estimating the impact of roads for two species of water snakes. *Biological Conservation,* Volume 130, pp. 161-168.

Rosen, P. C. & Lowe, C. H., 1994. Highway mortality of snakes in the Sonoran desert of Southern Arizona. *Biological Conservation,* Volume 68, pp. 143-148.

Rossi, J. & Rossi, R., 1991. Notes on the captive reproduction of the southern hognose snake, *Heterodon simus*. *Bulletin of Chicago Herpetological Society,* 26(12), pp. 265-266.

Row, J. R., Blouin-Demers, G. & Weatherhead, P. J., 2007. Demographic effects of road mortality in black ratsnakes (*Elaphe obsoleta*). *Biological Conservation,* 137(1), pp. 117-124.

Scheele, B. C. et al., 2019. Amphibian fungal panzootic causes catastrophic and ongoing loss of biodiversity. *Science,* Volume 363, pp. 1459-1463.

Scott, D., 1986. Notes of the eastern hognose snake, *Heterodon platyrhinos* Latreille (Squamata: Colubridae), on a Virginia barrier island. *Brimleyana,* pp. 51-55.

Shepard, D. B., Dreslik, M. J., Jellen, B. C. & Phillips, C. A., 2008. Reptile road mortality around an oasis in the Illinois corn desert with emphasis on the endangered eastern massasauga. *Copeia,* Volume 2, pp. 350-359.

Simberloff, D., 1993. Species-area and fragmentation effects on old growth forests: prospects for longleaf pine communities. In: S. M. Hermann, ed. *The longleaf pine ecosystem: ecology, restoration, and management. Tall Timber Fire Ecology Conference Proceedings, No. 18.* Tallahassee: Tall Timber Research Station, pp. 1-14.

Sinervo, B. et al., 2010. Erosion of lizard diversity by climate change and altered thermal niches. *Science,* Volume 328, pp. 894-899.

Smith, L., 2018. *Personal communication* [Interview] (1 November 2018).

South Carolina Department of Natural Resources, 2015. *South Carolina's State Wildlife Action Plan (SWAP) and Supplemental Volume,* Columbia: South Carolina Department of Natural Resources.

Stevenson, D. J., Enge, K. M. & Keller, W. S., 2018. *Heterodon simus* (Southern Hog-nosed Snake). Use of pocket gopher mounds and gopher tortoise burrows. *Herpetological Review,* 49(3), pp. 547-548.

Sutherland, R. W., 2009. *The Effects of Urbanization on Reptiles and Amphibians in the Sandhills Region of North Carolina. Dissertation.* Durham: Duke University.

Taylor, R. B. & Hellgren, E. C., 1997. Diet of feral hogs in the western south Texas plains. *The Southwestern Naturalist,* 42(1), pp. 33-39.

Terando, A. J. et al., 2014. The Southern Megalopolis: Using the Past to Predict the Future of Urban Sprawl in the Southeast U.S. *PLoS One,* 9(7), p. e102261.

Theobald, D. M. & Romme, W. H., 2007. Expansion of the US wildland–urban interface. *Landscape and Urban Planning,* Volume 83, pp. 340-354.

Thompson, N. E., Lankau, E. W. & Rogall, G. M., 2018. *Snake fungal disease in North America - U.S. Geological Survey updates: U.S. Geological Survey Fact Sheet 2017-3064.* [Online] Available at: https://doi.org/10.3133/fs20173064 [Accessed 31 October 2018].

Todd, B. D. & Andrews, K. A., 2008. Response of a reptile guild to forest harvesting. *Conservation Biology,* Volume 22, pp. 753-761.

Todd, B. D. et al., 2008. Habitat alteration increases invasive fire ant abundance to the detriment of amphibians and reptiles. *Biological Invasions,* Volume 10, pp. 539-546.

Todd, B. D., Willson, J. D. & Gibbons, J. W., 2010. The global status of reptiles and causes of their decline. In: S. Krest, ed. *Ecotoxicology of Amphibians and Reptiles.* Second ed. Pensacola: CRC Press, pp. 47-67.

Tuberville, T., 2018. *Personal communication* [Interview] (24 October 2018).

Tuberville, T. D. et al., 2000. Apparent decline of the southern hog-nosed snake, *Heterodon simus*. *The Journal of the Elisha Mitchell Scientific Society,* 116(1), pp. 19-40.

Tuberville, T. D. & Jensen, J. B., 2008. Southern hognose snake. In: J. B. Jensen, C. D. Camp, W. Gibbons & M. J. Elliott, eds. *Amphibians and Reptiles of Georgia.* Athens: University of Georgia Press, pp. 356-358.

U.S. Census Bureau, 2017. *TIGER/Line Shapefiles.* [Online] Available at: https://www.census.gov/geo/maps-data/data/tiger-line.html [Accessed 1 October 2018].

U.S. Fish and Wildlife Service, 2016. *USFWS Species Status Assessment Framework: an integrated analytical framework for conservation. Version 3.4 dated August 2016.*, Washington D.C.: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service, Florida Armory Board & Florida Fish and Wildlife Conservation Commission, 2017. *Candidate Conservation Agreement with Assurances for Multiple At-Risk Species in North Florida, Camp Blanding Joint Training Center,* Atlanta: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service, Florida Fish and Wildlife Conservation Commission & Georgia Department of Natural Resources, 2018. *Quail Country Candidate Programmatic Candidate Conservation Agreement with Assurances (CCAA) for North Florida and Southwest Georgia.* Atlanta: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service & South Carolina Department of Natural Resources, 2019. *DRAFT - South Carolina's Southern Pinelands Programmatic Candidate Conservation Agreement with Assurances,* Atlanta: U.S. Fish and Wildlife Service.

U.S. Geological Survey, 2016. *National Hydrography Dataset.* [Online] Available at: https://www.usgs.gov/core-science-systems/ngp/national-hydrography [Accessed 1 October 2018].

United States Department of Agriculture, 2017. *Imported Fire Ant and Household Insects Research: Gainesville, Florida.* [Online] Available at: https://www.ars.usda.gov/southeast-area/gainesville-fl/center-for-medical-agricultural-and-veterinary-entomology/imported-fire-ant-and-household-insects-research/docs/potential-united-states-range-expansion-of-the-invasive-fire-ant/ [Accessed 2017].

Vanek, J. P. & Wasko, D. K., 2017. Spatial ecology of the eastern hog-nosed snake (*Heterodon platirhinos*) at the northeastern limit of its range. *Herpetological Conservation and Biology,* 12(1), pp. 109-118.

Ware, S., Frost, C. & Doerr, P., 1993. Southern mixed hardwood forest: the former longleaf pine forest. In: W. H. Martin, S. G. Boyce & A. C. Echternacht, eds. *Biodiversity of the southeastern United States: upland terrestrial communities.* New York: Wiley, pp. 447-493.

Webb, J. K. & Shine, R., 1997. A field study of spatial ecology and movements of a threatened snake species, *Hoplocephalus bungaroides*. *Biological Conservation,* Volume 82, pp. 203-217.

Weinstein, S. A. & Keyler, D. E., 2009. Local envenoming by the Western hognose snake (*Heterodon nasicus*): A case report and review of medically significant *Heterodon* bites. *Toxicon,* 54(3), pp. 354-360.

Whitaker, P. B. & Shine, R., 2000. Sources of mortality of large elapid snakes in an agricultural landscape. *Journal of Herpetology,* Volume 34, pp. 121-128.

Wiens, J. A., 1994. Habitat fragmentation: island v landscape perspectives on bird conservation. *IBIS,* Volume 137, pp. S97-S104.

Wilcox, E. & Giuliano, W. M., 2014. *Red imported fire ants and their impacts on wildlife.* Gainesville: Florida Cooperative Extension Service, Institute of Food and Agricultural Science, University of Florida. WEC 207.

Willson, J. D., Pittman, S. E., Beane, J. C. & Tuberville, T. D., 2018. A novel approach for estimating densities of secretive species from road-survey and spatial-movement data. *Wildlife Research,* 45(5), pp. 446-456.

Wilson, E. O., 1951. Variation and adaptation in the imported fire ant. *Evolution,* 5(1), pp. 68-79.

Winter, G. J., Vogt, C. & Fried, J. S., 2002. Fuel treatments at the wildland-urban interface: common concerns in diverse regions. *Journal of Forestry,* Issue January/February, pp. 15-21.

Appendix A: Habitat Analysis Report

Habitat suitability analysis for southern hognose snake (*Heterodon simus*) Species Status Assessment (SSA)

April 2019

In a nutshell:

- We used southern hognose snake records and available habitat/landscape data layers in a Geographic Information System (GIS) to 1) identify habitat features that best predict species presence and 2) estimate the amount and distribution of potential suitable habitat across the species' range under current conditions. The results were used to model future changes in habitat conditions and population persistence for southern hognose snakes under scenarios of stressors and management effort in a subsequent analysis (see Appendix B).
- Model results show habitat suitability is strongly influenced by the amount of well-drained soil, compatible land cover, and fire interval.
- The spatial distribution of potential suitable habitat under current conditions highlights known species strongholds.
- Range-wide, we estimated 25.6 and 13.4 thousand km^2 of moderately and highly suitable habitat, respectively; 28% and 36% of moderately and highly suitable habitat, respectively, currently exists in patches larger than 1 km^2 on managed public and protected lands.

1. Introduction

1.1 Background and objectives

The southern hognose snake (*Heterodon simus*) is a small terrestrial species found in the Coastal Plain region in southeastern North Carolina, South Carolina, Georgia, Florida, west to Alabama and Mississippi. It is associated with xeric longleaf pine (*Pinus palustris*) savanna, flatwoods and sandhill habitats that are typically fire-maintained with well-drained, sandy soil, low canopy cover, and adequate herbaceous ground cover. Several of these systems have been impacted by anthropogenic land uses, especially longleaf pine forests, which have declined by 97% across their historical range (Outcalt and Sheffield 1996, entire).

This study developed habitat suitability models – using southern hognose snake records and available habitat/landscape data layers in a Geographic Information System (GIS) – to identify habitat features that best predict species presence and predict the amount and distribution of potentially suitable habitat across its current range. Habitat suitability models (sometimes called species distribution models) measure environmental and landscape attributes (e.g., soil characteristics, canopy cover, fragmentation, temperature) in places where a species is known to occur and map where similar conditions occur across its range (Boyce et al. 2002, entire ; Engler et al. 2004, entire; Elith and Leathwick 2009, entire). We use model results to understand relationships between environmental attributes and species presence and produce maps showing the amount and distribution of potentially suitable habitat under current conditions to inform further assessment.

1.2 Analysis area

The extent of the habitat suitability analysis differs slightly from the full species range shown in the main SSA document. The boundary of our analysis (Fig A-1) encompassed all records found since 1980 (see methods and justification below), and it does not extend to areas in central Alabama and eastern North Carolina that contain only historic records and are included in the full species range. Therefore, the actual southern hognose snake distribution may extend beyond the boundary used.

2. Methods

2.1 Species and environmental data

To develop habitat suitability models (HSMs), we first compiled a geospatial database of occurrence records (presence points) for southern hognose snakes. We compiled species records (Table A-1) from datasets maintained by Natural Heritage Programs, USFWS, USFS, DoD, State agencies, academic researchers, and HerpMapper – an online platform where species records are reported by the public and validated by professional herpetologists (HerpMapper 2018, unpaginated). Records included opportunistic sightings, as well as observations from systematic research and monitoring studies. From the full location dataset, we removed any record before 1980 and any record that was ranked by data managers (e.g., State agencies, Natural Heritage Programs) as extirpated, which typically signified the location has been developed since the animal was observed. These data filtering steps maximized the likelihood that all presence points used in the model indicated places currently occupied by southern hognose snakes. To reduce potential biases that can result from spatially-clustered localities, we randomly removed records so that no two records of the species occurred within 150 m of each other.

Because robust absence data do not currently exist for this species, we used an HSM approach that uses random (i.e., pseudo-absence or "background") points across a species' range to compare the range and variation of available habitat to the subset of habitat conditions found at known species locations. This approach has been applied successfully to various wildlife contexts, including those focused on conservation assessments of rare species (e.g., Engler et al. 2004, entire; Barrett et al. 2014, entire). We conducted an expert elicitation exercise where species experts identified areas in their region where they believed species were (1) present or (2) absent (but for which we did not have data) using Google Earth. We then generated background points randomly across the species' range with a higher proportion in "expert-absence" areas and no points in "expert-presence" areas. Additionally, we accounted for potential bias toward road sampling that can impact HSM results. We used the TIGER US road dataset (https://www.census.gov/geo/maps-data/data/tiger-line.html) to identify the proportion of presence points located on or within 30 m from roads and then used the road layer as a mask to generate an approximately equal proportion of background points on roads.

We gathered important environmental and landscape attributes (hereafter, predictors) that were expected to relate to southern hognose snake natural history based on previous studies and expert input. We obtained spatial data in the form of 30-m rasters for 19 predictors and grouped these into six categories: 1) geographic ecoregions, 2) edaphic (soil) factors, 3) vegetation, 4) disturbance and connectivity, 5) climate, and 6) topography (Table A-2). We "smoothed" several predictors by measuring average conditions within neighborhoods of 90 to 900 m because species presence may be influenced by conditions at larger scales (e.g., within a home range). Using this method assigns average conditions in a neighborhood to the cell at its center. We briefly describe predictor processing details below for each predictor category.

1) *Ecoregion.* Experts agreed the breadth of habitats used by southern hognose snakes varies geographically across its range, so we incorporated EPA level IV ecoregions as a blocking variable to account for regional variation. We adjusted the original EPA IV ecoregions by dividing them by the Savannah and Chattahoochee Rivers and merging several groups of adjacent ecoregions that 1) had similar ecological characteristics and/or 2) did not have sufficient numbers of species locations to be considered separate ecoregions in models. These steps yielded a final set of 7 ecoregion groups (Fig A-1) that each had a minimum of 25 presence points to aid model fitting. We note that these ecoregion groups differ slightly from the representative units described in the main SSA document (see Fig A-1).
2) *Edaphic factors.* We created soil predictors using gridded SSURGO (raster) data from NRCS and joined appropriate tables in the SSURGO dataset to display soil drainage class. We reclassified the categorical drainage class layer where well-drained classes = 1, moderately-drained classes = 0.5, and poorly-drained classes = 0, and we performed smoothing on the reclassified raster.
3) *Vegetation.* We created a layer representing compatible land cover types by reclassifying the National Land Cover Dataset where evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, and barren land = 1 (compatible) and all other types = 0. We used the recently-developed Florida Cooperative Land Cover Dataset (FLCLC) (http://myfwc.com/research/gis/applications/articles/fl-land-cover-classification/), which includes more and finer-resolution land cover classes (235, compared to 16 classes in the NLCD), to better characterize compatible habitat for the species in FL. We had FL species experts specify compatible FLCLC types (Table A-2.1) and merged the reclassified the FLCLC raster with the NLCD-derived raster across other states in the species range to create the final land cover layer. In addition to land cover, we included tree canopy cover and Enhanced Vegetation Index as predictors to capture vegetation conditions. We used the Landsat 8 Enhanced Vegetation Index (EVI) product to identify seasonal spectral characteristics of vegetation across the southeast. We used the Climate Engine Portal (http://clim-engine.appspot.com/#) to download rasters of mean

summer and winter EVI by querying Landsat images taken between 1 May to 31 July (1999-2016) and 1 Dec and 27 Feb (1999-2016), respectively. Lastly, we created a deciduous index raster by subtracting mean winter EVI from summer EVI and dividing by the maximum annual EVI; EVIdec = (EVIsum – EVIwin) / max(EVIsum, EVIwin).

4) *Disturbance and connectivity*. We developed a fire frequency predictor by combining two spatial datasets. First, we obtained MODIS data of annual fire detections from 2001-2016 as 1km^2 fire areas. We used annual rasters to calculate the proportion of years an area has burned within the 16-year period. MODIS data often does not detect low-intensity burns used in managing coastal plain forests, and experts noted that some areas known to be managed with prescribed burning were not represented in this dataset. Therefore, we obtained LANDFIRE fuel disturbance data, which shows areas burned within the past 10 years, assigned a value of 0.1 (burned once per 10 years) to these cells, and created a final fire frequency layer where cells were assigned the maximum value of the MODIS and LANDFIRE-derived rasters. We created an edge density predictor layer to represent degree of habitat fragmentation using GRASS GIS 7.2 (Neteler and Mitasova 2013, entire). We calculated edge density as the ratio of edge length to area of the compatible land cover layer using a 15- and 30-cell moving window.
5) Climate. We used the Climate Engine Portal to download rasters summarizing climatic conditions in a 30-year period (1981-2010). We obtained raster data for mean maximum summer temperature, mean minimum winter temperature, and mean annual, summer, and winter precipitation. We defined the summer period as 1 June through 31 Aug and the winter period between 1 Dec through 27 Feb. Climatic rasters were available at a 4-km resolution, and we resampled all rasters to 30-m resolution to align with all other predictors.
6) Topography. We created topographic predictors using a 30-m raster of the USGS Digital Elevation Model (DEM). We used the DEM to derive slope and Topographic Position Index (TPI) from the DEM raster. TPI represents a location's relative elevation to its local surroundings; positive TPI generally indicates ridges (or in the coastal plain, high sandhills), and negative TPI indicates valleys. We calculated TPI by subtracting the mean DEM in a 500-m radius neighborhood from the DEM of cell.

2.2 Modeling procedures and summarizing habitat suitability

We built HSMs using generalized linear models (logistic regression) where the presence (1) or absence (0) of southern hognose snakes is the response variable influenced by a set of predictor variables at a location. The predicted probability of presence is used as a habitat suitability index (HSI) ranging from 0 (unsuitable) to 1 (most suitable habitat). We followed standard modeling practices for presence-background HSMs: we tested predictors for multicollinearity, performed model comparison to select the combination of predictors that best fit the data (Burnham and Anderson 2002, entire), and conducted model validation to measure overall performance and accuracy of predictions. Specifically, we performed model selection in two stages to identify the set of predictors that best fit the data. Because species experts suspected species-habitat relationships vary from ecoregion to ecoregion, we subsetted the data and performed model selection for each of the seven ecoregion groups. In the first stage, we performed model selection for single variables derived at multiple scales (e.g., soil drainage) where we compared the 90, 450, and 900-m neighborhoods to identify the best-supported scale. In the second stage, we used the full set of predictors at their best-supported scales and performed backwards step-wise regression where predictor effects in the model are dropped if it improves model fit (AIC_c: Burnham and Anderson 2002, p. entire). We used the best-fitting models for each ecoregion group to predict and map habitat suitability across the species' range.

We used 5-fold cross-validation to test the best-fitting model's performance (Boyce et al. 2002, entire; Johnson et al. 2006, entire), and recorded several evaluation statistics using the ROCR package. We calculated the area under the curve (AUC), obtained by the receiver-operating characteristic plot method (Fielding and Bell 1997, entire), where values of 0.5 indicate model performance no better than random and values >0.7 indicate the model can acceptably discriminate between sites where the species is present or absent. We calculated sensitivity (the proportion of correctly classified presences), specificity (the proportion of correctly classified pseudo-absences), the True Skill Statistic (TSS = sensitivity + specificity – 1; Allouche et al. 2006, entire), and optimal cutoff value (resulting in the highest TSS). Lastly, we evaluated the influence of individual predictors on habitat suitability. We used hierarchical partitioning analysis (Mac Nally 2002, entire) through the hier. part package to measure percentage of variance explained by individual predictors.

To aid map users in interpreting patterns of suitable habitat, we converted the continuous HSI to classes of Unsuitable (HSI = 0 – 0.24), Low (HSI = 0.25 – 0.39), Moderate (HSI = 0.4 – 0.59), and High Suitability (HSI = 0.6 – 1). The threshold value separating low and moderate suitability classes was chosen because it resulted in highest model accuracy (presences and pseudo-absences correctly classified as suitable vs. unsuitable habitat, respectively) during cross-validation procedures. We chose thresholds for low and high suitability classes to examine patterns of habitat suitability using more inclusive or restrictive criteria. We created a version of the habitat suitability map that only showed suitable patches >100-ha (1-km^2) in size since conservation practitioners may be interested in larger areas that could support viable populations and be managed more efficiently than smaller patches. Using these maps, we summarized the area of habitat by suitability class at representative unit- and range-wide scales. Using the >100-ha patch map, we further summarized habitat by its current protection status to inform partners of the degree of conservation assurances and potential opportunities. Patches of suitable habitat were classified as "protected" if they were contained within areas included in the USGS Protected Areas Database (http://www.protectedlands.net/), FNAI Conservation Lands Database (http://fnai.org/conservationlands.cfm), GADNR Conservation Lands Database (https://glcp.georgia.gov/), and/or NCNHP Managed Areas Database (https://www.ncnhp.org/activities/conservation/managed-areas). These areas include publicly-owned and managed lands as well as private lands registered in state or federal programs where natural resource conservation is one of the management goals.

We performed spatial analyses in ArcGIS version 10.4 (ESRI, Redlands, CA) and statistical analyses in R version 3.1.

3. Results & Discussion

3.1 Influence of environmental predictors on habitat suitability

We used 1,113 southern hognose snake presence records and 4,424 pseudo-absences (Table A-1) for modeling habitat suitability. HSMs performed well (means across ecoregion models: AUC = 0.91, sensitivity = 0.84, specificity = 0.85) and showed relatively high degrees of accuracy. Together, models classified 86.0% of presence and pseudo-absence points correctly as suitable/unsuitable habitat across the species' range. In addition to ecoregion group, six predictors significantly influenced habitat suitability and were included in the final models, and we present estimates for effects between predictors and habitat suitability in Table A-3. We note that a few predictors were not significant ($0.05 < p < 0.15$) but were kept in final models because removing them resulted in poorer overall model fit. For all "smoothed" predictors, the versions created using the largest scale (900x900-m) performed best and were included in the final model. Soil drainage, compatible land cover, mean summer precipitation, and fire frequency had the highest percentage contributions (50.4%, 23.4%, 20.8%, and 12.6%, respectively; Table A-3) for predicting habitat suitability. Although the degree of their influence varied across ecoregion (Fig A-2), habitat suitability was positively associated with well-drained, sandy soils, compatible land cover, and fire frequency. These relationships agree with previous studies and expert opinion that the species generally favors fire-dependent, xeric habitat that is locally elevated (e.g., longleaf pine sandhills). For example, predicted suitability reached its peak in most ecoregions when fire frequency was between 0.5 and 0.25, corresponding to fires occurring once every 2 to 4 years, respectively. This fire return interval aligns well with recommendations of State managers and species experts regarding frequency of prescribed burning in upland habitats. Relationships between other predictors and HSI varied across ecoregions and could support that species habitat needs vary geographically, which warrants further study and consideration when conducting localized management. Because there was a modest degree of correlation between average precipitation and ecoregion, the relationships between precipitation and habitat suitability may be spurious and should be interpreted with caution. Further analysis will be required to account for spatial-autocorrelation with this and other climate data and better evaluate relationships between climate predictors and species distributions.

3.2 Results and discussion: Spatial patterns of habitat suitability

We present summarized metrics of suitable habitat by representative unit and range-wide in Table A-4 and range-wide suitability maps in Fig A-3. Predicted areas of higher habitat suitability tended to accurately highlight known species strongholds, such as National Forests, DoD lands, and other conservation lands, but results also highlighted additional unprotected areas of high suitability. The model predicted large patches of suitable habitat that occurred on protected lands with known recent records (since 2000) of southern hognose snakes in the following areas: Fort Bragg and Sandhills Game Land (NC), Carolina Sandhills National Wildlife Refuge and Savanah River Site (SC), Fort Gordon, Fort Stewart, Fort Benning, and Jones Ecological Research Center (GA), and Eglin Air Force Base, Apalachicola National Forest, and Withlacoochee State Forest (FL). Areas of potentially suitable habitat were sparse in AL and MS. For each representative unit, between 7 and 47% of moderately suitable habitat in >100-ha patches were predicted to exist on currently protected lands, with 28% of large, moderately suitable patches protected range-wide; between 17 and 59% of highly suitable habitat likely exists on protected lands for each representative unit, with 36% protected range-wide. Unsurprisingly, the lowest amount of suitable habitat was predicted for the western representative unit (AL and MS) where the species has not been observed since 1981. The upper coastal plain representative units in the Carolinas and GA/FL were predicted to have the largest amounts of suitable habitat among representative units.

The amount and distribution of currently protected suitable habitat likely reflects efforts by State and Federal agencies, along with other conservation practitioners, taken in recent years to proactively acquire and manage key areas for habitats occupied by the southern hognose snake and commensurate at-risk species such as the gopher tortoise and gopher frog. However, all representative units and states had fewer than 50% of their large patches of moderately suitable habitat fall on protected lands (Table A-4). These results may highlight opportunities for increased investment in conservation resources to secure suitable habitat across the species' range. In conjunction with maps and spatial data products, results may inform partners about specific parcels within their jurisdictions that either (1) are highly suitable and protected, motivating continued management, (2) are highly suitable but unprotected, motivating parcel acquisition, or (3) are less suitable but may serve as corridors between highly suitable patches if acquired, managed, or restored as necessary. Together, these results highlight distributions of suitable habitat, protected areas of suitable habitat where continued management may be a priority, and opportunities for acquiring suitable but currently unprotected areas.

3.3 Limitations

Several limitations of the current data and models should be acknowledged in order to better interpret the results and guide interpretation and any forthcoming decisions for the southern hognose snake.

All source datasets used were developed by entities outside the USFWS. The quality and accuracy of these data (ecological and spatial) may vary. Remotely-sensed data products and large national datasets may contain inherent errors of omission and commission. For example, in all states besides FL, we represented land cover with the commonly-used NLCD, which can misclassify land cover compatible to snakes as certain incompatible types (e.g., wetlands, agriculture, and open developed areas). Other land cover datasets have been developed recently (e.g., USGS GAP, LANDFIRE) but also have documented issues with misclassification. By using the FLCLC to classify compatible habitat in FL and NLCD across the remainder of the species' range, we feel we used the best available data to construct this important predictor layer. Still, current landcover/landuse status may differ from the data displayed in the analysis. Actual, on-the-ground, quality and/or condition of mapped covertypes is not addressed. No field verification or reviews of ancillary datasets/aerial imagery were done to verify the accuracy of the data. Raster data has a minimum spatial resolution of 30 m. This dataset, analysis, and all maps/products created from it are subject to change.

We could not include all attributes that were ranked by experts or known from previous studies to influence habitat suitability for southern hognose snakes (Fig 2-9, Main document) because the spatial data were not available at the extent or resolution required for our study. For example, experts and previous studies have suggested negative effects of red imported fire ants (*Solenopsis invicta*) and feral hogs (*Sus scrofa*) on habitat suitability and survival of southern hognose snakes (Tuberville et al. 2000, entire). However, fine-grain spatial datasets are not currently available for these predictors across broader scales. Habitat suitability predictions can be refined in the future as these datasets become available. Predicted patterns of suitable habitat in this study incorporated many of the most, well-known environmental and biophysical attributes associated with suitable conditions for southern hognose snakes and other species in the longleaf pine system and has produced reasonable estimates of habitat conditions across the species' range. The suitability of specific sites for southern hognose snakes would need to be assessed on-the-ground and incorporate additional attributes such as presence of red imported fire ants.

Species distribution models have been effectively applied using presence-only data, but prediction accuracy can increase when true presence as well as true absence data are used to build models. Robust absence data for the southern hognose snake does not exist across the species' range due to the cryptic nature of the species that causes very low detectability as well as a lack of systematic reporting of search effort by agencies and the general public who search and report observations (e.g., through HerpMapper.org). However, recent, novel monitoring and modeling approaches are being developed that allow estimation of metrics of interest, such as occupancy and demographic rates, without traditional absence data in future research (Willson et al. 2018, entire; Appendix B). Our approach used expert opinion and mapping exercises to produce valuable information about areas where the species was likely absent, which enhanced model construction and likely the accuracy of our results. However, using true absence data in future distribution and habitat modeling for the southern hognose snake is expected to further improve model accuracy.

Although we had access to a large database of species records, we encountered data limitations in certain ecoregions after applying our temporal and spatial filters. It was necessary to group some adjacent ecoregions that contained somewhat dissimilar habitat conditions in order to have a sufficient number of records per ecoregion block and enhance model performance. For example, we grouped all ecoregions in

AL, MS, and the FL peninsula and combined the Atlantic Coastal Plain ecoregions in GA and the Carolinas due to limited numbers of presence points. This merging of adjacent areas may have caused some degree of under- or over-predicting ecoregional habitat suitability. Specifically, the model likely underestimated the amount of potentially suitable habitat in AL and MS. AL and MS were included in the same ecoregion group as the FL Panhandle, including Eglin Air Force Base, but the habitat being used by remnant southern hognose snake populations and other commensal species (e.g., gopher tortoise) differs considerably between these regions. Since most of the species records in this ecoregion group came from Eglin Air Force Base, the model was strongly fit to habitat conditions in the FL Panhandle and underestimated suitability in AL and MS where similar conditions did not occur. The observed regional data gaps may indicate a need for increased monitoring efforts, or at least documentation of absences, in these underrepresented areas. Filling regional data gaps will allow future iterations of habitat models to use finer-scale ecoregion blocks that better capture ecoregional variation in snake-habitat relationships.

Acknowledgments

This work is funded and supported by the U.S. Fish & Wildlife Service (USFWS) through the Gulf Coastal Plains & Ozarks Landscape Conservation Cooperative, the Natural Resources Conservation Service (NRCS), and the Southeast Climate Science Center (SECSC). We thank Clint Moore (USGS Georgia Cooperative Fish and Wildlife Research Unit, University of Georgia), John Maerz (University of Georgia), and Mike Harris and D. Todd Jones-Farrand (USFWS- Region 4) for guidance and support toward all analyses. We thank the SSA expert team – consisting of Jeff Hall, Jeff Humphries, and Mike Martin (North Carolina Wildlife Resources Commission), Nathan Shepard (North Carolina Natural Heritage Program), Andrew Grosse (South Carolina Department of Natural Resources), John Jensen (Georgia Department of Natural Resources), Kevin Enge (Florida Fish and Wildlife Conservation Commission), Jeffrey Beane (North Carolina Museum of Natural Sciences), Jeff Camper (Francis Marion University), and Tracey Tuberville (University of Georgia Savannah River Ecology Laboratory) – for their substantive information and/or insights for our SSA analyses. In addition to the expert team, we thank Chris Smith (HerpMapper.org), Annalee Tutterow (Davidson College), Will Dillman (South Carolina Department of Natural Resources), Kurt Buhlmann (University of Georgia Savannah River Ecology Laboratory), Matt Elliott (Georgia Department of Natural Resources), Lora Smith, Jen Howze, and Beth Schlimm (Jones Ecological Research Center), Roy King (US Army, Ft. Stewart) Ericha Shelton-Nix and Ashley Peters (Alabama Department of Conservation and Natural Resources), David Laurencio and Michael Barbour (Auburn University), and Nicole Hodges (Mississippi Wildlife, Fisheries, and Parks) for providing species records.

Literature Cited

Allouche, O., Tsoar, A., Kadmon, R., 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of Applied Ecology 43, 1223-1232.

Barrett, K., N.P. Nibbelink, and J.C. Maerz. 2014. Identifying priority species and conservation opportunities under future climate scenarios: Amphibians in a biodiversity hotspot. Journal of Fish and Wildlife Management 5, 282-297.

Boyce, M.S., P.R. Vernier, S.E. Nielsen, and F.K. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157, 281-300.

Burnham, K., and D. Anderson. 2002. Model selection and multimodel inference: A practical information—Theoretic Approach. Springer, New York, NY.

Elith, J., and J.R. Leathwick. 2009. Species distribution models: ecological explanation and prediction across space and time. Annual review of ecology, evolution, and systematics 40:677-697.

Engler, R., A. Guisan, and L. Rechsteiner. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology 41, 263-274.

Fielding, A.H., Bell, J.F., 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental conservation 24, 38-49.

HerpMapper. 2018. HerpMapper - A Global Herp Atlas and Data Hub. Iowa, U.S.A. Available at http://www.herpmapper.org. Accessed: 01-12-2018.

Johnson, C.J., Nielsen, S.E., Merrill, E.H., McDonald, T.L., Boyce, M.S., 2006. Resource selection functions based on use–availability data: theoretical motivation and evaluation methods. Journal of Wildlife Management 70, 347-357.

Mac Nally, R., 2002. Multiple regression and inference in ecology and conservation biology: further comments on identifying important predictor variables. Biodiversity and Conservation 11, 1397-1401.

Neteler, M., and H. Mitasova. 2013. Open source GIS: a GRASS GIS approach. Springer Science & Business Media.

Outcalt, K.W., and R.M. Sheffield. 1996. The longleaf pine forest: trends and current conditions. Pages 28 *in* Resource Bulletin SRS-9. USDA Forest Service, Southern Research Station, Asheville, NC.

Tuberville, T.D., Bodie, J.R., Jensen, J.B., LaClaire, L., Gibbons, J.W., 2000. Apparent decline of the southern hog-nosed snake, *Heterodon simus*. Journal of the Elisha Mitchell Scientific Society, 19-40.

Willson, J.D., Pittman, S.E., Beane, J.C., Tuberville, T.D., 2018. A novel approach for estimating densities of secretive species from road-survey and spatial-movement data. Wildlife Research 45, 446-456.

Table A-1. Descriptive statistics for presence and pseudo-absence records used for habitat suitability modeling for the southern hognose snake.

Presences	
Total collected	2227
Removed with historical (Pre-1981) filter	549 (24.7%)
Removed with min. inter-point distance filter	840 (37.8%)
Total used	1113
Collected off roads	163 (14.6%)
Collected on roads	950 (85.4%)
Pseudo-absences	
Total used	4424
Expert absence areas	666 (15.0%)
Non-expert areas, non-roads	1367 (30.9%)
Non-expert areas, roads	2391 (54.1%)
Proportion of species range classified as “absence areas” by experts	12.8%

Table A-2. Environmental predictors tested in habitat suitability models.

Category	Code	Description	Unit	Source
Ecoregion	ecoreg	Ecoregion classes from EPA level IV, used as blocking variable	class	EPA ecoregion (https://www.epa.gov/eco-research/ecoregions)
Soil	drain*	Soil drainage index, developed from reclassifying excessively, somewhat excessively drained as suitable (1), well, moderately well, and somewhat poorly drained as 0.5, everything else as 0	%	NRCS Soil Survey Geographic Database (gSSURGO: https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/)
	sand*	Sand composition in top soil horizon	%	gSSURGO
Vegetation	landcov*	Reclassed NLCD types (evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, and barren land) and FLCLC type (see Table 2.1) as 1, everything else as 0	%	Derived from National Land Cover Dataset (https://www.mrlc.gov/nlcd11_data.php), Florida Cooperative Land Cover (FLCLC) Dataset (http://geodata.myfwc.com/pages/downloads)
	lc_hist_disturb*	Reclassed historical anthropogenic land-use between 1938-2001 (ever categorized as disturbed from anthropogenic use [developed, mining, agriculture] in 1938, 1950, 1975, or 2001 = 1, never categorized as disturbed = 0)	%	USGS / EROS (https://landcover-modeling.cr.usgs.gov/projects.php), Anthropogenic land use trends (https://pubs.er.usgs.gov/publication/ds948)
	cancov*	Tree canopy cover	%	NLCD
	EVIdec*	Deciduous index, calculated as the difference between summer (May-July) and winter (Dec-Feb) EVIs divided by the maximum EVI (1999-2016)	index	MODIS (https://modis.gsfc.nasa.gov/data/dataprod/ mod13.php)
Disturbance & connectivity	firefreq*	Fire frequency (2001-2016), derived from MODIS data and LANDFIRE where LANDFIRE cells were given value of 0.1 (burned within past 10 years)	%	MODIS, LANDFIRE (https://www.landfire.gov/)
	fireburn20*	Fire frequency (20-yr average: 1996-2015), derived from Burned Area ECV data	%	USGS BAECV (https://remotesensing.usgs.gov/ecv/BA_dps.php)
	roaddens	Density of roads weighted by road type; primary roads=1, secondary=0.6, and local=0.3	%	TIGER (https://www.census.gov/geo/maps-data/data/tiger-line.html)
Climate	tempsum	Mean maximum summer temperature (Jun-Aug, 1981-2010)	°C	University of Idaho Gridded Surface Meteorological Data (U of I METDATA)
	tempwin	Mean minimum winter temperature (Dec-Feb, 1981-2010)	°C	U of I METDATA
	precipyr	Mean annual precipitation (1981-2010)	mm	U of I METDATA
	precipsum	Mean summer precipitation (Jun-Aug, 1981-2010)	mm	U of I METDATA
	precipwin	Mean winter precipitation (Dec-Feb, 1981-2010)	mm	U of I METDATA
Topographic	TPI	Topographic Position Index targeting sandhills and uplands; derived from 500-m circular neighborhood	index	derived from DEM USGS Digital Elevation Model (DEM: http://eros.usgs.gov/#/Guides/dem)

* Predictor was calculated as the mean value of a 3, 15, and 30-cell (90, 450, and 900-m) neighborhood.

Table A-2.1. Land cover types in the Florida Cooperative Land Cover Dataset that species experts defined as compatible for the southern hognose snake.

Value	Land cover class name
1110	Upland Hardwood Forest
1111	Dry Upland Hardwood Forest
1120	Mesic Hammock
1150	Xeric Hammock
1200	High Pine and Scrub
1211	Oak Scrub
1230	Upland Coniferous
1231	Upland Pine
1240	Sandhill
1310	Dry Flatwoods
1311	Mesic Flatwoods
1312	Scrubby Flatwoods
1400	Mixed Hardwood-Coniferous
1831	Rural Open
1832	Rural Structures
1840	Transportation
1842	Rails
1850	Communication
1860	Utilities
1870	Extractive
1880	Bare Soil/Clear Cut
18211	Urban Open Land
18212	Residential, Low Density
18221	Residential, Med. Density - 2-5 Dwelling Units/AC
18225	Institutional
18311	Rural Open Forested
18312	Rural Open Pine
18331	Cropland/Pasture
18333	Tree Plantations
182111	Urban Open Forested
182112	Urban Open Pine
183313	Improved Pasture
183314	Unimproved/Woodland Pasture
183315	Other Open Lands - Rural
183332	Coniferous Plantations
1110	Upland Hardwood Forest

Table A-3. Model estimates of predictor effects and model fit statistics for the best-fitting model for southern hognose snake habitat suitability for each ecoregion group. All effects were significant ($p < 0.05$) unless otherwise noted with a superscripted "NS". Percentage contribution (i.e., variance explained), which is a measure of predictor importance, is reported for each of the six habitat predictors. Values indicate a predictor's mean percentage contribution when they were included in ecoregion-specific models.

	Ecoregion group							
Main effects	Coastal Plain (Carolinas)	Coastal Plain (GA)	Atl. Coastal Plain	FL Peninsula	FL Ridge	Red Hills	West (AL/MS/FL)	Mean % Contribution
Intercept	-620.129	-82.372	42.748^{NS}	-150.546	-26.302	-166.323	-26.095	
drain	9.488	8.613	8.052	1.292^{NS}	16.130	5.209	5.863	50.4
drain^2	-5.653	-	-	-	-12.217	-	-	
landcov	8.071	2.442	-	5.930	0.941^{NS}	1.555^{NS}	-	23.4
landcov^2	-4.529	-	-	-7.124	-	-	-	
cancov	11.505	-1.527^{NS}	-	-	-	-	-	3.0
cancov^2	-8.927	-	-	-	-	-	-	
firefreq	-8.913	6.426	11.627	-	6.331	5.946	11.253	12.6
precipsum	3.257	0.396	-0.212^{NS}	0.477	0.035	0.634	0.039	20.8
precipsum^2	-0.004	-0.001	0.000^{NS}	0.000	-	-0.001	-	
TPI	0.843	-	-	-	-	-	-	2.5
TPI^2	-0.238	-	-	-	-	-	-	
Interactions								
drain:landcov	-	-	-	7.18	-	-	-	
drain:firefreq	15.56	-	-	-	-	-	-	
drain:TPI	-0.92	-	-	-	-	-	-	
Model fit								**Mean**
AUC	0.92	0.88	0.91	0.85	0.81	0.87	0.94	0.91
Sensitivity	0.89	0.84	0.85	0.81	0.75	0.82	0.93	0.84
Specificity	0.85	0.87	0.89	0.81	0.78	0.82	0.90	0.85

Table A-4. Southern hognose snake habitat suitability metrics in units of area and percent of total area within summary unit. Metrics include area of suitable habitat in >1-km^2 (100-ha) patches and in protected areas[a] and are summarized by representative unit and state.

	Suitability class: Moderate & High			**Suitability class: High**		
Representative unit totals	**Total habitat (km^2)**	**Habitat (km^2) in > 1-km^2 patches**	**% of > 1-km^2 patches protected**	**Total habitat (km^2)**	**Habitat (km^2) in > 1-km^2 patches**	**% of > 1-km^2 patches protected**
Upper Coastal Plain (Carolinas)	5643.1 (15.7%)	5184.6 (14.4%)	30.90%	2824.7 (7.8%)	2416.9 (6.7%)	41.10%
Upper Coastal Plain (GA/FL)	6430.1 (8.6%)	5890.1 (7.9%)	15.10%	3436.7 (4.6%)	3085.8 (4.1%)	19.10%
Atl. Coastal Plain (Carolinas)	2227.7 (5.9%)	1937 (5.1%)	22.60%	1003.8 (2.6%)	856.9 (2.3%)	24.20%
Atl. Coastal Plain (GA/FL)	1591.2 (4.3%)	1381.1 (3.7%)	35%	792.4 (2.1%)	660.2 (1.8%)	38.70%
FL Peninsula	2714.8 (9.1%)	2572.4 (8.6%)	20.80%	1668.6 (5.6%)	1581 (5.3%)	17.60%
FL Ridge	2192.3 (16.2%)	2114.4 (15.6%)	28.60%	571.4 (4.2%)	522.3 (3.9%)	56.40%
AL/FL Panhandle	4708.9 (12.5%)	4532.6 (12%)	46.60%	3099.6 (8.2%)	2996.9 (7.9%)	59.20%
West (AL/MS)	164.9 (0.8%)	135.6 (0.7%)	7.40%	28.2 (0.1%)	19.7 (0.1%)	26.20%
State totals						
AL	564.9 (2.3%)	485.1 (2%)	3.20%	150.6 (0.6%)	120 (0.5%)	4.90%
FL	10866.3 (13.1%)	10431.8 (12.6%)	34.60%	6080 (7.3%)	5812.1 (7%)	44%
GA	6326.1 (7.1%)	5673.6 (6.4%)	17.70%	3352.7 (3.8%)	2925.8 (3.3%)	21.50%
MS	43.6 (0.3%)	35.6 (0.3%)	22.30%	13.4 (0.1%)	8 (0.1%)	52.50%
NC	2224.2 (8.7%)	2019.5 (7.9%)	40.40%	1228.8 (4.8%)	1082.1 (4.3%)	51%
SC	5646.6 (11.6%)	5102 (10.5%)	24%	2599.3 (5.4%)	2191.7 (4.5%)	29.60%
Range-wide total	25671.7 (9.1%)	23747.7 (8.4%)	28.10%	13425 (4.7%)	12139.8 (4.3%)	36.20%

[a] All patches (or portions of patches) that were contained within protected areas included in the USGS Protected Areas Database, FNAI Conservation Lands Database, and/or GADNR Conservation Lands Database.

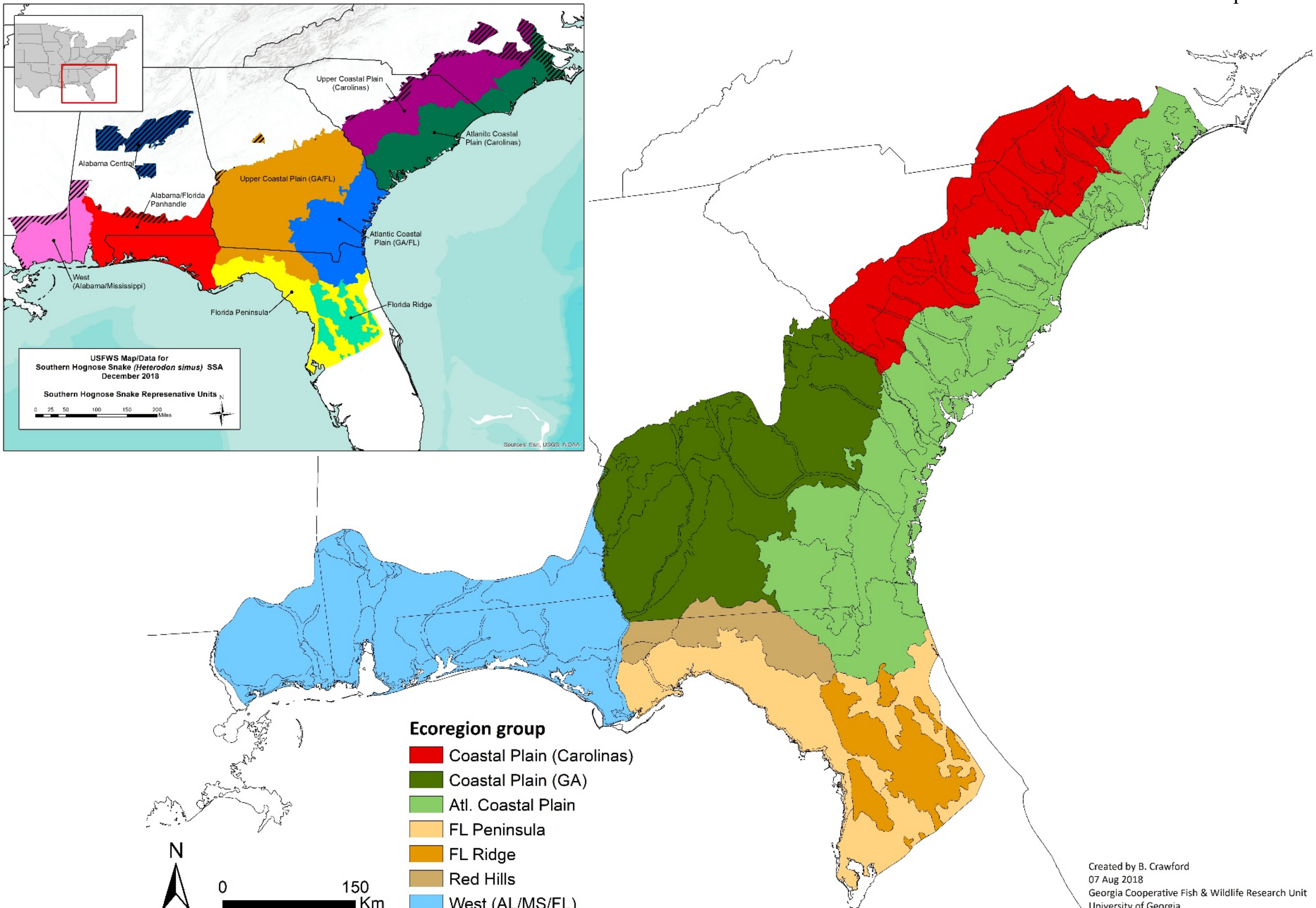

Figure A-1. Ecoregion groups used in the habitat suitability model, which differed slightly from representative units (inset) in order to have a sufficient number of presence locations in each ecoregion group.

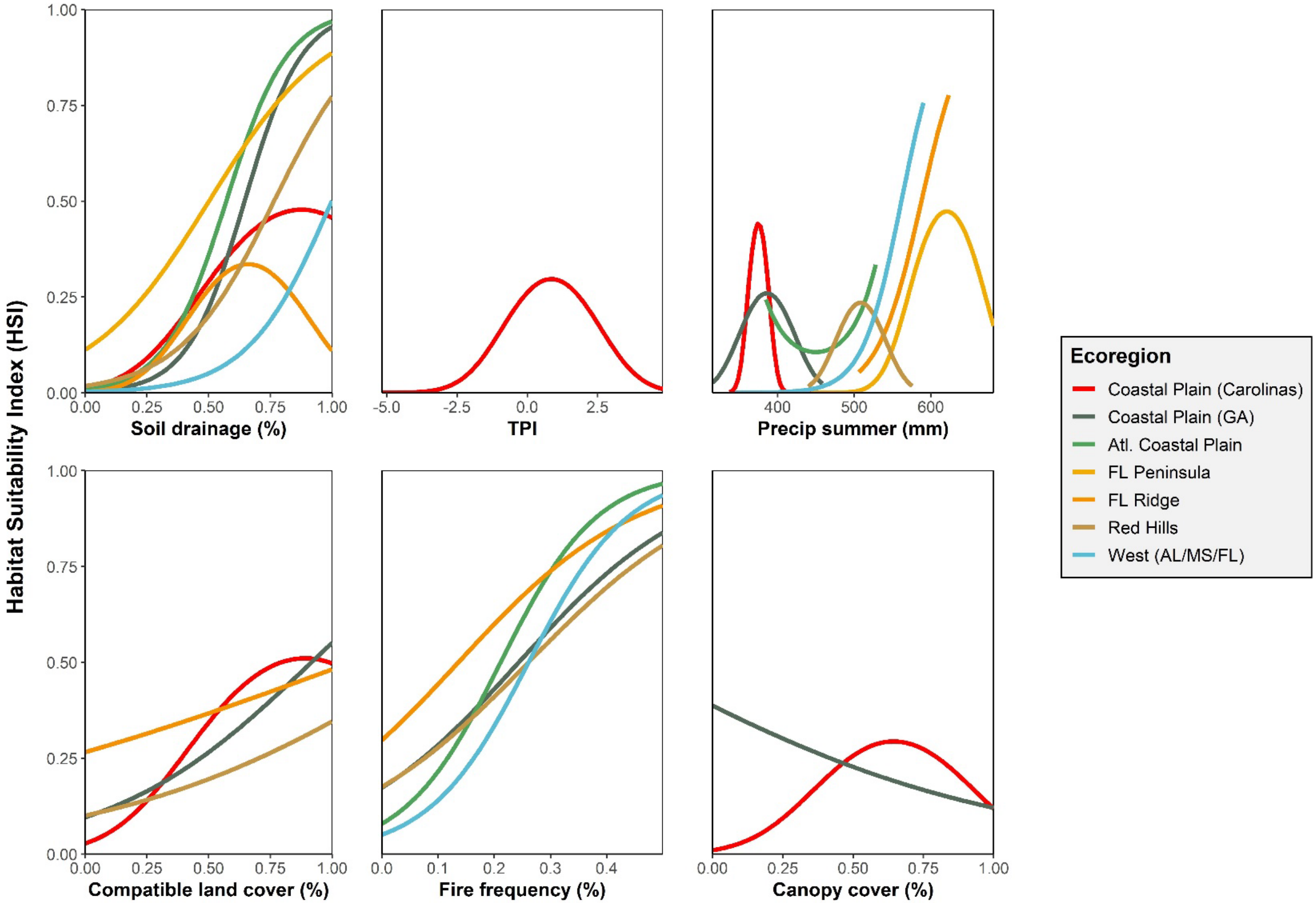

Figure A-2. Relationships from the best-fitting model between habitat suitability and environmental predictors, by ecoregion group, for the southern hognose snake. Predictors were dropped from ecoregion-specific models if not significant.

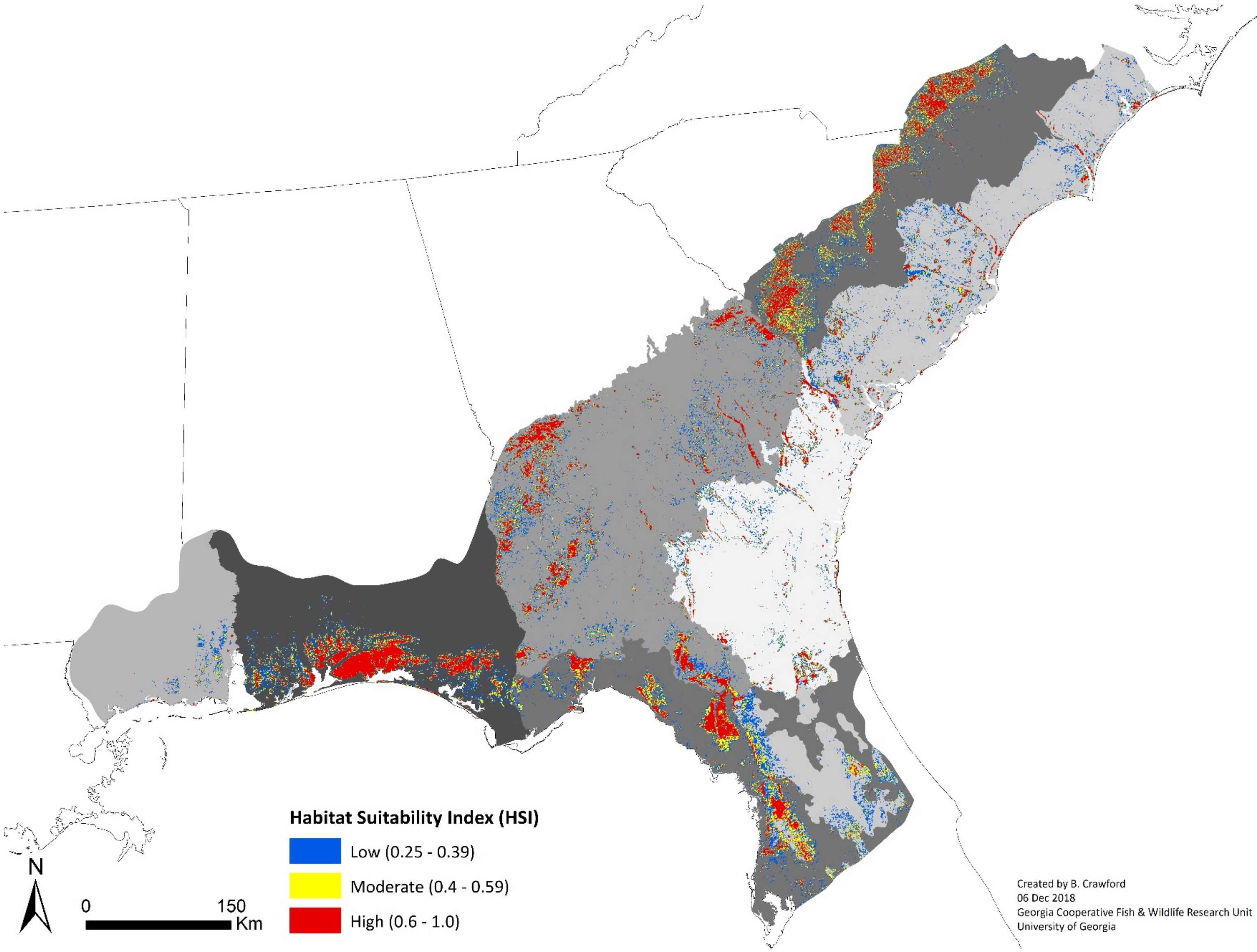

Figure A-3. Spatial distribution of suitable habitat for the southern hognose snake across its range in the southeast. Representative units are shown in grey in the background (with the Alabama Central representative unit omitted since the entire unit was outside of the analysis area).

Appendix B: Population Persistence Analysis Report

Population persistence analysis for southern hognose snake (*Heterodon simus*)
Species Status Assessment (SSA)
April 2019

In a nutshell:

- We used southern hognose snake locality records and spatial habitat/landscape data layers to estimate persistence for 222 southern hognose snake populations across the species' range under current conditions and future scenarios representing management, sea level rise, and urbanization.
- We used locality records of 13 other snake species commonly observed in southern hognose snake habitats, obtained from HerpMapper.org and other partners, as information about relative search effort across populations in order to improve persistence estimates.
- Current persistence varied considerably by population but was positively influenced by mean habitat suitability and proportion of protected lands and was negatively related to time since last observation.
- Currently, out of 222 populations, 89 (40%) were more likely than not to persist currently (probability of persistence greater than 50%), while 133 (60%) were more likely than not to be extirpated.
- With no additional management, 165 (74%) populations are likely to be extirpated by 2080 under the three stressor scenarios.
- Management scenarios, especially those that involved converting and managing unprotected populations to protected lands, improved resiliency, redundancy, and representation, relative to stressor scenarios. The number of populations more likely than not to persist increased to 58 (26%), 66 (30%), and 70 (32%) under the low, medium, and high management scenarios, respectively.
- Of the 9 representative units, it is extremely likely that 2 units (AL Central and West of the Mobile River in AL and MS) have become extirpated by 2018, and it is likely that between 1 and 3 additional units are at risk of extirpation by the year 2080 without additional management.
- Collectively, the number of persisting southern hognose snake populations has declined from historic conditions, and these declines are predicted to continue in the future, especially under no additional management. Redundancy (number of persisting populations within a representative unit) has decreased and is predicted to decrease further in the future. Representation (number of units with persisting populations) has decreased, as 2 of 9 units are likely extirpated at the present, and at least 1 additional unit is at risk of extirpation by 2080.

1. Introduction

1.1 Background and objectives

The southern hognose snake (*Heterodon simus*) is a small terrestrial species found in the Coastal Plain region in southeastern North Carolina, South Carolina, Georgia, Florida, west to Alabama and Mississippi. It is associated with xeric longleaf pine (*Pinus palustris*) savanna, flatwoods and sandhill habitats that are typically fire-maintained with well-drained, sandy soil, low canopy cover, and adequate herbaceous ground cover. Several of these systems have been impacted by anthropogenic land uses, especially longleaf pine forests which have declined by 97% across their historical range (Outcalt and Sheffield 1996, entire). In addition to habitat loss, threats to the species include degradation from inadequate prescribed fire management, fragmentation, spread of invasive species such as the red imported fire ant (*Solenopsis invicta*), road mortality, and other factors (Beane et al. 2014, entire; Gibbons et al. 2000, entire; Tuberville et al. 2000, entire). Tuberville et al. (2000, entire) conducted a comprehensive review of published information and species location records to identify general trends in distribution of occurrences, and evidence suggested population extirpations are likely to have occurred across a large portion of the species' range while other populations appeared stable at the time.

Estimates of demographic rates, population abundance, and risk of extinction are valuable criteria for assessing resiliency and informing conservation decisions (Beissinger and Westphal 1998, entire; McGowan et al. 2014, entire; McGowan and Ryan 2010, entire); however, acquiring these estimates remains challenging for rare, cryptic species on which conservation efforts often focus. The southern hognose snake is a highly cryptic species, which leads to low rates of detection. There have been no further efforts to characterize range-wide patterns in population trends, either through a similar approach to Tuberville et al. (2000, entire) using location records or one that uses demographic rates to estimate trends over time (i.e., a population viability analysis). Only a few, localized studies have been able to estimate parameters like certain demographic rates and population densities for this species (Beane et al. 2014, entire; Enge and Wood 2002, entire; Willson et al. 2018, entire).

This study used a novel approach to 1) estimate habitat suitability across the species' range, 2) use habitat suitability and other factors to estimate the probability of persistence for 222 populations under current conditions, and 3) simulate these conditions into the future under scenarios representing plausible conditions of urbanization, sea level rise, and potential management. We evaluated the relationships between certain site-level predictors (e.g., habitat suitability, proportion of site protected) and current persistence, and we evaluated the effects of future urbanization, sea level rise, and management on these habitat conditions and population persistence outcomes. Collectively, the results of this study aid in evaluating extinction risk for southern hognose snake populations across spatial (population-level, representative unit-level, and range-wide) and temporal (historic, current, and future) scales. As part of the species status assessment, this information will inform species listing decisions and conservation planning for Federal, State, and other partners.

1.2 Analysis area and representative units

The extent of the analysis differs slightly from the full species range shown in the main SSA document. The spatial extent of our analysis (Fig B-1) was restricted to the area used in the habitat suitability analysis (Appendix A), which does not extend to areas in central Alabama and eastern North Carolina that are included in the full species range. Although there were records outside of the analysis area, all were found prior to 1975 and likely represent extirpated populations. However, it is possible that there may be additional, undocumented southern hognose populations beyond or within the boundary used. This analysis used the nine representative units (Fig B-1) delineated in collaboration with species experts to represent variation in ecological roles of the species across its range. Units were based on EPA IV ecoregion that were grouped by similar ecological characteristics (e.g., soil, geology) and divided by the Savannah, Chattahoochee, and Mobile-Tombigbee Rivers.

2. Methods

We sequentially went through the following steps when conducting this analysis and describe each step in more detail in the sections below. First, we gathered a comprehensive dataset of southern hognose snake locality records and delineated population boundaries based on clusters of these records (Section 2.1). Second, we gathered locality records for other snake species commonly observed in hognose habitats that were found within population boundaries to represent search effort (Section 2.2). Third, we extracted metrics of site-level conditions at the present for each population to use as predictors of persistence (Section 2.3). These predictors included mean habitat suitability index that was estimated as part of the habitat suitability model (Appendix A). Fourth, we constructed a persistence model to estimate current population persistence (in 2018) that leveraged information from the southern hognose snake and other snake species locality datasets and accounting for imperfect detection (Section 2.4). Fifth, we created seven scenarios of stressors and management to evaluate a range of plausible future conditions for the species; we then performed spatial analyses to capture predicted changes in land cover and fire frequency under each scenario, and we extracted these conditions to populations (Section 2.5). Sixth, we built a simulation model that used habitat conditions and current persistence to forecast population persistence through 2080 under each scenario (Section 2.6; Fig B-2). Lastly, we summarized results by representative unit and range-wide currently (in 2018), in 2040, 2060, and 2080 (see Section 3. Results).

The core of this analysis – the persistence model – used a novel structure to estimate current population persistence, given data limitations of the southern hognose snake. Specifically, we adapted the Cormack-Jolly-Seber model, designed to estimate survival of individual animals based on mark-recapture data, to analogously estimate persistence ("survival") of populations based on detection-non-detection data within each population boundary. Only a few mark-recapture datasets of individuals exist for this species and contain low numbers of recaptures that prevent traditional survival analyses (L. Smith, pers. comm.). Aggregating and analyzing hognose records by populations can overcome challenges associated with low probability of recapture and allows for estimating processes occurring at the population-level.

We performed spatial analyses in ArcGIS version 10.4 (ESRI, Redlands, CA) and statistical analyses in R version 3.1.2 (R Core Team 2016, p. unpaginated).

2.1 Collecting southern hognose snake records & delineating populations

To develop population persistence models, we first compiled a geospatial database of occurrence records for southern hognose snakes and created population boundaries around clustered records. We compiled species records from datasets maintained by Natural Heritage Programs, USFWS, USFS, DoD, state agencies, academic researchers, and HerpMapper – an online platform where species records are reported by the public and validated by professional herpetologists (HerpMapper 2018, p. unpaginated). Records included opportunistic sightings, as well as observations from systematic research and monitoring studies. From the full location dataset, we removed 31 records, contained in 18 populations, that fell outside of the analysis area (all were found prior to 1975). We performed analyses on the remaining 204 populations.

We performed the following steps to delineate populations around all species locations (Fig B-3). We:

1) Buffered species locations by 5 km and joined buffers that overlapped. Ideally, we would have selected a buffer distance using a reported maximum annual movement, or dispersal, distance, but this information does not exist for the southern hognose snake. NatureServe suggests a separation distance for colubrid snakes of 10 km (6.2 miles) for suitable habitat and 1 km for unsuitable habitat (NatureServe 2018, p. unpaginated). This recommendation is based on a limited number

of studies of movement and home range in colubrid snakes but was selected by NatureServe for the colubrid group because it seems generally unlikely that two locations separated by less than 10 km of suitable habitat would represent distinct occurrences. Very little information about dispersal distances and home range sizes exists for this species, so this buffer size was chosen with the input of species experts and based off of NatureServe recommendations for small terrestrial snakes (NatureServe 2018, p. unpaginated).

2) Split the polygons from step 1 with ecologically-relevant barriers. Movement of individuals across these barriers is believed to be extremely unlikely, and thus, areas on either side of a barrier should be considered separate populations (expert team, pers. comm.). Specifically, we used:
    a. Large rivers of the 6th or higher order from the National Hydrography Dataset (https://viewer.nationalmap.gov/), and
    b. Major highways from the TIGER road dataset (https://www.census.gov/geo/maps-data/data/tiger-line.html)
3) Removed any polygons from step 2 that now did not have any species records within them and modified final boundaries to reflect 5-km buffers around locations within a population. We also clipped final population boundaries by major water bodies.

After we delineated populations, we associated the population ID number and representative unit for each southern hognose snake record using the Spatial Join tool in ArcGIS. Using the southern hognose snake record dataset, we created observation histories (denoted as $y_{i,t}$) describing if at least one individual was observed in a population (i) in a given year (t) ($y_{i,t} = 1$, 0 otherwise). These observation histories were used to model persistence (see Section 2.4).

2.2 Collecting non-target snake species records

Models similar to our approach rely on absence information – i.e., when searches occurred but the target species was not observed – to estimate survival, abundance, and persistence (Kery et al. 2009; Kery and Schaub 2012; MacKenzie et al. 2002). However, robust search effort and absence data do not exist for the southern hognose snake. Therefore, we developed a search effort index from occurrence records of southern hognose snakes and other snake species commonly observed in southern hognose snake habitats (hereafter search effort dataset) obtained from HerpMapper.org and other partners. We used the search effort dataset to account for imperfect detection of the southern hognose snake and improve the precision of persistence estimates. Records of other (non-target) snake species that fall within a given population boundary indicate that the area was searched by an individual in a given year and inform the likelihood a population is still persisting. For example, imagine two populations: A and B. Southern hognose snakes have not been observed in both Populations A and B since 1990. Population A has been frequently searched since then, and other species of common snakes continue to be reported in the area. Population B has only been searched once since then. Assuming everything else is equal, there is more evidence that Population A has become extirpated of southern hognose snakes while Population B is more uncertain. In using non-target species data, we made the following assumptions: 1) non-target records indicate an event when an area known to have southern hognose snakes at some time was searched, 2) the search was performed in a way that southern hognose snakes could be observed (e.g., road surveys), and 3) when a person submitted non-target records but not southern hognose records to HerpMapper after a search, this indicated the area was searched but no southern hognose was found (i.e., we assumed southern hognose snakes would be reported if found).

We developed a list of 13 non-target species most commonly observed while surveying for southern hognose snakes that are active during the same months of peak activity (May, June, September, and October): *Agkistrodon contortrix subspp.*, *Agkistrodon piscivorus subspp.*, *Cemophora coccinea subspp.*, *Coluber constrictor subspp.*, *Crotalus adamanteus*, *Crotalus horridus*, *Lampropeltis getula subspp.*, *Masticophis flagellum subspp.*, *Opheodrys aestivus subspp.*, *Pantherophis guttatus*, *Pantherophis obsoletus subspp*, *Pituophis melanoleucus subspp.*, and *Thamnophis sirtalis subspp.* (multiple experts, pers. comm.). We queried HerpMapper and accessed 11,631 records of these snake species. These records included data on observer name and date of observation. We added 1,522 Florida pine snake records to the non-target dataset that were collected from databases maintained by Natural Heritage Programs, States, and other Federal and research partners for a companion status assessment on that species. Finally, we added our full dataset of southern hognose records since these indicate search events as well. While HerpMapper launched in 2013, there were records included in this and the other snake datasets used to create a search effort index that were collected between 1880 and 2018.

We associated the population ID number for each record in the search effort dataset using the Spatial Join tool in ArcGIS. We removed any record falling outside of any population boundary, which left 5,473 records. We noticed occasions in the HerpMapper data where the same observer would submit multiple records from the same date. In order to better capture the number of search events and create an index of search effort, we filtered the search effort dataset to remove duplicate records coming from the same observer on the same date. Thus, the dataset now represented unique searches by individuals, which we refer to as observer-days, and included 3,825 observer-days in total. We then followed the same process used to create observation histories of southern hognose snakes to create search effort histories for each population. Search effort histories ($s_{i,t}$) described the number of observer-days for population (i) in year (t). Lastly, we scaled all search effort values so they were centered on 0 for use in the model.

2.3 Extracting current site-level conditions for populations

Using the population boundaries, we summarized population-specific metrics for several spatial variables that likely influence persistence and used these as predictors in the persistence model. We included three metrics representing site-level conditions in the analysis (Table B-1): 1) average Habitat Suitability Index (HSI), estimated in the habitat analysis (Appendix A), 2) proportion of the population area protected, and 3) number of additional populations within 10 km.

We used the Zonal Statistics tool in ArcGIS to calculate mean HSI within each population boundary (Fig B-4). HSI can be thought of as a measure of habitat quality between 0 (most unsuitable, lowest quality) to 100% (most suitable, highest quality). Predicted HSI for the southern hognose snake was positively related to the amount of well-drained, sandy soils, compatible landcover (e.g., mixed/evergreen forest, scrub/shrub, grasslands, flatwoods), and fire frequency.

We used the Zonal Statistics tool to calculate proportion of a population boundary currently in protected lands. We created a protected lands raster where areas included in the USGS Protected Areas Database (http://www.protectedlands.net/), FNAI Conservation Lands Database (http://fnai.org/conservationlands.cfm), GADNR Conservation Lands Database (https://glcp.georgia.gov/), and/or NCNHP Managed Areas Database (https://www.ncnhp.org/activities/conservation/managed-areas) were given a value of 1. These areas include publicly-owned and managed lands as well as private lands registered in state or federal programs where natural resource conservation is one of the management goals. All other area was given a value of 0. Therefore, calculating the mean of the protected lands raster within each population boundary yielded the proportion of protected land.

Lastly, we used the Near tool to calculate the distance between each population and all other populations within 10 km and recorded the number of nearby populations found. Although experts believed movement between two populations was unlikely if they were greater than 5 km apart, we recorded populations within 10 km because they may provide opportunities for "rescue" where recolonization can occur after a catastrophe; alternatively, nearby populations could provide a signal that there are localized conditions (e.g., geological, climatic) that promote population persistence that have not been otherwise captured in our analyses.

We used the Spatial Join tool to extract values from the three metrics to each southern hognose snake population. We note that all pair-wise correlations between these three predictors were not statistically significant, although protection of a site could facilitate natural resource management that improves habitat suitability.

2.4 Current persistence model

We developed a model (hereafter, persistence model) to estimate trends in southern hognose snake populations and derive probabilities that each population in the species' range persists currently in 2018. We adapted the Cormack-Jolly-Seber model (Brooks et al. 2000; Lebreton et al. 1992), designed to estimate survival of individual animals based on mark-recapture data, to analogously estimate persistence ("survival") of populations based on their observation histories. Under this framework, persistence can also be thought of as 1 – the probability of extinction for each population.

We developed the persistence model using a state-space formulation fitted in a Bayesian framework (Kery and Schaub 2012, p. 171-239). State-space models explicitly model how the state of a system changes over time (e.g., population persistence and extirpation) as well as the process of observing an individual, given the population has not become extirpated (Fig B-5). Thus, they are helpful in separating real biological signals from error in observation data.

We modeled the state history ($z_{i,t}$) of a population over the period from 1950 to 2018. Although 55 hognose records (2.5% of total records in dataset) were found between 1880 and 1950, fitting the model to this full time period would have been computationally difficult. We modeled state histories of populations as a function of an annual population-specific persistence probability $\varphi_{i,t}$, where a population could either persist ($z_{i,t}$ = 1) or become extirpated ($z_{i,t}$ = 0), given that it still persisted the year before ($z_{i,t-1}$ = 1). We assigned each population a state of z = 1 in the first year of the model timeframe (1950). By doing so, we assumed that any area where southern hognose snakes have been observed had a population persisting at that location in 1950. Because the species is highly difficult to detect and its small body and life history information indicate relatively low dispersal distances, it seems more likely that populations not discovered until after 1950 were actually there before but not detected rather than the area was recently colonized by dispersing individuals. Using this approach with our Bayesian formulation, we provided the model with information about the known state of populations, which helped it estimate parameters. For example, a population where southern hognose snakes were detected in 2000 but not after indicates that it persisted at least between 1950 and 2000, and we would supply known states (z = 1) for that population between these years (but the model would predict z states each year after 2000). In all years, the prediction of a z state in any year is a random outcome of the model (0 or 1) when no snake was observed in the population that year and is a deterministic outcome (1) for years when snakes were observed. In order to characterize current population resilience, we derived the probability that each population still persisted in 2018 by calculating the proportion of model iterations where a $z_{i,2018}$ = 1. We interpret this value as the probability a population has persisted through the entire time period modeled and still exists (which we refer to as current persistence), and we note that this value differs from $\varphi_{i,t}$ estimated in the model that reflects the probability a population will persist into the next year (which we refer to as annual persistence). We modeled observation histories ($y_{i,t}$) for a population as a function of the probability of detecting at least one individual, $p_{i,t}$, given that the population had not become extirpated.

We included additional effects on persistence and detection parameters. For persistence, we included a fixed effect for the population's representative unit (β_{rep}). This allowed for a different baseline persistence probability for each unit. We also included three fixed effects for each of the predictors indicating conditions measured at each population: mean Habitat Suitability Index (β_{HSI}), proportion of a population protected (β_{protect}), and number of nearby populations (β_{connect}). This allowed for estimating the relationships between each predictor and persistence probabilities across the species' range. For detection, we included a fixed effect for baseline detection (p_{mean}). We included a trend effect (p_{beta}) that allowed mean detection to change over time, given that the amount of search effort in our dataset substantially increased between 1950 and 2018 and the quality of search effort may be higher in recent years due to more easily accessible information on where and how to search for this species. Lastly, we included a fixed effort for population- and year-specific effort (p_{effort}), using the search effort index data.

We used standard practices for fitting Bayesian models following Kery and Schaub (2012, p. 171-239). We fit the persistence model with Markov chain Monte Carlo (MCMC) methods in Jags called from R via the R2jags package (Su and Yajima 2012, entire). We assigned diffuse prior distributions for all parameters, and we generated three MCMC chains using 100,000 iterations where we retained every third iteration from the last 50,000 iteration, yielding a final set of 50,001 samples from posterior distributions of the parameters. We assessed convergence for all models by visually inspecting chain mixing in MCMC trace plots and posterior distribution plots for evidence of unimodality and by conducting posterior predictive checks (Gelman et al. 2000, entire). For the latter technique, we simulated datasets using parameters estimated in the model, calculated the mean number of populations with simulated detections of southern hognose snakes in three time periods (1970-1974, 2000-2004, and 2014-2018), and compared mean observations in these periods from the real dataset with values from simulated datasets. We based parameter inferences on posterior means and 95% Bayesian credible intervals (BCIs; 2.5th – 97.5th percentile of the distribution).

We measured southern hognose snake population resiliency by using current persistence probabilities (between 0 and 100%), and we summarized results by grouping populations into categories representing ranges of persistence probabilities. The categories we chose were unlikely or extirpated (< 50%), more likely than not on landscape (50 – 79%), very likely on landscape (80 – 89%), highly likely on landscape (90 – 95%), and extremely likely on landscape or extant (95 – 100%). For a population to be highly resilient, it must have a relatively high current persistence probability.

To characterize representation and redundancy, we captured predictions of the number of resilient populations within a representative unit and range-wide in two ways. First, we summed the number of populations within a unit and range-wide with current persistence probabilities at or above each category (threshold) as described for characterizing population resiliency (Section 4.1.3). Second, we recorded the number of populations predicted to persist in 2018 within each unit and range-wide using direct outputs from the model. Each model iteration recorded the number of populations persisting in 2018 in each representative unit and range-wide, and we used all model iterations to calculate the mean (the most likely prediction) and 95% confidence intervals for the predicted number of persisting populations in 2018.

One can think of the difference between a specific population's probability of persistence and the mean number of populations persisting within a representative unit by considering a set of four fair coins. Each has a 50% probability of getting a heads – this is a population's persistence probability. If we flip all four coins many times, the most likely outcome, on average, is getting two heads and two tails – this is the mean number of persisting populations predicted in a model iteration. The specific coins that yield a heads may change each trial, but we still expect two out of four heads most commonly. Therefore, when assessing representation and redundancy at the scale of a representative unit and range-wide, it may be helpful to consider the two types of results alongside each other. One can interpret the mean number of persisting populations as the most likely outcome then further assess the current resiliency of populations within a representative unit and range-wide using the number of populations above a certain persistence threshold (e.g., 80%). We also note that the laws of probability make it so this mean number of persisting populations approximately equals the number of populations with a 50% or greater persistence probability.

We measured representation using the number and distribution of resilient populations (i.e., those above a certain persistence probability threshold) across representative units in the species' range as well as assessing the spatial distribution (latitudinal and longitudinal variability) of resilient populations. To have high representation the species must have multiple highly resilient populations located in each of the representative units, and those occupied units should span the latitudinal and longitudinal extent of historical populations.

We measured redundancy using the current number and distribution of resilient populations within representative units and across the range of the species. To have high redundancy, the southern hognose snake would need to have multiple resilient populations within a representative unit and throughout its range.

2.5 Future scenarios and spatial analysis

We considered several processes that may influence future habitat suitability and population persistence of the southern hognose snake and grouped these into seven plausible scenarios to simulate future conditions (Table B-2). The first three scenarios forecast persistence under varying levels of future stressors (threats) with current management conditions continuing. The last four scenarios used the most likely level of future stressors and varying levels of management effort. We used spatial analyses performed in ArcGIS to capture changes in land cover and fire frequency due to future urbanization, sea level rise, and potential management actions. Changes in these spatial predictors subsequently influenced future habitat suitability, as predicted by the habitat suitability model (Appendix A), and population persistence, as predicted by the stochastic simulation model (described in Section 5.3; Fig B-2). We describe spatial analyses of future stressors and management below.

We captured the effects of future urbanization and sea level rise on compatible land cover for southern hognose snake populations (Fig B-6). First, we mapped areas predicted to be urbanized in the future using the Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade (SLEUTH) model. SLEUTH is a cellular automata model that applies transition rules to the states of a gridded series of cells, and in this case the transition is that from undeveloped to developed land cover, otherwise known as urbanization (Chaudhuri and Clarke 2013, entire) and has been successfully applied worldwide over the last 15 years to simulate land use change. SLEUTH simulates patterns of urban expansion that are consistent with spatial observations of past urban growth and transportation networks, including the sprawling, fragmented, "leapfrog" development that has been the dominant form of development in the Southeast (Terando et al. 2014, entire). The SLEUTH model predicts the probability of urbanization ranging from 0-100% within 60-m square cells, which we resampled to 30-m cells to coincide with other spatial data layers, and urbanization is modeled for each decade from 2010 (baseline) to 2100. The SLEUTH model algorithm specifies a 0% probability of urbanization for protected areas (e.g., National Forests, State-owned conservation lands); however, new conservation lands have been created by government agencies and other partners since the model was developed. Therefore, we set the probability of urbanization to 0 for any cell that overlapped our raster of currently protected areas. We used SLEUTH projections from 2040, 2060, and 2080 and selected all cells with a 90 (most conservative), 50, and 10% (most liberal) probability of urbanization to represent low, medium, and high levels of urbanization, respectively. In addition to urbanization, we captured potential loss of habitat due to inundation from sea level rise. We used NOAA's rasters available at their online sea level rise viewer (https://coast.noaa.gov/slr/; accessed 15 Nov 2018). Projected sea level rise scenarios from NOAA provide a range of inundation levels from low to extreme through the year 2100. We reviewed local scenarios for locations in the Southeast, available through the online viewer, and selected inundation heights of 1, 3, and 6 ft in 2080 to represent low, medium, and high stressor levels, respectively, and created rasters showing inundated areas, given each height, at 2040, 2060, and 2080. Finally, we captured the reduction in compatible land cover from urbanization and sea level rise for each time period and stressor level by removing areas predicted to be urbanized or inundated from the current compatible land cover layer using the Raster Calculator tool and calculated the proportion of compatible land cover in each population boundary using the Zonal Statistics tool.

We also captured the effects of urbanization on fire frequency. This was done to account for fire exclusion/suppression that often occurs in habitat adjacent to urban areas, known as the wildland-urban interface, due to safety and smoke management restrictions (Theobald and Romme 2007, entire). Studies have found evidence of fire exclusion/suppression in habitats within 600 m to 5 km of urban areas (Pickens et al. 2017, entire; Theobald and Romme 2007, entire). Therefore, we chose a moderate value of 3.2 km (2 mi) to capture the interaction between urbanization and fire frequency. Using the predicted urbanized areas at each time period and urbanization probability level, we identified areas within 3.2 km of urban areas using the Euclidian Distance tool. We then projected future reductions in fire frequency starting with the current fire frequency raster and applying a distance-weighted reduction to any cell within 3.2 km of urban areas. Using this approach, fire frequency for any cell overlapping future urban areas was reduced by 100% (equaled 0) and any cell more than 3.2 km away from urban areas was reduced by 0% (unchanged). Any cell between 0 and 3.2 km away from urban areas was reduced by a percentage proportional to its distance – i.e., a cell 1.6 km from urban areas was reduced by 50%.

For the first three scenarios (Low Stressors, Medium Stressors, and High Stressors), we used the resulting land cover and fire frequency layers from low, medium, and high levels of urbanization and sea level rise, respectively, as inputs for predicting future habitat suitability and population persistence. For the last four scenarios, we selected the medium threat level conditions and modified compatible land cover and fire frequency to represent various management strategies, and we describe these changes for each scenario below.

Low Stressors – This scenario considered a future where management remains at the status quo and evaluated the future condition of the southern hognose snake under a low rate of urbanization by selecting areas with a greater than 90% probability of being urbanized (only includes areas with high certainty of development) and a low level of SLR (1 ft.).

Medium Stressors – This scenario considered a future where management remains at the status quo and evaluated the future condition of the southern hognose snake under a medium rate of urbanization by selecting areas with a greater than 50% probability of being urbanized and a medium level of SLR (3 ft.).

High Stressors – This scenario considered a future where management remains at the status quo and evaluated the future condition of the southern hognose snake under a high rate of urbanization by selecting areas with a greater than 10% probability of being urbanized (includes areas with a low probability of development) and a high level of SLR (6 ft.).

Decreased Management – This scenario considered a future where it is difficult to continue to manage habitat for the southern hognose snake. In this scenario, we simulated decreased management effort where habitat suitability declines for populations that are currently on protected lands. We decreased fire frequency on protected lands by simulating the equivalent of applying one less prescribed burn every five years in these areas, and we used the updated mean fire frequency for each population to predict habitat suitability and population persistence in the future. We also used the medium rate of urbanization (50 % probability) and a medium level of SLR (3 ft.), since these are considered the most likely levels.

Improved management – This scenario represented an "Improve protected areas" strategy. We considered a future in which we improve the management for the southern hognose snake. In this scenario, we simulated additional management effort that focuses on improving habitat suitability for populations that are currently on protected lands. We increased the fire frequency by simulating the equivalent of applying 1 additional prescribed burn every 5 years to populations that occur on protected lands, and we used the updated mean fire frequency for each population to predict habitat suitability and population persistence in the future. We also used the medium rate of urbanization (50 % probability) and a medium level of SLR (3 ft.), since these are considered the most likely levels for these stressors.

Protect More Populations – This scenario considered a future where additional populations were permanently protected. In this scenario, we considered acquiring, protecting, and improving additional land within population boundaries for those populations that are very likely to currently persist (≥ 80% current persistence probability) but are not currently protected (< 0.1 proportion of protected land). We assigned a new proportion of protected land of 0.9 on these populations to simulate protecting the majority (90%) of land within the population boundary. We also increased the proportion of compatible land cover by 0.1 to simulate restoring habitat in 10% of the population area. As in the improved management scenario, we also simulated additional management effort for the newly protected lands as well as the lands already protected by increasing the fire frequency to simulate 1 additional prescribe burn every 5 years in these areas. Since future urbanization cannot occur on protected areas, we reduced the loss of land cover due to urbanization by 90% - i.e., predicted urbanization was still allowed to remove up to 10% of the population area that was not protected. Land acquisition and habitat improvement into the future is plausible for 3 main reasons: 1) current longleaf restoration initiatives, such as the Longleaf Pine Alliance, are currently increasing acres of longleaf pine across the Southeast, and have plans to continue this work into the foreseeable future, 2) southern hognose snake habitats are used by other listed species; thus, acquisition and restoration of habitat that supports these currently listed species is likely to benefit the southern hognose snake, and 3) state-level land acquisitions that have the potential to benefit the southern hognose snake have occurred in the past, are currently happening now, and are likely to occur in the future. We used the medium rate of urbanization (50 % probability) and a medium level of SLR (3 ft.), since these are considered the most likely levels for these stressors.

Protect Even More Populations – For the last scenario, we considered a future where all populations that are currently more likely than not to persist, are permanently protected. We followed the same steps as in the Protect More Populations scenario, except that we considered acquiring, protecting, and improving additional land within population boundaries for those populations that are more likely than not to persist (> 50% current persistence probability) but are not currently protected (< 0.1 proportion of protected land). As in the previous scenario, we simulated protecting the majority of land within these populations' boundaries, increasing compatible land cover, and increasing fire frequency by 1 additional burn every 5 years. We used the medium rate of urbanization (50 % probability) and a medium level of SLR (3 ft.), since these are considered the most likely levels for these stressors.

2.6 Future simulation persistence model

We developed a stochastic simulation model that used a Markovian process to predict the probability of persistence in the future for each population in the analysis area based on the current probability of persistence and future predicted changes in habitat suitability and land protection. The primary output metric for this model was the probability a population persists at a given year in the future (2040, 2060, and 2080), which we call "future persistence probability." We calculated the future persistence probability for each population as the proportion of model iterations where the population was persisting at a given year. The complement of future persistence probability can be interpreted as the probability a population has become extirpated by a given year.

We built a multi-loop simulation model (following McGowan et al. 2014, entire) that allowed us to simulate thousands of replicates of each population under different scenarios and examine the relationship between threats and management with future persistence. This approach accounted for random year-to-year stochasticity as well as uncertainty around rates (i.e., annual persistence probability) estimated from the current persistence model. The model looped through 10,000 iterations for each of the seven scenarios. It then looped through each of the 204 southern hognose snake populations within the analysis area and simulated persistence from the present (2018) to 2080. We briefly discuss the model framework, inputs, and outputs below.

In short, the model calculated inputs from the spatial analysis (compatible land cover, fire frequency, and proportion of protected area), predicted habitat suitability, selected a set of parameter estimates from the current persistence model, used inputs and the parameter estimates to predict annual probabilities of persistence in the future, and used the annual persistence probabilities to predict the state of each population (persisting or extirpated) each year through 2080 (Fig B-2). It accomplished this through a series of steps.

Step 1) Each iteration of the model began by calculating annual values of land cover, fire frequency, and proportion of protected area by interpolating the values of these predictors calculated in the spatial analysis at 2040, 2060, and 2080. These input values were scenario-dependent.

Step 2) The model then used inputs of land cover and fire frequency, along with all other predictors used in the habitat suitability model (e.g., soil drainage, local elevation) that did not change in future scenarios, to calculate mean habitat suitability for each population and year, given conditions of each scenario. This was done using the habitat suitability model (Appendix A) and the predict.glm function in R.

Step 3) Each iteration of the simulation selected a single set of parameter estimates ("posterior estimates") generated from one iteration of the current persistence model. These parameters included mean current persistence probability for each population and the estimated effects of all predictors of the annual persistence probability (mean representative unit persistence, habitat suitability, proportion of protected land, and number of populations within 10 km). This was done in order to account for the uncertainty around parameters (parametric uncertainty) estimated in the current analysis, as well as year-to-year stochasticity in the simulation model. Therefore, the simulation model results varied between iterations based on which parameter estimates were randomly selected.

Step 4) Once we had a sample of posterior estimates and scenario-, population-, and year-specific inputs, the model calculated annual probabilities of persistence using the same model structure as the persistence analysis (Section 4.2). Annual persistence probability was a function of mean representative unit persistence, habitat suitability, proportion of protected area, and number of populations within 10 km. The model simulated the state of each population each year through 2080. The probability of persistence in 2019 was equal to the mean current persistence probability for each population multiplied by the annual persistence probability for that population that was randomly selected from the estimates generated in the current persistence model ($\varphi_{current}*\varphi_t$). The state of the population (persisting or extirpated) in the next year was drawn from a Bernoulli trial using that probability. For years 2020 through 2080, the state of a population was drawn from a Bernoulli trial using the annual persistence probability, given that the population had persisted in the previous year.

Step 5) The model recorded summary outputs useful for characterizing resiliency, redundancy, and representation. For this model, the primary output was the probability a population persists at a given year in the future through 2080, which we call "future persistence probability." We calculated the future persistence probability for each population as the proportion of model iterations where the population was persisting at a given year. The complement of future persistence probability can be interpreted as the probability a population has become extirpated by a given year. These future persistence probabilities for populations are directly comparable to the current persistence probabilities. We characterized future conditions similarly to current conditions by summarizing the number of populations at or above certain persistence probability thresholds (50, 80, 90, and 95%) in each representative unit and range-wide, given each of the seven scenarios. Like in the current conditions analysis, in addition to a specific population's persistence probability, each model iteration recorded the number of populations persisting at each time step in each representative unit and range-wide. We used all model iterations to calculate the mean (the most likely prediction) and 95% confidence intervals for the number of persisting populations in each representative unit and range-wide each year. Similar to results for current conditions, the mean number of persisting populations approximately equals the number of populations with a 50% or greater persistence probability. We summarized these outputs for three future time horizons: 2040, 2060, and 2080.

3. Results & Discussion

3.1 Current and historical populations

We obtained 2,227 southern hognose snake records from years 1880-2018. Many of the early occurrence records were for the county only and no coordinates were available for these records. The occurrence records were spread throughout the species range, but a majority of the records came from the Upper Coastal Plain (Carolinas) representative unit (Table B-5). From these records, we identified 222 potential populations of southern hognose snakes (Fig B-1). Of the total pool of records and populations, we used 2,196 occurrence records grouped into 204 populations within the analysis area to fit the persistence model and simulate future persistence. The remaining 31 occurrence records that fell outside of the analysis area were grouped into 18 populations. All of these records were found prior to 1975 and likely represent extirpated populations, and thus are included in our analysis as extirpated.

3.2 Predictor effects on current persistence

Out of the 69 years we modeled (1950-2018), the mean number of years southern hognose snakes were found in a population was 2.67 (range = 1 to 45). From the search effort dataset, the number of observer-days per year per population ranged from 0 to 82 (mean = 0.167), and records of non-target species came from 124 of 204 (60.8%) populations within the analysis area.

The persistence model showed adequate convergence and fit to the data, as assessed with traditional practices (MCMC chains were mixing well, posterior predictive checks showed agreement between metrics calculated from data simulated with the model and the real dataset, Brooks-Gelman-Rubin statistics < 1.1 for all parameters). As estimated in the persistence model, persistence varied considerably by population but was positively and significantly influenced by mean habitat suitability and number of populations within 10 km (Table B-3, Fig B-7). Persistence was also positively influenced by the proportion of protected area, but the effect was not as strong as the other predictors, with the 95% BCIs slightly overlapping 0 (Table B-3, Fig B-7). Mean annual persistence rates were similar across representative units. The baseline detection rate – the probability of detecting at least one hognose in a population in a given year – was low (0.01) but the significant positive effect for p_{beta} shows detection rates have increased gradually over time. The effect of the effort index on detection was slightly – but not significantly – positive.

Relationships between persistence and site predictors agree with expert judgment that the species generally uses and survives best in fire-dependent, xeric habitat (e.g., longleaf pine sandhills) – attributes that are associated with a higher Habitat Suitability Index (Appendix A). It is also reasonable that populations on protected lands likely have a reduced risk to direct threats such as habitat loss, road mortality, and collection, especially if protected lands have been established and managed for conservation goals over longer periods, which would cause higher population persistence probabilities. The strong relationship between number of populations within 10 km and persistence could support that nearby populations may provide opportunities for "rescue" where recolonization can occur after a catastrophe or could provide a signal that there are localized conditions (e.g., geological, climatic) that promote long-term population persistence that have not been otherwise captured in our analyses. However, we caution that this relationship is somewhat phenomenological without further research into dispersal capabilities of the species to inform the degree that populations within 10 km of each other could interact. Additional search effort in suitable looking areas between nearby populations may also be warranted. It is almost certain that the dataset of hognose locations does not include every area where the species exists, so it is possible that areas between 2 or more populations within 10 km are also occupied, which would represent larger, more connected populations that may have higher persistence. Again, innovative future research is needed to better assess individual movement patterns and population dynamics of this species while dealing with challenges of low detection rates.

3.3 Current conditions

3.3.1 Current resiliency

As mentioned previously, we used the model to derive the probability that each population was still persisting in 2018 (current persistence), and we summarized range-wide patterns of resiliency using the proportion of populations at or above a certain persistence threshold. Overall, resiliency, as measured by number of extant populations, has decreased for this species range-wide. Across the species' range, 89 of 222 (40%) delineated populations had a probability of current persistence greater than 50%, 68 (31%) had a probability of current persistence greater than 80%, 59 (27%) had a probability of current persistence greater than 90%, and 49 (22%) had a probability of current persistence greater than 95% (Table B-4; Fig. 8). We have likely lost at least 59.9% of southern hognose snake populations (i.e., populations with a less than 50% probability of current persistence). Each representative unit has likely lost between 50% and 100% of their total populations (Table B-5).

At the population level, current persistence was equal to 1 for populations where hognose snakes were observed in 2018 and generally decreases with years since the last observation (Fig B-9). We report mean persistence estimates and 95% confidence intervals for each population in Table B-6. A few populations have not been observed since 1972 but had higher current persistence probabilities, relative to other populations not observed since then (Fig B-9). Most of these populations had favorable site-level conditions (i.e., high habitat suitability, proportion of protected land, and nearby other populations; Table B-6), and none had any known search effort in years following the last observation according to our records. Because of these conditions, the model predicted these populations had a higher chance of persistence than average for populations not observed since the 1970s. While conducting additional searches at any site would improve the accuracy of model estimates, searching populations like these that 1) have had many years pass since an animal was observed and 2) have not been searched since then may especially change estimates of current persistence. It is possible that some populations with a relatively high probability of current persistence may have become extirpated recently. Alternatively, some populations with a low probability of persistence have not been surveyed in many years, but contain areas with suitable habitat that make it possible they are still extant but have not been recently detected.

3.3.2 Current representation and redundancy

We examined patterns of population persistence across representative units to characterize representation and redundancy. Historically, the southern hognose snake had a wider-ranging distribution and exhibited some variability in ecoregion. Currently, for the nine representative units delineated across the geographic range of the species, based on ecoregions, two of the units (Alabama Central and West of the Mobile River in Alabama and Mississippi) currently have zero populations with a probability of current persistence greater than 50% (Table B-5). It is very likely that these two representative units are no longer occupied by the species. In addition, one unit (Atlantic Coastal Plain in GA and FL) has only one population that is likely to be persisting (current persistence greater than 80%) and one additional population that is more likely than not to be persisting (current persistence greater than 50% probability); it is likely this representative unit has lost 85.7% of its populations (Table B-5). Therefore, this unit is also at a higher risk of unit-wide extirpation and indicates the potential for further loss of representation. While these representative units have experienced changes in their respective environment, some longleaf pine habitat continues to be present on the landscape, yet the southern hognose snake is not. This suggests that the species has a very narrow ecological niche in both time and space and lacks the adaptive capacity needed to respond to rapid land use changes and other threats such as imported fire ants or feral hogs. The spatial distribution of likely extirpated populations suggests that the southern hognose snake has experienced a decrease in latitudinal and longitudinal variability (i.e., a range contraction), relative to its historic range extent. Specifically, all populations in the western portion of its range – the West (AL/MS) and Alabama Central representative units – and in the northeastern edge of the range are more likely than not to be extirpated. Within the occupied portion of the range, populations with higher persistence probabilities are spread throughout the range but exhibit a degree of clustering, which has left large areas lacking resilient populations (e.g., southern Alabama, middle Georgia, eastern Florida Peninsula, and coastal South Carolina). Because the Alabama Central unit represents a distinct ecoregion (Ridge and Valley) and associated habitats not existing in any other unit, extirpation of southern hognose snakes from this unit has decreased the species' representation in terms of ecological variability.

There has been a reduction in redundancy for the southern hognose snake within each representative unit, highlighted by the loss of the western units and that only two representative units (Florida Ridge and Alabama/Florida Panhandle) had at least 50% of their total populations currently existing at a level of 50% probability of persistence. In other words, each of the 9 representative units has likely lost at least 50% of their populations. Furthermore, all representative units have seen a reduction in the number of highly resilient populations, and many of those remaining populations exhibit a degree of spatial clustering within the unit (they tend to be clumped near each other), which has left portions of the unit no longer occupied. It is not surprising that the number of populations predicted to persist was lowest for the Alabama Central and Western representative units, where the species has not been observed since 1981. Range-wide redundancy for the southern hognose snake has been reduced from historic levels. Out of 222 populations, only 89 are more likely than not to be currently persisting (>50% probability), and even fewer populations are at or above the 80, 90, and 95% persistence thresholds. However, there are certain areas within the range of the southern hognose snake that populations are persisting on the landscape, and, in general, these are populations that are currently on land that is being managed, is currently protected, and the populations are near each other. Together, these results mostly corroborate previous studies and expert beliefs regarding the status of the southern hognose snake and provide quantitative patterns of persistence across the species' range.

3.4 Future conditions

3.4.1 Future habitat conditions

The spatial inputs used to predict habitat suitability and future persistence varied slightly between scenarios (Table B-7). Specifically, there were similar reductions of land cover, fire frequency, and habitat suitability index (HSI) due to projected urbanization and sea level rise across the low, medium, and high stressor scenarios. Across these scenarios, the average population lost between 12% of its compatible land cover (under low stressor levels) to 16% (under high stressor levels). Among the four management scenarios, the percent change in land cover, fire frequency, and HSI increased from decreased management to the protect even more populations scenarios. We note that populations were still predicted to experience some degree of compatible land cover loss for all management scenarios; however, the two management scenarios involving protection of more populations resulted in an increase in HSI for populations, on average.

3.4.2 Future resiliency

We used the simulation model to predict the future persistence probability for each of the 204 populations in the analysis area through the year 2080. We assumed that the 18 populations outside of the analysis area will remain unlikely to persist (i.e., extirpated) on the landscape. We followed similar steps to the current conditions analysis to summarize population resiliency across the species' range by reporting the number of populations in each category of persistence probability (50%, 80%, 90%, and 95%), and we report results for current conditions and the seven future scenarios in years 2040, 2060, and 2080 (Table B-8). We also show the spatial distributions of populations in each persistence category under current conditions, the most likely stressor scenario (medium stressor levels), and the highest degree of management (protect even more populations scenario) for comparison (Fig B-10). We note that the four management scenarios also included effects of urbanization and sea level rise at the medium stressor level.

For all scenarios, many populations that fell within the extremely likely on landscape (≥95%) and very likely on landscape (≥80%) threshold under current conditions were predicted to have lower persistence probabilities in the future and, thus, dropped to lower categories. However, the change in future persistence varied by scenario. The number and percentage of resilient populations (those in the higher persistence categories) decreased the most in the decreased management scenario and decreased least (but still decreased) in the protect even more populations scenarios, relative to current conditions. The three stressor scenarios resulted in nearly identical predictions of resiliency when assessed by number of populations in each persistence category. These patterns were seen across all future time horizons (2040, 2060, and 2080). Concurrently, we predicted the number and percentage of populations likely to be extirpated (<50%) to increase for all scenarios and future time horizons, relative to current conditions. Currently, 40% of populations had a probability of persistence greater than 50%. By 2040, this percentage dropped to between 33% (decreased management scenario) and 37% of populations (protect even more populations scenario). By 2060, between 28% and 34% of populations met this persistence threshold. By 2080, between 25% and 32% of populations met this persistence threshold. In other words, under no additional management (i.e., the three stressor scenarios), we estimated 12 or 13 additional populations will likely become extirpated by 2040, 26 or 27 populations will be extirpated by 2060, and 32 will be extirpated by 2080. Under the highest management effort (the protect even more populations scenario), we estimated that an additional 7 populations will likely become extirpated by 2040, 14 populations will be extirpated by 2060, and 19 populations will be extirpated by 2080.

We compared range-wide future conditions between the seven scenarios using the number of persisting populations predicted from the model in each year (Fig B-11), which highlighted several takeaways that are supported across the other summary tables and figures from the simulation analysis. First, there was substantial overlap in the confidence intervals around predictions for each scenario. This is expected since the simulation model accounted for uncertainty around parameter estimates from the current analysis, as well as random year-to-year stochasticity. Still, conclusions can be drawn by comparing mean predictions relative to one another. Second, the three stressor scenarios yielded nearly identical predictions of the number of persisting populations. This is not surprising since there were only minimal differences between the low and high threat scenarios in the amount of land cover loss, reduction in fire frequency, and HSI for populations, on average. Third, the decreased management scenario and improved management scenario only marginally reduced and increased, respectively, the mean number of persisting populations relative to the stressor scenarios. These two scenarios included the effects of stressors at their medium level as well as small adjustments to habitat management (a decrease or increase of 1 prescribed fire every 5 years) on lands that are currently protected. Fourth, the two scenarios representing highest management effort (the protect more populations and protect even more populations scenarios) yielded a greater number of persisting populations, on average. Comparing the outcomes of the improved management scenario vs. the two higher management effort scenarios highlights the value of protecting additional populations, rather than solely managing populations on currently protected lands, if one’s goal is to increase the number of persisting southern hognose snake populations in the future.

Because we predicted the number of populations to decline overall and at the upper persistence thresholds (>95% and >80%), resiliency for this species was reduced in all scenarios we tested. Habitat suitability was reduced under the three stressor scenarios, and although there was some improvement of habitat predicted from the management scenarios, the improvement was not substantial enough to overcome the habitat suitability reductions resulting from the influence of SLR and urbanization. As habitat suitability is reduced and populations are predicted to become extirpated, connectivity of habitats and those remaining populations will decrease, which is another factor that can potentially reduce future resilience for southern hognose snake.

3.4.3 Future representation and redundancy

There was some evidence of risk of loss of representation and redundancy in the future across all scenarios – especially the stressor scenarios that did not include additional management and the decreased management scenario. Again, we have summarized results in two ways to aid characterization of representation and redundancy: 1) we calculated the number of populations in each representative unit and range-wide that were at or above the 50, 80, 90, and 95% persistence probability thresholds (Table B-9), and 2) we calculated the mean (and 95% confidence intervals) number of persisting populations predicted directly by the simulation model for each representative unit and range-wide (Table B-10). Additionally, we created maps showing the number of populations in each representative unit in 2080 that were predicted to be above a 50% (Fig B-12), 80% (Fig B-13), and 90% (Fig B-14) probability of persistence. We did not include a map showing results for the 95% persistence threshold since only 1 unit (Upper Coastal Plain in Georgia and Florida) had any populations predicted to remain at this threshold in 2080. (Table B-9). We note that we categorized populations into persistence threshold using mean estimates of persistence, and there is uncertainty around these estimates. We report mean persistence estimates and 95% confidence intervals for each population in Table B-11.

Again, we define redundancy as the number of populations above a certain threshold or the number of persisting populations predicted by the model. We can assume that the risk of an entire representative unit becoming extirpated increases as the number of populations predicted to persist within that unit decreases. Therefore, we interpret a higher risk of loss of representation when a representative unit has 0 populations above a certain persistence threshold, moderate risk when a unit has 1 or 2 populations above a certain threshold, and lower risk when a unit has 3 or more populations above a certain threshold. We discuss the risk for particular units in relative terms to other units.
Redundancy, as measured by the number of populations above the 50, 80, 90, and 95% persistence threshold (Table B-9), decreased in all scenarios, time periods, and representative units, relative to current conditions. We note that we report cumulative numbers of populations at or above a persistence threshold in Table B-8 and Table B-9. In other words, a value in the 80% category indicates the number of populations with probabilities of persistence between 80 and 100%.

Two of nine representative units (Alabama Central and West of the Mobile River in Alabama and Mississippi) were likely to be extirpated currently and under all future scenarios (i.e., they had 0 populations with a greater than 50% probability of persistence).

For the three stressor scenarios, future conditions were nearly identical for all representative units regardless of different threat levels captured by the scenarios. One representative unit (Atlantic Coastal Plain in Georgia and Florida) was predicted to have only 1 remaining population with a greater than 50% probability of persistence by 2080 (orange cells in Table B-9; Fig B-12). This representative unit, the two units predicted to be currently extirpated, and four additional units (7 of 9 total units) were predicted to have 0 remaining populations with a greater than 90% probability of persistence by 2080 (Fig B-14), and no unit had a population with a 95% or greater persistence probability in 2080 (red cells in Table B-9). Thus, the Atlantic Coastal Plain in Georgia and Florida is predicted to be at the highest risk of extirpation, relative to the other units, and indicates the potential for losing representation of the species in this unit in the future. Two representative units, the Upper Coastal Plain in Georgia and Florida and the Alabama and Florida Panhandle, were predicted to have at least 1 population above the 90% persistence probability threshold and at least 6 above the 50% threshold in 2080 under the three threat scenarios. With this higher redundancy of resilient populations (i.e., those with high persistence probabilities), these two representative units have a lower risk of unit-wide extirpation relative to other units. The Upper Coastal Plain unit had the highest number of populations currently and was predicted to maintain much of its redundancy in the future. On the other hand, the Alabama and Florida Panhandle unit had much fewer populations currently, but many of them were clustered on Eglin Air Force Base – a protected area with the highest habitat suitability index in the species' range. Despite having fewer populations currently, multiple populations in this unit were predicted to persist over time due to these favorable conditions.

For the four management scenarios, similar patterns emerged. Future conditions were similar between the stressor scenarios and the improved management scenario: five additional representative units were predicted to have 0 remaining populations with a greater than 90% probability of persistence by 2080 (Fig B-14), and the Atlantic Coastal Plain in Georgia and Florida unit was also predicted to have only 1 remaining population with a greater than 50% probability of persistence by 2080 (Fig B-12). No unit was predicted to have any populations with a greater than 90% persistence probability under the decreased management scenario. Four of 9 units were predicted to have 0 remaining populations meeting the 90% persistence threshold in 2080 under the two scenarios where more populations were protected (Fig B-14). By examining differences between the improved management scenario and the two scenarios with higher management effort in Table B-9 and Fig B-14, the additional protection for populations was predicted to allow at least one population to persist with a probability greater than 90% in the Atlantic Coastal Plain in the Carolinas, Florida Peninsula, and Florida Ridge representative units. Under improved management, these units were predicted to have 0 populations meeting the 90% threshold. Although the protect even more populations scenario resulted in the 2 currently existing populations to be likely to persist to 2080 in the Atlantic Coastal Plain in Georgia and Florida unit, this unit was still predicted to have 0 populations with a greater than 90% persistence probability for all scenarios. Again, these results indicate that this unit may be experiencing the highest risk of loss of redundancy and extirpation, relative to other representative units in the southern hognose snake range.

In addition to summarizing future conditions using the number of populations meeting a certain persistence probability threshold, we present the mean number of populations still persisting (and 95% confidence intervals), as predicted directly from the simulation model. The means represent the most likely outcome in the future. One can see that the means in Table B-10 are relatively close (± 2 populations) to the number of populations above a 50% persistence probability in Table B-9. We used cell shadings in Table B-10 to highlight relative risks to losing redundancy within a representative unit. Future predictions were similar across the three stressor scenarios, and these scenarios predicted an average of 56 of 222 populations persisting in 2080. As before, the Atlantic Coastal Plain in Georgia and Florida was the representative unit with a higher risk of losing redundancy, relative to other units, since the 95% confidence intervals included 0 populations persisting in 2080. The Florida Ridge unit had a moderate risk of losing redundancy as the lower 95% confidence interval included only 2 populations persisting in 2080. All other units (besides the two units that are presumed to be currently extirpated) were predicted to have a lower risk of losing redundancy, since all units had lower confidence intervals that included 3 or more populations predicted to persist in 2080 under all stressor scenarios.

For the four management scenarios, two important takeaways emerged. First, the three management scenarios representing additional effort reduced the risk of losing redundancy, as seen by increases in the lower confidence intervals, for two representative units in 2080. The lower confidence interval increased from 0 to 1 population persisting in the Atlantic Coastal Plain in Georgia and Florida unit; the lower confidence interval increased from 2 to 3 or more populations persisting in the Florida Ridge unit. Second, the range-wide mean number of persisting populations predicted under the improved management scenario was only 2 higher than the stressor scenarios. In comparison, the protect more populations scenario resulted in 8 more populations persisting and the protect even more populations scenario resulted in 10 more populations persisting in 2080, relative to stressor scenarios. These results indicate that strategies involving improved management and the protection of additional populations may be especially necessary for the Florida Ridge and Atlantic Coastal Plain in Georgia and Florida if one's goal is to maintain higher levels of redundancy and reduce the risk of extirpation of southern hognose snakes in these units.

4. Limitations & conclusions

In any status assessment of a species, the process of modeling population conditions and projecting those into the future requires making strategic simplifications of reality, accounting for multiple uncertainties, and making informed assumptions when necessary. The level of uncertainty is especially high for a species as difficult to detect (and study) and data-limited as the southern hognose snake. Still, this assessment addressed some of the uncertainties and yielded useful predictions for characterizing the species' status through the use of predictive models and multiple scenarios that captured a range of possible conditions in the future. We highlight and explain some of the key limitations and assumptions of the analyses below.

Quantitative models are essential tools for capturing the dynamics of complex, ecological systems, predicting species' outcomes, and informing conservation decisions for at-risk and listed species (Morris, et al., 2002, entire; McGowan, et al., 2017, entire). We developed three types of models in our analyses, (1) the habitat suitability model, (2) a current persistence model, and (3) a future simulation model. Each one, like all models, required simplifications and assumptions about the underlying ecological systems. Our models generated specific quantitative results, but these should be interpreted as estimates rather than precise predictions of reality. For example, the results of the habitat suitability model represented areas of relatively high and low suitability based on a set of predictors; however, a specific site may have additional factors, such as presence of non-native invasive species or a history of over-collection, that we were not able to pick up on in the model.

We were not able to include all the factors that may be influencing viability for the southern hognose snake (Chapter 3) because spatial data for these stressors was not available across the species' range or at all, such as impacts from invasive feral hogs and red imported fire ants. These limitations likely did not hinder the reliability of results from the habitat suitability model since we included several of the most influential factors identified in the literature and by expert judgment as predictors – specifically, soil drainage, compatible land cover, and fire frequency. Simplifications were also made in the persistence model where we only included three predictors even though an infinite number of factors could influence population persistence locally; however, we again used the best available data and expert judgment for the southern hognose snake and its ecological systems to include factors believed to be most influential. Subsequently, the results of this assessment tended to agree with expert judgment and previous studies characterizing trends in southern hognose snake habitat use and population persistence. We also projected population outcomes under multiple scenarios using the same model structure, and although there was uncertainty around all model predictions, one can consider and compare the range of plausible future conditions predicted across scenarios to effectively evaluate relative risks to the species.

We delineated 222 populations that served as the primary units for analyses, but creating these population boundaries required a set of assumptions that are important to consider when interpreting the results. Most importantly, we assumed that our full database of species locations, which came from datasets maintained by a network of major State and Federal agencies and other researchers and served as the basis for delineating populations, adequately represented the distribution of southern hognose snake populations in the Southeast. While the full dataset likely captured most of the areas occupied by southern hognose snakes, it likely did not capture all of the occupied areas due to the cryptic nature of the species and lower search effort and data availability from private lands that may contain suitable habitat. In other words, our analyses presented results from these 222 populations, but it is possible that additional, undocumented populations exist. Moreover, we made other informed assumptions after consulting with published studies and species experts to delineate populations, such as using NatureServe's recommendations for small terrestrial snakes to group points together in the same population that fell within 5 km of each other. We also assumed large rivers and interstate roads are substantial barriers to southern hognose snake movement and would effectively separate populations on opposite sides. The full set of assumptions resulted in identifying 222 populations, but there is some uncertainty around this number if any of those assumptions is violated. Still, we employed a transparent and collaborative process to delineate populations and develop models, and while assumptions are unavoidable, they were based on best available information and supported by previous studies and species experts.

Models used in current and future conditions hinged on a novel approach estimate persistence of populations, but we had to make several assumptions about how persistence probability was related to population resiliency. First, we assumed if the population is currently on the landscape then it must display some level resiliency for it to have persisted all this time. Secondly, most likely larger populations will have a higher current persistence probability than smaller populations. Third, we assumed the more resilient populations are more likely to occur in highly suitable habitat, on protected lands and in proximity to other populations. Since we were able to account for these factors in our model, populations that meet these factors most likely have higher current persistence probability and therefore, more resiliency. Persistence was estimated while accounting for imperfect detection, which was informed by evidence that an area was searched and other non-target snake species were observed whether or not southern hognose snakes were observed as well. We used records of 13 non-target species that experts identified as commonly found during surveys for southern hognose snakes. However, many non-target species are also found in more mesic habitats not used by southern hognose snakes. By using these non-target species records within population boundaries, we assumed that either 1) non-target species were found in the same habitat as southern hognose snakes or 2) non-target species were in adjacent habitats and the surveyor (often conducting road surveys) extended the search into upland habitats used by southern hognose snakes. If a large proportion of non-target records were actually found in adjacent habitats, our approach could underestimate detection probability and increase uncertainty of persistence estimates. However, our assumptions seem reasonable based on expert input and the nature of road surveying methods commonly used when reporting non-target species, and the model captured any uncertainty related to detection when estimating persistence. Still, the accuracy and certainty of model estimates would improve with true presence-absence data from systematic surveys that is not currently available across the southern hognose snake's range.

While persistence probability is a reasonable indicator of resilience, we did not explicitly account for further dynamics within the population (e.g., increases in recruitment, abundance) or between populations (e.g., colonization rates between neighboring populations) that could influence viability. More complex models (e.g., population viability analysis) exist that directly estimate these biological processes; however, they require basic life history and demographic information that have not been estimated for southern hognose snakes. It is possible that our models are under or overestimating persistence for certain populations by not explicitly estimating other processes like recruitment or colonization. Accounting for fragmentation would require fine-scale information about southern hognose snake movement capabilities through different habitat types that is not currently available.

However, biological processes like recruitment and colonization are represented, at least to some degree, in the set of predictors of annual persistence. We can assume that the predictor of HSI, which was positively related to the annual persistence probability, is also positively related to recruitment and survival rates for a population as the habitat it occupies contains more compatible land cover, forage, and fewer anthropogenic threats. Similarly, we did not explicitly estimate colonization between populations, but this process was represented by including the number of nearby populations as a predictor a population's annual persistence probability. We also acknowledge that many – or most – population boundaries include some proportion of unsuitable habitat that, in some cases, could be causing a single population defined in our study to be functioning as several isolated subpopulations. It is likely that smaller, isolated subpopulations would each have lower growth rates and persistence probabilities than a single large population. Directly accounting for fragmentation would require fine-scale information about southern hognose snake movement capabilities through different habitat types that is not currently available. However, we found in preliminary analysis for the habitat suitability models (Appendix A) that mean HSI was related to the amount and connectivity of suitable habitat in populations; thus, we can assume that including HSI as a predictor of persistence also partially accounted for the influence of fragmentation in a boundary. Even without explicitly estimating recruitment or colonization rates, the model structure allows for populations to be stable (i.e., persist and not become extirpated over time) over time, which is useful for assessing the degree and distribution of risk of extinction for populations across the species' range. Still, improving the quality and quantity of data for southern hognose snakes in the future will greatly improve predictions of population outcomes using additional types of models.

Finally, as previously stated, the habitat suitability model was based on a set of predictors, but there are likely other important climate related factors that were not included in the model, but are likely to affect habitat suitability and population persistence. Although we did include the projected impacts of sea level rise to habitat suitability, there are many other probable climate change related impacts that we were not able to model. For example, projected increases in temperature and decreases in precipitation due to climate change are likely to further constrain the ability to implement prescribed fire, which would lower habitat suitability and consequently population persistence for most, if not all populations of southern hognose snake. Also, projected increases in mean temperature will result in increases in soil temperature, which has the potential to negatively impact burrowing species such as the southern hognose snake. Additionally, there is a great amount of uncertainty in how the longleaf pine ecosystem will respond to climate change (e.g. range contraction vs shifting range), and any changes in the total acreage or distribution of longleaf pine will likely impact the southern hognose snake.

All source datasets used were developed by entities outside the USFWS. The quality and accuracy of these data (ecological and spatial) may vary. Actual, on-the-ground, quality and/or condition of mapped habitat suitability is not addressed. No field verification or reviews of ancillary datasets/aerial imagery were done to verify the accuracy of the data. Raster data has a minimum spatial resolution of 30 m. This dataset, analysis, and all maps/products created from it are subject to change.

Acknowledgments

This work is funded and supported by the U.S. Fish & Wildlife Service (USFWS) through the Gulf Coastal Plains & Ozarks Landscape Conservation Cooperative, the Natural Resources Conservation Service (NRCS), and the Southeast Climate Science Center (SECSC). We thank Clint Moore (USGS Georgia Cooperative Fish and Wildlife Research Unit, University of Georgia), John Maerz (University of Georgia), and Mike Harris and D. Todd Jones-Farrand (USFWS- Region 4) for guidance and support toward all analyses. We thank the SSA expert team – consisting of Jeff Hall, Jeff Humphries, and Mike Martin (North Carolina Wildlife Resources Commission), Nathan Shepard (North Carolina Natural Heritage Program), Andrew Grosse (South Carolina Department of Natural Resources), John Jensen (Georgia Department of Natural Resources), Kevin Enge (Florida Fish and Wildlife Conservation Commission), Jeffrey Beane (North Carolina Museum of Natural Sciences), Jeff Camper (Francis Marion University), and Tracey Tuberville (University of Georgia Savannah River Ecology Laboratory) – for their substantive information and/or insights for our SSA analyses. In addition to the expert team, we thank Chris Smith (HerpMapper.org), Annalee Tutterow (Davidson College), Will Dillman (South Carolina Department of Natural Resources), Kurt Buhlmann (University of Georgia Savannah River Ecology Laboratory), Matt Elliott (Georgia Department of Natural Resources), Lora Smith, Jen Howze, and Beth Schlimm (Jones Ecological Research Center), Roy King (US Army, Ft. Stewart) Ericha Shelton-Nix and Ashley Peters (Alabama Department of Conservation and Natural Resources), David Laurencio and Michael Barbour (Auburn University), and Nicole Hodges (Mississippi Wildlife, Fisheries, and Parks) for providing species records.

Literature Cited

Beane, J.C., Graham, S.P., Thorp, T.J., Pusser, L.T., 2014. Natural history of the southern hognose snake (*Heterodon simus*) in North Carolina, USA. Copeia 2014, 168-175.

Beissinger, S.R., Westphal, M.I., 1998. On the use of demographic models of population viability in endangered species management. Journal of Wildlife Managemen, 821-841.

Brooks, S.P., Catchpole, E.A., Morgan, B.J., 2000. Bayesian animal survival estimation. Statistical Science 15, 357-376.

Chaudhuri, G., Clarke, K., 2013. The SLEUTH land use change model: A review. Environmental Resources Research 1, 88-105.

Enge, K.M., Wood, K.N., 2002. A pedestrian road survey of an upland snake community in Florida. Southeastern Naturalist 1, 365-380.

Gelman, A., Goegebeur, Y., Tuerlinckx, F., Van Mechelen, I., 2000. Diagnostic checks for discrete data regression models using posterior predictive simulations. Journal of the Royal Statistical Society: Series C (Applied Statistics) 49, 247-268.

Gibbons, J.W., Scott, D.E., Ryan, T.J., Buhlmann, K.A., Tuberville, T.D., Metts, B.S., Greene, J.L., Mills, T., Leiden, Y., Poppy, S., 2000. The Global Decline of Reptiles, Déjà Vu Amphibians. BioScience 50, 653-666.

HerpMapper, 2018. HerpMapper - A Global Herp Atlas and Data Hub. Iowa, U.S.A. Retrieved 01-12-2018, from http://www.herpmapper.org.

Kery, M., Dorazio, R.M., Soldaat, L., Van Strien, A., Zuiderwijk, A., Royle, J.A., 2009. Trend estimation in populations with imperfect detection. Journal of Applied Ecology 46, 1163-1172.

Kery, M., Schaub, M., 2012. Bayesian Population Analysis Using WinBUGS: A Hierarchical Perspective. Academic Press, Waltham, Mass.

Lebreton, J.-D., Burnham, K.P., Clobert, J., Anderson, D.R., 1992. Modeling survival and testing biological hypotheses using marked animals: A unified approach with case studies. Ecological Monographs 62, 67-118.

MacKenzie, D.I., Nichols, J.D., Hines, J.E., Knutson, M.G., Franklin, A.B., 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. Ecology 84, 2200-2207.

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Andrew Royle, J., Langtimm, C.A., 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83, 2248-2255.

McGowan, C.P., Allan, N., Servoss, J., Hedwall, S., Wooldridge, B., 2017. Incorporating population viability models into species status assessment and listing decisions under the US Endangered Species Act. Global Ecology and Conservation 12, 119-130.

McGowan, C.P., Catlin, D.H., Shaffer, T.L., Gratto-Trevor, C.L., Aron, C., 2014. Establishing endangered species recovery criteria using predictive simulation modeling. Biological Conservation 177, 220-229.

McGowan, C.P., Ryan, M.R., 2010. Arguments for using population models in incidental take assessments for endangered species. Journal of Fish & Wildlife Management 1, 183-188.

Morris, W.F., Bloch, P.L., Hudgens, B.R., Moyle, L.C., Stinchcombe, J.R., 2002. Population viability analysis in endangered species recovery plans: Past use and future improvements. Ecological applications 12, 708-712.

NatureServe, 2018. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.0. NatureServe, Arlington, VA. U.S.A. Retrieved 4 December 2018, from http://explorer.natureserve.org.

Outcalt, K.W., Sheffield, R.M., 1996. The longleaf pine forest: trends and current conditions, In Resource Bulletin SRS-9. p. 28. USDA Forest Service, Southern Research Station, Asheville, NC.

Pickens, B.A., Marcus, J.F., Carpenter, J.P., Anderson, S., Taillie, P.J., Collazo, J.A., 2017. The effect of urban growth on landscape-scale restoration for a fire-dependent songbird. Journal of Environmental Management 191, 105-115.

R Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Su, Y., Yajima, M., 2012. R2jags: A package for running JAGS from R.

Terando, A.J., Costanza, J., Belyea, C., Dunn, R.R., McKerrow, A., Collazo, J.A., 2014. The southern megalopolis: Using the past to predict the future of urban sprawl in the Southeast US. PLoS One 9, e102261.

Theobald, D.M., Romme, W.H., 2007. Expansion of the US wildland–urban interface. Landscape and Urban Planning 83, 340-354.

Tuberville, T.D., Bodie, J.R., Jensen, J.B., LaClaire, L., Gibbons, J.W., 2000. Apparent decline of the southern hog-nosed snake, *Heterodon simus*. Journal of the Elisha Mitchell Scientific Society, 19-40.

Willson, J.D., Pittman, S.E., Beane, J.C., Tuberville, T.D., 2018. A novel approach for estimating densities of secretive species from road-survey and spatial-movement data. Wildlife Research 45, 446-456.

Table B-1. List of predictors used to model southern hognose snake population persistence, the hypothesized relationships to population resilience, and the average and range of predictors across 204 populations modeled.

Site condition predictor	Biological justification	Mean (range)
Habitat Suitability Index (HSI)	Higher habitat suitability (predicted by our habitat analysis in Appendix A) represents areas of higher quality (well-drained, sandy soils, compatible forest/grassland landcover, frequent fires) that should increase hognose survival, recruitment, and persistence. The average HSI within a population boundary is highly correlated to the amount of suitable habitat.	22% (0 – 83.2%)
Proportion protected	Higher proportions of a population protected should increase habitat quality through regular management practices and may limit direct threats such as road mortality and collection.	21.1% (0 – 100%)
No. of populations within 10 km	Populations close to (within 10 km) of other populations may have a higher chance of long-term persistence. Nearby populations may provide opportunities for "rescue" where recolonization can occur after a catastrophe; alternatively, nearby populations could provide a signal that there are localized conditions (e.g., geological, climatic) that promote population persistence that have not been otherwise captured in our analyses.	1.8 (0 – 7)

Table B-2. Future Scenario Summary. List of scenarios used to project future habitat suitability and population persistence for the southern hognose snake. Note: SLR represents inundation levels at 2080.

Scenario Name	Urbanization	Sea Level Rise	Management Level
Low Stressors	Low (90%)	Low (1ft)	Status Quo
Medium Stressors	Medium (50%) (most likely)	Medium (3ft) (most likely)	Status Quo
High Stressors	High (10%)	High (6ft)	Status Quo
Decreased Management	Medium (50%) (most likely)	Medium (3ft) (most likely)	Decreased e management effort on protected lands by decreasing fire frequency by 20% (One less burn every 5 years).
Improved Management	Medium (50%) (most likely)	Medium (3ft) (most likely)	Increased management on protected lands by increasing fire frequency by 20% (One extra burn every 5 years).
Protect More Populations	Medium (50%) (most likely)	Medium (3ft) (most likely)	Acquire, protect, and improve additional land within population boundaries for those populations that are very likely to currently persist (> 80% current persistence probability) but are not currently protected and improve mgmt. on all protected lands by increasing fire frequency by one extra burn every 5 years.
Protect Even More Populations	Medium (50%) (most likely)	Medium (3ft) (most likely)	Acquire, protect, and improve additional land within population boundaries for those populations that are more likely than not to persist (> 50% current persistence probability) but are not currently protected and improve mgmt. on all protected lands by increasing fire frequency by one extra burn every 5 years.

Table B-3. Parameter estimates (means and 95% Bayesian credible intervals) for the persistence model predicting the probability of persistence and detection between 1950 and 2018 for 204 populations of southern hognose snakes. Posterior parameter estimates that do not overlap zero are interpreted as ecologically important.

Parameter	Mean	Lower 95%	Upper 95%
Persistence			
φ_{UCPC}	0.967	0.944	0.984
φ_{UCPG}	0.969	0.952	0.982
φ_{ACPC}	0.969	0.949	0.985
φ_{ACPG}	0.933	0.874	0.974
φ_{PEN}	0.939	0.896	0.970
φ_{RID}	0.928	0.856	0.973
φ_{PAN}	0.943	0.904	0.971
φ_{W}	0.933	0.864	0.976
β_{HSI}	3.074	1.595	4.682
$\beta_{protect}$	0.748	-0.079	1.643
$\beta_{connect}$	3.782	2.208	5.445
Detection			
p_{mean}	0.012	0.009	0.014
p_{beta}	0.043	0.038	0.049
p_{effort}	0.007	-0.045	0.053

Parameter notations: φ – representative unit effects on annual persistence; β – site condition effects on persistence; p – mean, slope, and effort effects on detection. Representative unit codes: UCPC – Upper Coastal Plain (Carolinas); UCPG – Upper Coastal Plain (GA/FL); ACPC – Atlantic Coastal Plain (Carolinas); ACPG – Atlantic Coastal Plain (GA/FL); PEN – FL Peninsula; RID – FL Ridge; PAN – AL/FL Panhandle; W – West (AL/MS).

Table B-4. Number and percentage of southern hognose snake populations in each persistence category and the cumulative number of populations at or above each threshold.

Population persistence	Number of populations in each category	% of total	Cumulative number of populations at or above each threshold	% of Total
Extremely Likely on Landscape (Extant) 95-100%	49	22.1%	49	22.1%
Highly Likely on Landscape 90-94.9%	10	4.5%	59	26.6%
Very Likely on Landscape 80-89.9%	9	4.0%	68	30.6%
More Likely than Not 50-79.9%	21	9.5%	89	40.1%
Unlikely < 50% (Extirpated)	133	59.9%	-	-
Total	222	100%		

Table B-5. Southern hognose snake summary statistics of number of occurrence records, number of populations (pops) grouped by year of last observation and persistence probability threshold, and estimated probabilities of current persistence for representative units and range-wide. Cell shadings indicate representative units that have 0 populations (red), 1 or 2 populations (orange), or 3 or more populations (green) above each persistence threshold.

			No. of pops with observations		**No. of pops above persistence threshold (as percentage of no. pops/unit)**						
Representative unit	**No. of records**	**No. of pops total**	**after 1970**	**after 2000**	**50%**	**80%**	**90%**	**95%**	**Mean pop persistence**	**Prob. of ≥ 1 pop persisting**	**Prob. of ≥ 2 pops persisting**
Upper Coastal Plain (Carolinas)	1438	30	24	10	11 (36.7%)	7 (23.3%)	4 (13.3%)	3 (10.0%)	41.2%	100.0%	100.0%
Upper Coastal Plain (GA/FL)	285	58	44	30	28 (48.3%)	25 (43.1%)	23 (39.7%)	20 (34.5%)	51.5%	100.0%	100.0%
Atl. Coastal Plain (Carolinas)	117	34	25	14	13 (38.2%)	8 (23.5%)	7 (20.6%)	6 (17.6%)	43.5%	100.0%	100.0%
Atl. Coastal Plain (GA/FL)	32	14	10	5	2 (14.3%)	1 (7.1%)	1 (7.1%)	1 (7.1%)	29.2%	99.9%	95.5%
FL Peninsula	76	33	26	16	14 (42.4%)	12 (36.4%)	9 (27.3%)	6 (18.2%)	44.4%	100.0%	100.0%
FL Ridge	194	16	12	8	8 (50.0%)	8 (50.0%)	8 (50.0%)	7 (43.8%)	51.1%	100.0%	100.0%
AL/FL Panhandle	54	26	16	11	13 (50.0%)	7 (26.9%)	7 (26.9%)	6 (23.1%)	41.0%	100.0%	100.0%
West (AL/MS)	18	7	5	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1.3%	6.2%	1.3%
AL Central	13	4	0	0	-	-	-	-	-	-	-
Range-wide	2227	222	162	95	89 (40.1%)	68 (30.6%)	59 (26.6 %)	49 (22.1%)	43.8%	6.2%	1.2%

Table B-6. Southern hognose snake population summary statistics of number of occurrence records, last year observed, site-level conditions, mean and lower and upper 95% Bayesian credible intervals for current persistence - the probability of a population being extant in 2018. Cell shadings for current persistence indicate populations with > 90% (blue) and < 50% probabilities (red). Populations have been sorted by state and from highest to lowest current persistence probability. The table also includes the twelve populations in AL and NC that were outside the analysis area.

Pop ID	County	State	Total no. of records	Last year observed	Habitat Suitability Index	Proportion protected	No. of pops within 10 km	Current persistence prob. (%)		
								Mean	Lower 95%	Upper 95%
130	Baldwin	AL	4	1967	22.8	0.3	1	2.0	0.8	5.3
6	Baldwin	AL	1	1967	18.5	3.5	2	1.8	0.4	7.3
27	Covington	AL	4	1970	3.5	100.0	0	0.8	0.2	2.2
24	Escambia	AL	3	1966	10.8	61.8	0	0.6	0.1	2.1
25	Covington	AL	2	1970	1.1	0.3	0	0.3	0.0	1.4
13	Mobile	AL	3	1931	26.6	0.2	0	0.1	0.0	1.0
32	Dale	AL	1	1944	0.7	0.0	0	0.0	0.0	1.0
71	Choctaw	AL	1	1975	-	-	-	-	-	-
73	Autauga	AL	1	1910	-	-	-	-	-	-
77	Tuscaloosa	AL	1	1931	-	-	-	-	-	-
78	Shelby	AL	8	1966	-	-	-	-	-	-
79	Calhoun	AL	3	1968	-	-	-	-	-	-
3	Taylor	FL	2	2018	31.5	13.3	1	100.0	100.0	100.0
12	Leon	FL	28	2018	34.9	50.5	2	100.0	100.0	100.0
40	Lake	FL	10	2018	6.9	3.9	2	100.0	100.0	100.0
57	Gilchrist	FL	3	2018	68.3	1.8	4	100.0	100.0	100.0
61	Suwannee	FL	3	2018	49.8	21.5	5	100.0	100.0	100.0
149	Hernando	FL	64	2018	41.2	24.8	7	100.0	100.0	100.0
153	Marion	FL	16	2018	24.9	18.2	4	100.0	100.0	100.0
164	Hamilton	FL	7	2018	18.7	22.4	4	100.0	100.0	100.0
165	Hamilton	FL	8	2018	36.9	13.8	4	100.0	100.0	100.0
217	Walton	FL	1	2018	43.7	0.0	1	100.0	100.0	100.0
163	Madison	FL	32	2017	51.3	10.8	4	99.8	98.6	100.0
41	Hernando	FL	12	2017	30.7	27.7	5	99.5	98.2	99.9
15	Walton	FL	1	2015	81.1	100.0	2	99.4	98.2	99.9
51	Levy	FL	20	2017	26.5	8.1	5	99.3	97.8	99.8
66	Suwannee	FL	3	2014	38.4	5.1	6	99.3	97.8	99.8
132	Okaloosa	FL	13	2014	67.3	87.3	4	99.0	97.5	99.6
156	Dixie	FL	1	2016	25.1	5.3	6	99.0	97.5	99.6
69	Suwannee	FL	1	2014	64.0	3.3	3	98.9	97.5	99.6
62	Lafayette	FL	7	2015	21.1	9.0	5	98.9	97.5	99.6
133	Santa Rosa	FL	2	2015	42.4	74.8	4	98.8	97.1	99.5
150	Sumter	FL	8	2017	7.2	0.9	5	98.8	97.1	99.5
162	Columbia	FL	2	2016	6.3	8.7	3	97.9	96.1	99.0
48	Levy	FL	1	2016	38.1	2.1	2	97.2	95.1	98.5

129	Santa Rosa	FL	1	2011	74.0	99.9	2	97.0	94.8	98.3
11	Okaloosa	FL	1	2007	83.2	100.0	3	97.0	94.8	98.3
63	Columbia	FL	2	2013	16.0	0.4	5	96.8	94.5	98.1
161	Suwannee	FL	3	2013	30.1	15.2	3	96.3	93.9	97.7
58	Taylor	FL	7	2015	44.7	1.5	2	96.2	93.9	97.7
67	Columbia	FL	3	2013	16.1	0.0	4	96.0	93.6	97.5
152	Sumter	FL	5	2014	9.9	0.0	6	95.6	93.3	97.3
37	Pasco	FL	1	2011	43.7	16.0	3	92.5	89.5	94.7
60	Taylor	FL	1	2013	44.4	0.0	2	92.5	89.5	94.7
137	Liberty	FL	4	2012	36.8	41.7	1	92.5	89.5	94.7
34	Pasco	FL	1	2013	32.6	1.2	3	92.1	89.2	94.5
59	Columbia	FL	1	2010	38.0	9.7	4	91.3	88.1	93.6
166	Madison	FL	3	2014	12.7	3.8	1	91.0	87.8	93.4
7	Walton	FL	1	2005	80.3	99.9	2	90.8	87.5	93.2
46	Levy	FL	1	2011	24.3	0.0	4	88.8	85.3	91.5
155	Levy	FL	1	2009	28.3	47.3	4	88.0	84.4	90.8
159	Dixie	FL	2	2002	71.5	0.0	4	84.5	80.3	87.8
5	Bay	FL	1	2008	27.8	35.6	1	71.2	66.6	75.5
8	Walton	FL	2	2008	26.8	47.1	1	70.9	66.4	75.2
151	Sumter	FL	2	2007	9.9	38.4	3	67.7	63.0	72.1
45	Levy	FL	1	2004	9.6	88.8	3	67.0	61.5	72.1
14	Okaloosa	FL	1	1995	48.4	74.8	3	58.9	43.3	71.6
131	Escambia	FL	1	2008	26.2	0.7	1	58.7	53.9	63.5
134	Santa Rosa	FL	1	1994	52.0	82.9	2	55.6	43.3	67.5
20	Jefferson	FL	1	2005	19.3	21.0	0	53.9	48.9	58.6
16	Jackson	FL	1	2008	17.2	0.0	1	51.3	46.4	56.1
147	Hillsborough	FL	1	2003	12.9	45.4	2	45.8	40.9	50.6
68	Suwannee	FL	1	2003	6.8	21.1	1	43.8	38.2	49.5
38	Hernando	FL	1	1996	40.8	64.3	1	36.9	29.6	45.4
55	Gilchrist	FL	1	1992	32.2	2.4	4	30.7	25.6	36.3
53	Gilchrist	FL	1	1972	66.2	10.7	4	25.3	11.8	48.8
36	Pasco	FL	1	1982	48.5	7.8	2	14.8	9.6	21.7
64	Lafayette	FL	1	1973	58.5	8.0	2	14.3	5.3	29.7
145	Hillsborough	FL	1	1994	12.6	0.0	2	14.1	10.5	18.4
54	Taylor	FL	1	1983	38.6	52.5	2	11.9	7.1	18.6
136	Leon	FL	1	1984	16.3	8.0	1	11.8	9.0	15.3
42	Citrus	FL	1	1984	34.7	12.6	1	10.8	8.1	14.2
35	Pasco	FL	1	1979	38.2	8.6	1	8.4	5.0	14.4
56	Alachua	FL	1	1969	33.6	0.0	4	8.0	5.7	11.1
157	Levy	FL	1	1960	69.7	13.9	6	6.5	2.7	16.4
49	Marion	FL	3	1970	8.8	100.0	2	4.5	2.0	9.0
21	Jefferson	FL	1	1953	27.0	17.2	1	4.4	2.9	7.0
158	Alachua	FL	5	1983	3.3	15.0	3	4.2	1.8	11.5

18	Jackson	FL	1	1978	0.9	0.0	3	4.0	1.6	9.8
22	Leon	FL	1	1970	6.8	36.2	0	3.4	0.9	9.1
4	Escambia	FL	3	1969	54.0	0.0	1	3.4	2.1	5.8
135	Gadsden	FL	1	1968	14.1	2.3	2	3.1	1.2	7.6
2	Escambia	FL	1	1904	7.3	49.7	2	2.9	0.5	9.6
52	Putnam	FL	1	1975	2.5	90.0	2	2.9	1.7	5.2
154	Marion	FL	14	1970	4.4	18.7	4	1.8	0.9	4.2
160	Alachua	FL	27	1975	1.5	25.3	3	1.6	0.6	4.0
39	Orange	FL	1	1969	14.8	0.7	1	1.3	0.5	3.0
17	Gadsden	FL	1	1933	9.6	0.6	1	1.1	0.0	4.6
138	Calhoun	FL	2	1959	3.2	3.2	2	0.8	0.3	2.7
50	Taylor	FL	1	1969	15.4	30.3	1	0.8	0.2	2.4
146	Hillsborough	FL	1	1963	14.8	5.1	2	0.7	0.1	3.0
144	Pinellas	FL	1	1969	5.4	1.6	0	0.7	0.2	2.2
47	Marion	FL	1	1919	5.7	55.4	2	0.7	0.0	3.7
167	Duval	FL	1	1959	13.6	1.5	0	0.6	0.2	2.2
65	Lafayette	FL	1	1976	10.9	0.0	1	0.5	0.1	1.8
148	Orange	FL	2	1950	13.6	0.2	1	0.4	0.0	1.9
33	Pinellas	FL	1	1969	12.5	3.3	0	0.3	0.0	1.4
216	Franklin	FL	1	1968	4.7	34.6	1	0.3	0.0	1.4
1	Escambia	FL	1	1952	3.5	38.1	1	0.3	0.0	1.4
44	Marion	FL	1	1914	2.4	24.1	2	0.2	0.0	1.4
140	Jackson	FL	1	1964	0.5	6.7	1	0.1	0.0	1.0
139	Holmes	FL	3	1969	0.5	0.0	0	0.1	0.0	1.0
43	Seminole	FL	1	1950	6.3	0.5	0	0.0	0.0	1.0
75	Marion	GA	43	2018	55.8	25.3	0	100.0	100.0	100.0
142	Baker	GA	50	2018	46.7	47.3	2	100.0	100.0	100.0
211	Burke	GA	25	2018	47.6	15.3	4	100.0	100.0	100.0
210	Screven	GA	2	2017	16.4	3.3	5	99.5	98.2	99.9
83	Long	GA	5	2017	27.9	100.0	3	99.4	98.2	99.9
97	Richmond	GA	21	2015	42.6	44.2	3	99.0	97.5	99.6
76	Bibb	GA	2	2017	9.4	0.1	0	97.3	95.1	98.5
181	Burke	GA	6	2015	15.8	10.5	2	96.2	93.9	97.7
173	Tattnall	GA	5	2016	4.5	34.2	1	96.1	93.6	97.5
31	Mitchell	GA	5	2013	42.6	5.4	2	95.9	93.6	97.5
72	Stewart	GA	1	2015	10.9	6.9	1	93.6	90.6	95.5
208	Screven	GA	2	2010	11.8	7.9	3	86.8	83.1	89.7
143	Baker	GA	1	2000	57.5	27.1	2	82.6	78.5	86.0
198	Effingham	GA	2	2008	41.5	0.2	2	74.4	69.7	78.3
141	Decatur	GA	3	2010	13.2	1.0	0	66.7	62.0	71.2
84	Tattnall	GA	1	2005	6.0	0.0	2	54.8	49.9	59.6
82	Liberty	GA	2	2000	18.9	100.0	2	48.9	44.1	53.9
174	Bryan	GA	2	2000	19.1	61.8	3	48.9	39.9	58.3

176	Bryan	GA	5	2000	22.6	57.6	2	44.8	40.0	49.6
29	Mitchell	GA	2	2000	10.3	1.0	2	43.1	38.0	48.2
28	Miller	GA	1	1997	24.8	5.1	1	41.0	36.3	45.9
98	McDuffie	GA	1	1998	16.3	2.9	1	32.4	28.1	37.2
93	Burke	GA	1	1987	11.2	0.2	4	26.8	17.1	39.0
170	Pulaski	GA	2	2000	7.8	0.9	1	25.8	18.2	34.3
81	Coffee	GA	1	1994	25.8	20.5	0	24.2	20.3	28.7
172	Dodge	GA	1	1999	3.6	4.0	1	23.4	19.6	27.9
95	Jefferson	GA	1	1994	7.8	0.0	1	15.1	11.8	18.8
85	Bulloch	GA	1	1985	35.0	4.5	2	14.9	11.8	18.8
74	Bleckley	GA	2	1980	4.2	10.1	1	7.5	4.9	11.6
177	Bryan	GA	2	1987	14.4	0.0	2	7.2	4.3	12.7
178	Effingham	GA	6	1984	7.7	0.8	3	5.9	3.8	9.3
168	Dougherty	GA	1	1959	30.0	5.8	1	5.1	1.1	19.6
94	Burke	GA	1	1973	21.4	4.8	2	4.7	2.1	9.7
175	Bulloch	GA	3	1974	7.5	0.0	1	4.6	2.8	7.7
169	Stewart	GA	1	1960	12.2	21.4	1	3.1	1.9	5.5
179	Effingham	GA	2	1974	13.9	0.8	2	3.0	1.7	5.2
88	Screven	GA	1	1975	20.5	1.9	1	2.6	1.4	4.7
90	Baldwin	GA	1	1977	0.0	0.0	0	2.2	1.2	4.2
23	Decatur	GA	1	1956	4.3	19.3	0	0.9	0.1	2.8
80	Irwin	GA	3	1957	5.3	0.3	0	0.8	0.1	2.8
171	Houston	GA	1	1941	5.1	3.2	0	0.7	0.0	3.9
30	Early	GA	1	1957	9.5	0.0	0	0.6	0.1	1.8
127	Wilcox	GA	1	1948	4.1	0.0	1	0.5	0.1	1.9
26	Thomas	GA	1	1953	3.3	4.3	0	0.5	0.1	1.8
91	Jefferson	GA	2	1961	5.7	0.0	0	0.3	0.0	1.4
87	Johnson	GA	1	1957	8.8	1.6	0	0.3	0.0	1.4
70	Ware	GA	1	1969	1.9	0.0	0	0.2	0.0	1.4
218	Butts	GA	1	1952	-	-	-	-	-	-
222	Camden	GA	1	1969	-	-	-	-	-	-
223	Charlton	GA	1	1946	-	-	-	-	-	-
9	Harrison	MS	3	1980	3.9	45.8	1	2.8	1.1	6.0
10	Stone	MS	1	1975	1.3	77.4	1	2.4	1.0	5.5
19	Forrest	MS	3	1976	0.2	92.4	0	1.7	0.9	3.6
197	Harrison	MS	6	1981	1.0	10.8	0	0.6	0.1	1.8
128	Harrison	MS	1	1931	3.7	0.0	0	0.1	0.0	1.0
117	Sampson	NC	10	2018	8.4	2.3	4	100.0	100.0	100.0
194	Moore	NC	343	2018	36.1	35.6	4	100.0	100.0	100.0
214	New Hanover	NC	22	2018	25.9	14.8	2	100.0	100.0	100.0
215	Scotland	NC	781	2018	40.7	29.6	2	100.0	100.0	100.0
190	New Hanover	NC	25	2014	25.3	3.8	4	97.7	95.8	98.8

204	Onslow	NC	2	2014	44.5	78.5	0	96.1	93.9	97.7
121	Sampson	NC	5	2016	2.2	3.7	1	94.2	91.5	96.1
189	Brunswick	NC	2	2009	32.8	52.5	3	93.9	91.2	95.9
191	Pender	NC	3	2012	12.7	15.6	2	89.6	86.1	92.1
110	Bladen	NC	1	2013	1.3	0.4	2	86.3	82.5	89.3
113	Pender	NC	1	2007	9.0	0.0	3	76.3	71.8	80.2
107	Brunswick	NC	5	2006	12.4	13.6	1	63.9	59.2	68.6
201	Brunswick	NC	1	2009	10.4	0.3	0	60.5	55.6	65.2
118	Duplin	NC	2	2007	0.0	0.7	1	49.0	44.1	53.9
192	Bladen	NC	6	1981	0.4	35.9	4	16.5	13.2	20.5
195	Cumberland	NC	1	1991	13.3	0.6	1	16.2	12.5	20.6
116	Robeson	NC	1	1989	2.1	0.2	2	12.8	9.7	17.3
193	Bladen	NC	1	1989	1.0	2.4	2	12.6	9.5	16.3
203	Richmond	NC	1	1974	47.2	0.0	1	10.4	5.7	20.2
109	Bladen	NC	1	1983	0.6	0.0	3	7.8	4.5	12.6
115	Robeson	NC	1	1989	2.1	0.2	1	7.5	5.3	10.7
111	Bladen	NC	1	1977	4.4	16.0	2	7.1	3.7	12.6
114	Bladen	NC	1	1968	0.9	0.1	3	5.2	3.1	8.7
202	Pender	NC	1	1983	14.0	5.6	0	5.2	3.5	7.9
196	Cumberland	NC	1	1969	24.3	2.9	1	4.2	2.0	7.7
124	Jones	NC	1	1968	13.2	49.7	0	3.0	0.8	8.5
112	Pender	NC	1	1973	12.2	2.4	3	2.5	1.1	5.1
119	Duplin	NC	1	1974	0.0	0.1	1	1.8	0.9	3.6
120	Craven	NC	1	1905	-	-	-	-	-	-
122	Moore	NC	1	1988	-	-	-	-	-	-
123	Craven	NC	1	1944	-	-	-	-	-	-
125	Wayne	NC	1	1964	-	-	-	-	-	-
126	Wayne	NC	1	1972	-	-	-	-	-	-
205	Carteret	NC	1	1961	-	-	-	-	-	-
206	Craven	NC	1	1905	-	-	-	-	-	-
219	Pitt	NC	1	1967	-	-	-	-	-	-
220	Edgecombe	NC	1	1990	-	-	-	-	-	-
221	Wake	NC	1	1930	-	-	-	-	-	-
183	Berkeley	SC	12	2018	34.5	98.8	0	100.0	100.0	100.0
212	Barnwell	SC	249	2017	40.8	48.2	4	99.8	98.6	100.0
180	Jasper	SC	3	2017	34.4	1.8	0	98.7	97.1	99.5
108	Chesterfield	SC	17	2011	42.5	50.0	0	89.3	85.8	91.9
184	Aiken	SC	1	2014	13.0	0.0	0	85.7	82.0	88.8
89	Hampton	SC	1	2007	21.3	2.1	0	63.8	58.9	68.3
103	Aiken	SC	3	2001	38.7	0.0	2	62.4	57.7	67.1
207	Jasper	SC	8	1996	32.3	16.2	2	58.4	45.2	71.2
209	Allendale	SC	4	2002	26.6	2.2	2	57.4	51.6	63.2
105	Sumter	SC	2	1999	34.8	39.9	1	54.2	49.4	59.1

106	Richland	SC	2	1995	50.3	98.8	0	52.2	44.9	59.7
186	Marion	SC	2	1997	27.5	94.2	0	49.1	44.1	53.9
102	Berkeley	SC	1	2000	12.6	23.3	0	31.3	26.9	36.0
188	Horry	SC	1	2000	6.0	4.1	1	28.4	24.3	33.1
213	Georgetown	SC	1	1986	36.3	50.7	0	23.3	19.4	27.6
187	Horry	SC	1	1972	7.9	24.3	1	4.0	2.5	6.4
200	Horry	SC	1	1973	17.9	33.8	0	3.5	1.7	7.0
182	Dorchester	SC	1	1976	10.9	18.4	0	2.6	1.5	4.9
185	Aiken	SC	4	1934	34.8	0.1	1	2.5	1.0	6.7
86	Beaufort	SC	1	1975	15.3	7.2	0	2.3	0.9	5.9
92	Colleton	SC	1	1977	16.6	0.0	0	1.9	1.0	3.9
100	Berkeley	SC	1	1938	7.0	44.0	0	1.5	0.7	3.5
199	Charleston	SC	1	1911	10.4	0.9	0	1.0	0.2	2.6
104	Clarendon	SC	1	1954	3.4	9.6	1	0.7	0.2	2.2
99	Bamberg	SC	1	1974	8.1	0.2	0	0.6	0.1	3.0
96	Bamberg	SC	1	1958	27.1	0.4	0	0.6	0.1	1.8

Table B-7. Predicted changes in habitat variables (compatible land cover, fire frequency, and Habitat Suitability Index [HSI]) between the present and 2080. All values represent the percent change (losses or gains) in habitat variables under each scenario in the future conditions analysis. Means (top value in each cell) represent the average change across populations, and minimums and maximums (bottom values in each cell) represent the lowest and highest changes, respectively, predicted for a single population.

Habitat variable	**Scenario**						
	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
Compatible land cover	-12.2 (-74.5, 0.0)	-13.7 (-76, 0.0)	-15.8 (-77.7, 0.0)	-13.7 (-76.0, 0.0)	-13.7 (-76, 0.0)	-9.6 (-76, 8.7)	-7.5 (-57.6, 9.0)
Fire frequency	-1.9 (-16.1, 0.0)	-1.9 (-16.4, 0.0)	-2.1 (-16.6, 0.0)	-6.1 (-22.2, 0.0)	2.3 (-10.9, 20.0)	4.8 (-10.9, 20.0)	6.3 (-10.9, 20.0)
HSI	-3.9 (-51.4, 0.0)	-4.3 (-53.9, 0.0)	-4.9 (-56.5, 0.0)	-7.5 (-53.9, 0.0)	-0.1 (-53.9, 51.6)	2.8 (-53.9, 51.6)	4.9 (-34.1, 51.6)

Table B-8. Distribution of southern hognose snake populations (N = 222) in each category of population persistence in 2040, 2060, and 2080, for the seven scenarios. *Indicates the numbers are reported at cumulative totals and percentage.

Year - 2040	Scenario							
Population persistence category	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
*Extremely Likely on Landscape (Extant) 95-100%	49 (22.1%)	8 (3.6%)	8 (3.6%)	8 (3.6%)	5 (2.3%)	10 (4.5%)	15 (6.8%)	16 (7.2%)
*Highly Likely on Landscape 90-94.9%	59 (26.6 %)	23 (10.4%)	23 (10.4%)	23 (10.4%)	20 (9.0%)	24 (10.8%)	32 (14.4%)	32 (14.4%)
*Very Likely on Landscape 80-89.9%	68 (30.6%)	44 (19.8%)	45 (20.3%)	45 (20.3%)	43 (19.4%)	46 (20.7%)	54 (24.3%)	54 (24.3%)
*More Likely than Not 50-79.9%	89 (40.1%)	76 (34.2%)	77 (34.7%)	77 (34.7%)	74 (33.3%)	77 (34.7%)	78 (35.1%)	82 (36.9%)
Unlikely (Extirpated) < 50%	133 (59.9%)	146 (65.8%)	145 (65.3%)	145 (65.3%)	148 (66.7%)	145 (65.3%)	144 (64.9%)	140 (63.1%)
Year - 2060	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
*Extremely Likely on Landscape (Extant) 95-100%	49 (22.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.5%)	4 (1.8%)	4 (1.8%)
*Highly Likely on Landscape 90-94.9%	59 (26.6 %)	9 (4.1%)	10 (4.5%)	9 (4.1%)	0 (0%)	15 (6.8%)	24 (10.8%)	24 (10.8%)
*Very Likely on Landscape 80-89.9%	68 (30.6%)	27 (12.2%)	28 (12.6%)	27 (12.2%)	24 (10.8%)	31 (14.0%)	41 (18.5%)	42 (18.9%)
*More Likely than Not 50-79.9%	89 (40.1%)	63 (28.4%)	62 (27.9%)	62 (27.9%)	62 (27.9%)	64 (28.8%)	74 (33.3%)	75 (33.8%)
Unlikely (Extirpated) < 50%	133 (59.9%)	159 (71.6%)	160 (72.1%)	160 (72.1%)	160 (72.1%)	158 (71.2%)	148 (66.7%)	147 (66.2%)
Year - 2080	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
*Extremely Likely on Landscape (Extant) 95-100%	49 (22.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.5%)	2 (0.9%)
*Highly Likely on Landscape 90-94.9%	59 (26.6 %)	4 (1.8%)	4 (1.8%)	4 (1.8%)	0 (0%)	5 (2.3%)	15 (6.8%)	15 (6.8%)
*Very Likely on Landscape 80-89.9%	68 (30.6%)	20 (9.0%)	20 (9.0%)	20 (9.0%)	14 (6.3%)	14 (6.3%)	35 (15.8%)	36 (16.2%)
*More Likely than Not 50-79.9%	89 (40.1%)	57 (25.7%)	57 (25.7%)	57 (25.7%)	56 (25.2%)	58 (26.1%)	66 (29.7%)	70 (31.5%)
Unlikely (Extirpated) < 50%	133 (59.9%)	165 (74.3%)	165 (74.3%)	165 (74.3%)	166 (74.8%)	164 (73.9%)	156 (70.3%)	152 (68.5%)

Table B-9. Number of southern hognose snake populations at or above the 50, 80, 90, and 95% threshold of persistence probability in 2040, 2060, and 2080, given seven scenarios of threats and management actions, across each representative unit and range-wide. Cell shadings: Red – 0 populations meeting the persistence threshold; Light orange – 1 or 2 populations meeting the threshold.

Year - 2040	**Scenario**																															
	Current				Low Stressor				Med Stressor				High Stressor				Decreased Mgmt				Improved Mgmt				Protect More Pops.				Protect Even More Pops.			
Rep unit	50	80	90	95	50	80	90	95	50	80	90	95	50	80	90	95	50	80	90	95	50	80	90	95	50	80	90	95	50	80	90	95
Upper Coastal Plain (Carolinas)	11	7	4	3	7	3	3	1	7	3	3	1	7	3	2	1	7	3	2	1	7	3	3	1	8	3	3	1	9	3	2	1
Upper Coastal Plain (GA/FL)	28	25	23	20	25	18	11	4	25	18	11	4	25	18	11	4	25	17	11	3	25	18	11	4	25	19	14	7	26	19	14	7
Atl. Coastal Plain (Carolinas)	13	8	7	6	10	6	1	0	10	6	0	0	10	6	1	0	10	5	0	0	10	6	1	0	10	7	4	2	11	7	4	1
Atl. Coastal Plain (GA/FL)	2	1	1	1	2	1	0	0	2	1	0	0	2	1	0	0	2	1	0	0	2	1	1	0	2	1	1	0	2	1	1	0
FL Peninsula	14	12	9	6	14	5	2	0	14	6	2	0	14	6	2	0	14	6	2	0	14	6	2	0	14	10	2	1	14	10	2	1
FL Ridge	8	8	8	7	8	5	1	1	8	5	2	1	8	5	2	1	8	5	1	1	8	6	1	1	8	7	2	1	8	7	3	2
AL/FL Panhandle	13	7	7	6	10	6	5	2	11	6	5	2	11	6	5	2	8	6	4	0	11	6	5	4	11	7	6	3	12	7	6	4
West (AL/MS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AL Central	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Range-wide	89	68	59	49	76	44	23	8	77	45	23	8	77	45	23	8	74	43	20	5	77	46	24	10	78	54	32	15	82	54	32	16
Year - 2060	Current				Low Stressor				Med Stressor				High Stressor				Decreased Mgmt				Improved Mgmt				Protect More Pops.				Protect Even More Pops.			
Upper Coastal Plain (Carolinas)	11	7	4	3	4	3	1	0	4	3	2	0	4	3	1	0	4	3	1	0	4	3	1	0	8	3	1	0	9	3	1	0
Upper Coastal Plain (GA/FL)	28	25	23	20	22	12	4	0	22	12	4	0	22	12	4	0	22	12	4	0	22	13	6	0	24	16	10	2	25	17	11	2
Atl. Coastal Plain (Carolinas)	13	8	7	6	9	2	0	0	9	2	0	0	9	2	0	0	9	1	0	0	9	4	1	0	10	6	3	0	10	6	2	0
Atl. Coastal Plain (GA/FL)	2	1	1	1	1	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	1	0	2	1	1	0	2	1	1	0
FL Peninsula	14	12	9	6	12	2	0	0	11	2	0	0	11	2	0	0	12	2	0	0	12	2	0	0	12	3	2	1	12	4	2	1
FL Ridge	8	8	8	7	7	2	1	0	7	2	1	0	7	2	1	0	7	2	1	0	7	2	1	0	8	5	2	0	8	4	2	0
AL/FL Panhandle	13	7	7	6	8	6	3	0	8	6	3	0	8	6	3	0	7	4	0	0	9	6	5	1	9	7	5	1	9	7	5	1
West (AL/MS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

AL Central	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Range-wide	89	68	59	49	63	27	9	0	62	28	10	0	62	27	9	0	62	24	6	0	64	31	15	1	74	41	24	4	75	42	24	4

Year - 2080	Current				Low Stressor				Med Stressor				High Stressor				Decreased Mgmt				Improved Mgmt				Protect More Pops.				Protect Even More Pops.			
Upper Coastal Plain (Carolinas)	11	7	4	3	4	2	0	0	4	2	0	0	4	2	0	0	4	2	0	0	4	2	0	0	6	2	0	0	8	2	0	0
Upper Coastal Plain (GA/FL)	28	25	23	20	21	10	1	0	21	10	1	0	21	10	1	0	21	8	0	0	21	10	1	0	24	13	7	1	24	14	7	2
Atl. Coastal Plain (Carolinas)	13	8	7	6	7	0	0	0	7	0	0	0	7	0	0	0	6	0	0	0	7	3	0	0	8	6	2	0	10	6	2	0
Atl. Coastal Plain (GA/FL)	2	1	1	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	1	1	0	0	2	1	0	0
FL Peninsula	14	12	9	6	11	1	0	0	11	1	0	0	11	0	0	0	11	1	0	0	11	1	0	0	11	3	1	0	11	3	1	0
FL Ridge	8	8	8	7	7	1	0	0	7	1	0	0	7	1	0	0	7	1	0	0	7	1	0	0	8	3	1	0	7	3	1	0
AL/FL Panhandle	13	7	7	6	6	6	3	0	6	6	3	0	6	6	3	0	6	2	0	0	7	6	4	0	8	7	4	0	8	7	4	0
West (AL/MS)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AL Central	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Range-wide	89	68	59	49	57	20	4	0	57	20	4	0	57	19	4	0	56	14	0	0	58	24	5	0	66	35	15	1	70	36	15	2

Table B-10. Mean number of southern hognose snake populations (Lower, Upper 95% confidence intervals) predicted to persist in 2040, 2060, and 2080, given seven scenarios of stressors and management actions, across each representative unit and range-wide.

Year - 2040	Scenario							
Rep unit	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
Upper Coastal Plain (Carolinas)	11 (8, 13)	8 (5, 11)	8 (5, 11)	8 (5, 11)	8 (5, 11)	8 (5, 11)	9 (6, 11)	9 (6, 12)
Upper Coastal Plain (GA/FL)	28 (26, 33)	25 (21, 29)	25 (21, 29)	25 (21, 29)	25 (21, 29)	25 (21, 29)	26 (22, 30)	26 (22, 30)
Atl. Coastal Plain (Carolinas)	13 (10, 15)	10 (7, 13)	10 (7, 13)	10 (7, 13)	10 (7, 13)	10 (7, 13)	11 (10, 14)	11 (8, 14)
Atl. Coastal Plain (GA/FL)	2 (2, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)	3 (1, 5)
FL Peninsula	14 (12, 17)	12 (9, 16)	12 (9, 15)	12 (9, 16)	12 (9, 15)	12 (9, 16)	13 (10, 16)	13 (10, 16)
FL Ridge	8 (7, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)	7 (5, 9)
AL/FL Panhandle	13 (8, 14)	9 (7, 12)	9 (7, 12)	9 (7, 12)	9 (6, 11)	9 (7, 12)	10 (7, 12)	10 (7, 12)
West (AL/MS)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
AL Central	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Range-wide	89 (73, 106)	75 (55, 95)	75 (55, 94)	75 (55, 95)	74 (54, 93)	75 (55, 95)	77 (61, 97)	79 (59, 98)
Year - 2060	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
Upper Coastal Plain (Carolinas)	11 (8, 13)	7 (4, 10)	7 (4, 10)	7 (4, 10)	7 (4, 10)	7 (4, 10)	8 (5, 11)	8 (5, 11)
Upper Coastal Plain (GA/FL)	28 (26, 33)	22 (17, 27)	22 (17, 26)	22 (17, 26)	22 (17, 26)	22 (18, 27)	24 (19, 28)	24 (20, 28)
Atl. Coastal Plain (Carolinas)	13 (10, 15)	8 (5, 12)	8 (5, 12)	8 (5, 12)	8 (4, 11)	9 (6, 12)	9 (6, 13)	10 (7, 13)
Atl. Coastal Plain (GA/FL)	2 (2, 5)	2 (1, 4)	2 (1, 4)	2 (1, 4)	2 (0, 4)	3 (1, 5)	3 (1, 5)	3 (1, 5)
FL Peninsula	14 (12, 17)	11 (7, 14)	11 (7, 14)	11 (7, 14)	11 (7, 14)	11 (7, 14)	11 (8, 15)	11 (8, 15)
FL Ridge	8 (7, 9)	6 (3, 8)	6 (3, 8)	6 (3, 8)	6 (3, 8)	6 (3, 8)	7 (4, 8)	7 (4, 8)
AL/FL Panhandle	13 (8, 14)	8 (6, 11)	8 (6, 11)	8 (6, 11)	8 (5, 10)	9 (6, 11)	9 (6, 11)	9 (7, 12)
West (AL/MS)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
AL Central	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Range-wide	89 (73, 106)	65 (43, 86)	64 (43, 85)	64 (43, 85)	63 (40, 83)	66 (45, 87)	70 (49, 91)	72 (52, 92)
Year - 2080	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
Upper Coastal Plain (Carolinas)	11 (8, 13)	6 (3, 9)	6 (3, 9)	6 (3, 9)	6 (3, 9)	6 (3, 9)	7 (4, 10)	7 (4, 10)
Upper Coastal Plain (GA/FL)	28 (26, 33)	19 (14, 24)	19 (14, 24)	19 (14, 24)	19 (14, 24)	20 (15, 24)	22 (17, 26)	22 (18, 27)
Atl. Coastal Plain (Carolinas)	13 (10, 15)	7 (4, 11)	7 (4, 11)	7 (4, 11)	6 (3, 10)	8 (4, 11)	8 (5, 12)	9 (6, 12)
Atl. Coastal Plain (GA/FL)	2 (2, 5)	2 (0, 4)	2 (0, 4)	2 (0, 4)	2 (0, 4)	2 (1, 4)	2 (1, 4)	3 (1, 4)
FL Peninsula	14 (12, 17)	9 (5, 13)	9 (5, 13)	9 (5, 13)	9 (5, 13)	9 (5, 13)	10 (7, 14)	10 (7, 14)
FL Ridge	8 (7, 9)	5 (2, 7)	5 (2, 7)	5 (2, 7)	5 (2, 7)	5 (3, 7)	6 (4, 8)	6 (4, 8)
AL/FL Panhandle	13 (8, 14)	8 (5, 10)	8 (5, 10)	8 (5, 10)	6 (4, 9)	8 (6, 11)	8 (6, 11)	9 (6, 11)
West (AL/MS)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
AL Central	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Range-wide	89 (73, 106)	56 (33, 78)	56 (33, 78)	56 (33, 78)	54 (31, 76)	58 (37, 79)	64 (44, 85)	66 (46, 86)

Cell shadings: Red – lower 95% confidence interval includes 0 populations persisting in a unit; Orange – lower 95% confidence interval includes 1 or 2 populations persisting in a unit.

Table B-11. Mean persistence probability (Lower, Upper 95% confidence intervals) for southern hognose snake populations under current conditions and future conditions in 2080, given seven scenarios of stressors and management actions. Cell shadings for current persistence indicate populations with > 90% (blue) and < 50% probabilities (red). Populations have been sorted by state and from highest to lowest current persistence probability. The table also includes the twelve populations in AL and NC that were outside the analysis area.

Pop ID	County	State	Current	Low Stressor	Med Stressor	High Stressor	Decreased Mgmt	Improved Mgmt	Protect More Pops.	Protect Even More Pops.
130	Baldwin	AL	2 (0.8, 5.3)	0.7 (0.6, 0.9)	0.6 (0.4, 0.7)	0.5 (0.4, 0.7)	0.5 (0.4, 0.6)	0.6 (0.4, 0.7)	0.6 (0.4, 0.7)	0.6 (0.4, 0.7)
6	Baldwin	AL	1.8 (0.4, 7.3)	0.7 (0.6, 0.9)	0.8 (0.6, 1)	0.7 (0.6, 0.9)	0.7 (0.6, 0.9)	0.7 (0.5, 0.9)	0.8 (0.6, 1)	0.6 (0.5, 0.8)
27	Covington	AL	0.8 (0.2, 2.2)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.2, 0.3)	0.3 (0.2, 0.5)
24	Escambia	AL	0.6 (0.1, 2.1)	0.2 (0.1, 0.2)	0.2 (0.1, 0.3)	0.1 (0, 0.2)	0.1 (0, 0.2)	0.1 (0.1, 0.2)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)
25	Covington	AL	0.3 (0, 1.4)	0 (0, 0)	0 (0, 0)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0)	0 (0, 0.1)
13	Mobile	AL	0.1 (0, 1)	0 (0, 0.1)	0 (0, 0)	0 (0, 0)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)
32	Dale	AL	0 (0, 1)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0.1)	0 (0, 0)
71	Choctaw	AL	-	-	-	-	-	-	-	-
73	Autauga	AL	-	-	-	-	-	-	-	-
77	Tuscaloosa	AL	-	-	-	-	-	-	-	-
78	Shelby	AL	-	-	-	-	-	-	-	-
79	Calhoun	AL	-	-	-	-	-	-	-	-
40	Lake	FL	100 (100, 100)	21.2 (20.4, 22.1)	21.3 (20.5, 22.1)	20.6 (19.8, 21.4)	21.1 (20.3, 21.9)	20.8 (20, 21.6)	50.1 (49.1, 51.1)	49.7 (48.7, 50.6)
3	Taylor	FL	100 (100, 100)	36.6 (35.7, 37.6)	35.5 (34.6, 36.5)	34.4 (33.5, 35.3)	35.6 (34.6, 36.5)	36.7 (35.7, 37.6)	35.2 (34.2, 36.1)	36.1 (35.2, 37.1)
217	Walton	FL	100 (100, 100)	47.9 (46.9, 48.8)	47.9 (47, 48.9)	47.9 (46.9, 48.9)	48.7 (47.7, 49.6)	48.8 (47.8, 49.8)	85.1 (84.4, 85.8)	84.8 (84.1, 85.5)
153	Marion	FL	100 (100, 100)	61 (60, 61.9)	60.5 (59.5, 61.4)	60 (59.1, 61)	57.7 (56.7, 58.7)	64.4 (63.4, 65.3)	64.2 (63.3, 65.2)	64.6 (63.7, 65.5)
12	Leon	FL	100 (100, 100)	62 (61, 62.9)	60.9 (59.9, 61.8)	61.8 (60.8, 62.7)	60.4 (59.4, 61.3)	63 (62.1, 64)	61.6 (60.7, 62.6)	62.8 (61.9, 63.8)
164	Hamilton	FL	100 (100, 100)	78.6 (77.8, 79.4)	77.6 (76.7, 78.4)	78.2 (77.3, 78.9)	77.9 (77.1, 78.7)	79.1 (78.3, 79.9)	79.7 (78.9, 80.5)	80.1 (79.3, 80.9)
57	Gilchrist	FL	100 (100, 100)	83.4 (82.7, 84.2)	82.6 (81.8, 83.3)	79.7 (78.9, 80.5)	82.2 (81.4, 82.9)	82.5 (81.7, 83.2)	93.2 (92.7, 93.7)	93.5 (93, 93.9)
165	Hamilton	FL	100 (100, 100)	83.9 (83.2, 84.6)	84 (83.2, 84.7)	84 (83.2, 84.7)	82.7 (81.9, 83.4)	84.6 (83.9, 85.3)	85 (84.3, 85.7)	85.4 (84.7, 86.1)
149	Hernando	FL	100 (100, 100)	88.8 (88.2, 89.4)	88.6 (88, 89.2)	88.2 (87.6, 88.9)	89.1 (88.5, 89.7)	88.6 (88, 89.2)	88.2 (87.5, 88.8)	89.3 (88.7, 89.9)
61	Suwannee	FL	100 (100, 100)	91.3 (90.7, 91.8)	91.1 (90.5, 91.6)	90.4 (89.8, 91)	90 (89.4, 90.5)	91.4 (90.9, 92)	92.1 (91.5, 92.6)	91.7 (91.1, 92.2)
163	Madison	FL	99.8 (98.6, 100)	83.8 (83.1, 84.5)	82.9 (82.1, 83.6)	83.4 (82.7, 84.1)	82.4 (81.6, 83.1)	84 (83.3, 84.7)	84.1 (83.4, 84.8)	84.4 (83.7, 85.1)
41	Hernando	FL	99.5 (98.2, 99.9)	73.5 (72.7, 74.4)	73.8 (72.9, 74.6)	73.5 (72.6, 74.4)	73.5 (72.6, 74.3)	73.8 (73, 74.7)	73.6 (72.7, 74.5)	73.7 (72.8, 74.5)
15	Walton	FL	99.4 (98.2, 99.9)	90.5 (89.9, 91.1)	90.4 (89.8, 91)	90.4 (89.8, 90.9)	74.7 (73.8, 75.6)	92.8 (92.2, 93.2)	92.3 (91.8, 92.8)	92.6 (92, 93.1)
51	Levy	FL	99.3 (97.8, 99.8)	68 (67.1, 68.9)	67 (66.1, 68)	67 (66, 67.9)	66.1 (65.2, 67.1)	69 (68.1, 69.9)	90.3 (89.7, 90.9)	90.4 (89.8, 90.9)

66	Suwannee	FL	99.3 (97.8, 99.8)	89.2 (88.5, 89.8)	88.7 (88, 89.3)	87.7 (87, 88.3)	88.1 (87.5, 88.7)	89.3 (88.7, 89.9)	96.9 (96.5, 97.2)	97.2 (96.9, 97.5)
156	Dixie	FL	99 (97.5, 99.6)	79.4 (78.6, 80.2)	79.1 (78.2, 79.8)	78.3 (77.5, 79.1)	79.3 (78.5, 80.1)	79.4 (78.6, 80.2)	87.2 (86.6, 87.9)	87.3 (86.6, 87.9)
132	Okaloosa	FL	99 (97.5, 99.6)	92.1 (91.6, 92.6)	92.1 (91.6, 92.6)	92.3 (91.7, 92.8)	80.6 (79.8, 81.4)	95 (94.5, 95.4)	94.4 (93.9, 94.8)	94.3 (93.8, 94.7)
62	Lafayette	FL	98.9 (97.5, 99.6)	83.7 (82.9, 84.4)	83 (82.2, 83.7)	83 (82.3, 83.7)	82.7 (82, 83.5)	83.9 (83.2, 84.6)	93 (92.5, 93.5)	92.9 (92.4, 93.4)
69	Suwannee	FL	98.9 (97.5, 99.6)	86.3 (85.6, 86.9)	85.7 (85, 86.4)	85.2 (84.5, 85.9)	85.4 (84.7, 86.1)	85.6 (84.8, 86.2)	95.2 (94.8, 95.6)	94.9 (94.4, 95.3)
150	Sumter	FL	98.8 (97.1, 99.5)	54.4 (53.4, 55.4)	53.5 (52.5, 54.4)	51.6 (50.6, 52.6)	54.8 (53.8, 55.7)	54.5 (53.6, 55.5)	73.4 (72.5, 74.2)	72.9 (72, 73.7)
133	Santa Rosa	FL	98.8 (97.1, 99.5)	82.7 (81.9, 83.4)	82 (81.3, 82.8)	82.4 (81.7, 83.1)	75 (74.1, 75.8)	90.7 (90.1, 91.2)	90.6 (90, 91.1)	91.1 (90.5, 91.7)
162	Columbia	FL	97.9 (96.1, 99)	58.3 (57.3, 59.2)	58.1 (57.1, 59)	58.7 (57.7, 59.7)	58.5 (57.5, 59.4)	58.6 (57.6, 59.6)	76.7 (75.9, 77.5)	77.3 (76.5, 78.1)
48	Levy	FL	97.2 (95.1, 98.5)	52.4 (51.5, 53.4)	52.7 (51.7, 53.6)	53.4 (52.4, 54.4)	52.8 (51.9, 53.8)	52 (51, 53)	68.5 (67.6, 69.4)	69 (68, 69.8)
129	Santa Rosa	FL	97 (94.8, 98.3)	86.3 (85.6, 87)	86.8 (86.1, 87.4)	87 (86.3, 87.6)	68.6 (67.7, 69.5)	89.4 (88.8, 90)	89.5 (88.9, 90.1)	89.3 (88.7, 89.9)
11	Okaloosa	FL	97 (94.8, 98.3)	91.1 (90.5, 91.6)	91.3 (90.7, 91.8)	90.5 (90, 91.1)	80.7 (80, 81.5)	92.2 (91.7, 92.7)	92.5 (91.9, 93)	92.6 (92, 93.1)
63	Columbia	FL	96.8 (94.5, 98.1)	77.1 (76.3, 77.9)	76.8 (75.9, 77.6)	76 (75.1, 76.8)	76.7 (75.9, 77.5)	76.9 (76.1, 77.8)	90.7 (90.2, 91.3)	90.9 (90.3, 91.4)
161	Suwannee	FL	96.3 (93.9, 97.7)	71.9 (71, 72.8)	72.4 (71.5, 73.3)	70.9 (70, 71.8)	70.7 (69.8, 71.5)	73.5 (72.6, 74.4)	74 (73.1, 74.8)	73.5 (72.6, 74.4)
58	Taylor	FL	96.2 (93.9, 97.7)	56.9 (56, 57.9)	56.4 (55.4, 57.4)	56.1 (55.1, 57)	56.4 (55.4, 57.4)	55.7 (54.7, 56.7)	73 (72.1, 73.9)	72.2 (71.3, 73)
67	Columbia	FL	96 (93.6, 97.5)	66.9 (66, 67.8)	67.1 (66.2, 68)	67.2 (66.3, 68.1)	66.3 (65.3, 67.2)	66.6 (65.7, 67.5)	86.4 (85.7, 87.1)	86.2 (85.5, 86.8)
152	Sumter	FL	95.6 (93.3, 97.3)	64.5 (63.6, 65.5)	64.5 (63.6, 65.4)	64.2 (63.3, 65.1)	64.4 (63.4, 65.3)	64.3 (63.4, 65.3)	83.4 (82.6, 84.1)	83.3 (82.6, 84)
60	Taylor	FL	92.5 (89.5, 94.7)	54.9 (54, 55.9)	55.2 (54.2, 56.1)	55.2 (54.2, 56.2)	54.9 (54, 55.9)	55.4 (54.4, 56.3)	68.3 (67.4, 69.2)	68.1 (67.1, 69)
137	Liberty	FL	92.5 (89.5, 94.7)	63.4 (62.5, 64.4)	62.1 (61.1, 63)	61.1 (60.1, 62)	56.8 (55.8, 57.7)	67.4 (66.5, 68.3)	67.6 (66.7, 68.5)	67.6 (66.7, 68.5)
37	Pasco	FL	92.5 (89.5, 94.7)	66.8 (65.9, 67.7)	65.9 (64.9, 66.8)	66 (65.1, 66.9)	66 (65, 66.9)	65.9 (64.9, 66.8)	66.2 (65.2, 67.1)	64.8 (63.9, 65.8)
34	Pasco	FL	92.1 (89.2, 94.5)	52.1 (51.1, 53)	51.6 (50.6, 52.6)	50.7 (49.7, 51.7)	51.3 (50.3, 52.3)	51.2 (50.2, 52.1)	72.1 (71.2, 72.9)	72.8 (71.9, 73.6)
59	Columbia	FL	91.3 (88.1, 93.6)	65.5 (64.5, 66.4)	65.1 (64.1, 66)	64.8 (63.9, 65.8)	64.6 (63.7, 65.5)	66.3 (65.4, 67.2)	81.7 (80.9, 82.4)	82.2 (81.4, 82.9)
166	Madison	FL	91 (87.8, 93.4)	36 (35.1, 37)	36 (35.1, 37)	36.4 (35.4, 37.3)	36 (35, 36.9)	36.4 (35.5, 37.4)	65.1 (64.1, 66)	64.7 (63.7, 65.6)
7	Walton	FL	90.8 (87.5, 93.2)	83 (82.2, 83.7)	83.3 (82.6, 84)	82.7 (81.9, 83.4)	67.4 (66.5, 68.3)	84.7 (84, 85.4)	84.6 (83.9, 85.3)	85.1 (84.3, 85.7)
46	Levy	FL	88.8 (85.3, 91.5)	58.1 (57.1, 59)	57.9 (57, 58.9)	58.2 (57.2, 59.1)	57.4 (56.4, 58.3)	58 (57, 58.9)	68.4 (67.5, 69.3)	67.5 (66.5, 68.4)
155	Levy	FL	88 (84.4, 90.8)	65.9 (64.9, 66.8)	65.5 (64.6, 66.4)	65 (64.1, 65.9)	66.3 (65.3, 67.2)	65.5 (64.5, 66.4)	66.4 (65.4, 67.3)	64.7 (63.7, 65.6)
159	Dixie	FL	84.5 (80.3, 87.8)	64 (63.1, 64.9)	63 (62, 63.9)	59.9 (58.9, 60.8)	63.1 (62.1, 64)	62 (61.1, 63)	80.3 (79.5, 81.1)	79.3 (78.5, 80.1)
5	Bay	FL	71.2 (66.6, 75.5)	25.9 (25.1, 26.8)	26.8 (26, 27.7)	25.6 (24.8, 26.5)	22 (21.2, 22.9)	33.9 (33, 34.9)	33.3 (32.4, 34.2)	33.3 (32.4, 34.2)
8	Walton	FL	70.9 (66.4, 75.2)	28.2 (27.3, 29.1)	28.6 (27.7, 29.5)	27.9 (27, 28.7)	22.6 (21.8, 23.5)	37.5 (36.5, 38.4)	38.6 (37.7, 39.6)	38 (37, 38.9)
151	Sumter	FL	67.7 (63, 72.1)	31.6 (30.7, 32.5)	32 (31.1, 33)	32.2 (31.3, 33.2)	31 (30.1, 31.9)	32.9 (32, 33.8)	33.2 (32.2, 34.1)	33.3 (32.3, 34.2)
45	Levy	FL	67 (61.5, 72.1)	40 (39, 41)	40 (39, 40.9)	38.3 (37.4, 39.3)	39.3 (38.3, 40.3)	39.5 (38.5, 40.4)	39 (38, 39.9)	38.8 (37.8, 39.7)
14	Okaloosa	FL	58.9 (43.3, 71.6)	48.6 (47.7, 49.6)	48.4 (47.4, 49.3)	48.7 (47.7, 49.7)	42.1 (41.1, 43.1)	53.7 (52.8, 54.7)	53.4 (52.4, 54.3)	53.5 (52.5, 54.5)
131	Escambia	FL	58.7 (53.9, 63.5)	18 (17.3, 18.8)	18.3 (17.6, 19.1)	18 (17.2, 18.7)	18.2 (17.4, 19)	18.6 (17.8, 19.3)	18.3 (17.5, 19)	45.9 (44.9, 46.8)

134	Santa Rosa	FL	55.6 (43.3, 67.5)	41.7 (40.7, 42.7)	41.4 (40.4, 42.4)	41.1 (40.2, 42.1)	29.3 (28.4, 30.1)	49.8 (48.8, 50.8)	48.9 (47.9, 49.9)	49.1 (48.1, 50)
20	Jefferson	FL	53.9 (48.9, 58.6)	20.9 (20.2, 21.7)	21.2 (20.4, 22)	20.8 (20, 21.6)	19.7 (18.9, 20.4)	21.7 (20.9, 22.5)	22.8 (22, 23.6)	22.2 (21.4, 23.1)
16	Jackson	FL	51.3 (46.4, 56.1)	11.3 (10.6, 11.9)	10.5 (9.9, 11.1)	10.6 (10.1, 11.3)	10.9 (10.3, 11.5)	11.2 (10.6, 11.8)	10.8 (10.2, 11.4)	35.3 (34.4, 36.2)
147	Hillsborough	FL	45.8 (40.9, 50.6)	19 (18.2, 19.7)	17.9 (17.2, 18.7)	18.5 (17.7, 19.3)	18.5 (17.7, 19.3)	18 (17.2, 18.7)	18.2 (17.4, 18.9)	18.7 (17.9, 19.4)
68	Suwannee	FL	43.8 (38.2, 49.5)	17.1 (16.4, 17.9)	17.1 (16.3, 17.8)	17.8 (17, 18.5)	17.1 (16.3, 17.8)	17.4 (16.7, 18.1)	17.9 (17.1, 18.6)	17.9 (17.1, 18.6)
38	Hernando	FL	36.9 (29.6, 45.4)	19.8 (19, 20.6)	19.8 (19, 20.6)	19.2 (18.4, 19.9)	14.5 (13.8, 15.2)	24.5 (23.7, 25.4)	24.6 (23.7, 25.4)	25.5 (24.6, 26.3)
55	Gilchrist	FL	30.7 (25.6, 36.3)	19.3 (18.6, 20.1)	19.6 (18.9, 20.4)	19.1 (18.3, 19.8)	19 (18.2, 19.8)	18.8 (18.1, 19.6)	19.5 (18.7, 20.3)	18.5 (17.8, 19.3)
53	Gilchrist	FL	25.3 (11.8, 48.8)	22 (21.2, 22.8)	21.6 (20.8, 22.4)	22 (21.1, 22.8)	22.2 (21.4, 23)	22.7 (21.8, 23.5)	21.4 (20.6, 22.2)	22.1 (21.3, 22.9)
36	Pasco	FL	14.8 (9.6, 21.7)	8.4 (7.9, 8.9)	8.7 (8.2, 9.3)	8.4 (7.9, 8.9)	8.5 (7.9, 9)	8.7 (8.2, 9.3)	8.7 (8.2, 9.3)	8.2 (7.7, 8.7)
64	Lafayette	FL	14.3 (5.3, 29.7)	12 (11.4, 12.7)	11.2 (10.6, 11.9)	10.7 (10.1, 11.3)	11.3 (10.7, 11.9)	11.4 (10.7, 12)	11.5 (10.8, 12.1)	11 (10.4, 11.6)
145	Hillsborough	FL	14.1 (10.5, 18.4)	4 (3.6, 4.4)	3.2 (2.9, 3.6)	3.5 (3.2, 3.9)	3.7 (3.3, 4.1)	3.5 (3.1, 3.8)	3.4 (3, 3.8)	3.6 (3.3, 4)
54	Taylor	FL	11.9 (7.1, 18.6)	7.9 (7.4, 8.4)	7.5 (7, 8)	7.3 (6.8, 7.8)	7.4 (6.9, 8)	7.3 (6.8, 7.8)	7.6 (7.1, 8.2)	7.8 (7.3, 8.4)
136	Leon	FL	11.8 (9, 15.3)	4.7 (4.3, 5.1)	4.5 (4.1, 5)	4.4 (4, 4.8)	4.9 (4.5, 5.3)	4.7 (4.3, 5.1)	4.6 (4.2, 5.1)	4.2 (3.9, 4.6)
42	Citrus	FL	10.8 (8.1, 14.2)	3.3 (2.9, 3.6)	2.9 (2.6, 3.2)	3.2 (2.8, 3.5)	2.8 (2.5, 3.1)	2.9 (2.6, 3.3)	3.2 (2.9, 3.6)	3.5 (3.1, 3.9)
35	Pasco	FL	8.4 (5, 14.4)	2.7 (2.4, 3.1)	2.4 (2.1, 2.7)	2.2 (1.9, 2.5)	2.4 (2.1, 2.7)	2.3 (2, 2.6)	2.1 (1.8, 2.4)	2.4 (2.1, 2.7)
56	Alachua	FL	8 (5.7, 11.1)	4.8 (4.4, 5.2)	4.7 (4.3, 5.1)	4.3 (3.9, 4.7)	5.1 (4.7, 5.5)	4.9 (4.5, 5.4)	5 (4.6, 5.5)	5.1 (4.7, 5.5)
157	Levy	FL	6.5 (2.7, 16.4)	6.2 (5.7, 6.7)	5.6 (5.2, 6.1)	5.7 (5.2, 6.2)	5.8 (5.3, 6.2)	6.2 (5.7, 6.7)	6.2 (5.7, 6.7)	6.4 (5.9, 6.9)
49	Marion	FL	4.5 (2, 9)	2 (1.7, 2.3)	2.2 (1.9, 2.5)	1.8 (1.5, 2)	1.7 (1.4, 1.9)	2.8 (2.5, 3.2)	2.6 (2.3, 2.9)	2.6 (2.3, 2.9)
21	Jefferson	FL	4.4 (2.9, 7)	2.2 (1.9, 2.5)	2.1 (1.8, 2.4)	2.5 (2.2, 2.8)	2.2 (1.9, 2.5)	2.2 (1.9, 2.5)	2.1 (1.8, 2.4)	2.4 (2.1, 2.7)
158	Alachua	FL	4.2 (1.8, 11.5)	1.5 (1.2, 1.7)	1.5 (1.2, 1.7)	1.5 (1.3, 1.8)	1.4 (1.2, 1.6)	1.4 (1.2, 1.6)	1.8 (1.6, 2.1)	1.3 (1.1, 1.6)
18	Jackson	FL	4 (1.6, 9.8)	1.4 (1.2, 1.6)	1.4 (1.2, 1.6)	1.1 (0.9, 1.3)	1.2 (1, 1.5)	1.1 (0.9, 1.4)	1.4 (1.1, 1.6)	1.2 (1, 1.5)
22	Leon	FL	3.4 (0.9, 9.1)	1.1 (0.9, 1.3)	1 (0.8, 1.2)	0.9 (0.7, 1.1)	1.1 (0.9, 1.3)	1.2 (1, 1.4)	0.9 (0.7, 1)	0.9 (0.7, 1.1)
4	Escambia	FL	3.4 (2.1, 5.8)	2 (1.7, 2.3)	2 (1.7, 2.3)	2 (1.7, 2.3)	2.1 (1.8, 2.4)	2.2 (1.9, 2.5)	1.9 (1.6, 2.1)	2.2 (1.9, 2.5)
135	Gadsden	FL	3.1 (1.2, 7.6)	1.6 (1.3, 1.8)	1.5 (1.3, 1.7)	1.3 (1.1, 1.6)	1.3 (1.1, 1.5)	1.6 (1.3, 1.8)	1.5 (1.3, 1.8)	1.4 (1.2, 1.7)
2	Escambia	FL	2.9 (0.5, 9.6)	1 (0.9, 1.3)	1.2 (1, 1.4)	1.1 (0.9, 1.3)	0.9 (0.8, 1.1)	1.1 (0.9, 1.3)	1.3 (1.1, 1.5)	1.3 (1.1, 1.6)
52	Putnam	FL	2.9 (1.7, 5.2)	1.2 (1, 1.5)	1.2 (1, 1.4)	1.1 (0.9, 1.3)	0.9 (0.8, 1.1)	1.3 (1.1, 1.6)	1.5 (1.3, 1.8)	1.3 (1.1, 1.5)
154	Marion	FL	1.8 (0.9, 4.2)	0.8 (0.6, 1)	0.7 (0.6, 0.9)	0.8 (0.6, 1)	0.7 (0.6, 0.9)	0.9 (0.7, 1.1)	0.9 (0.7, 1.1)	0.8 (0.7, 1)
160	Alachua	FL	1.6 (0.6, 4)	0.6 (0.4, 0.7)	0.6 (0.5, 0.8)	0.6 (0.5, 0.8)	0.5 (0.4, 0.7)	0.5 (0.3, 0.6)	0.5 (0.4, 0.7)	0.6 (0.5, 0.8)
39	Orange	FL	1.3 (0.5, 3)	0.2 (0.2, 0.4)	0.2 (0.2, 0.3)	0.3 (0.2, 0.4)	0.3 (0.2, 0.4)	0.2 (0.2, 0.4)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)
17	Gadsden	FL	1.1 (0, 4.6)	0.4 (0.3, 0.5)	0.4 (0.3, 0.5)	0.4 (0.3, 0.5)	0.4 (0.3, 0.6)	0.4 (0.3, 0.5)	0.4 (0.3, 0.6)	0.4 (0.3, 0.5)
138	Calhoun	FL	0.8 (0.3, 2.7)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.2, 0.4)
50	Taylor	FL	0.8 (0.2, 2.4)	0.2 (0.1, 0.3)	0.1 (0.1, 0.2)	0.2 (0.2, 0.3)	0.2 (0.1, 0.3)	0.1 (0.1, 0.2)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)

47	Marion	FL	0.7 (0, 3.7)	0.3 (0.2, 0.4)	0.3 (0.2, 0.4)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)	0.3 (0.2, 0.4)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)
146	Hillsborough	FL	0.7 (0.1, 3)	0.1 (0.1, 0.2)	0.3 (0.2, 0.4)	0.2 (0.1, 0.3)	0.2 (0.1, 0.2)	0.2 (0.1, 0.3)	0.2 (0.2, 0.3)	0.3 (0.2, 0.4)
144	Pinellas	FL	0.7 (0.2, 2.2)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)
167	Duval	FL	0.6 (0.2, 2.2)	0.1 (0, 0.2)	0 (0, 0.1)	0.1 (0, 0.1)	0.1 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.1)	0.1 (0, 0.1)
65	Lafayette	FL	0.5 (0.1, 1.8)	0.1 (0, 0.2)	0.1 (0, 0.2)	0.1 (0.1, 0.2)	0.1 (0, 0.1)	0.1 (0, 0.1)	0.1 (0, 0.1)	0.1 (0, 0.1)
148	Orange	FL	0.4 (0, 1.9)	0.1 (0.1, 0.2)	0.1 (0, 0.1)	0.1 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.1)
33	Pinellas	FL	0.3 (0, 1.4)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0)	0 (0, 0.1)
1	Escambia	FL	0.3 (0, 1.4)	0.1 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.1)	0.1 (0, 0.1)	0.1 (0, 0.2)	0 (0, 0.1)	0.1 (0, 0.1)
216	Franklin	FL	0.3 (0, 1.4)	0.1 (0.1, 0.2)	0 (0, 0.1)	0.1 (0, 0.1)	0.1 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.1)
44	Marion	FL	0.2 (0, 1.4)	0.1 (0, 0.1)	0 (0, 0)	0.1 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)
139	Holmes	FL	0.1 (0, 1)	0 (0, 0)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0.1)
140	Jackson	FL	0.1 (0, 1)	0 (0, 0.1)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0.1)	0 (0, 0)
43	Seminole	FL	0 (0, 1)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
75	Marion	GA	100 (100, 100)	67.5 (66.6, 68.4)	66.1 (65.1, 67)	65.8 (64.9, 66.7)	60.8 (59.8, 61.7)	71.5 (70.6, 72.4)	70.6 (69.7, 71.5)	71.1 (70.2, 71.9)
142	Baker	GA	100 (100, 100)	81.8 (81, 82.6)	81.3 (80.5, 82)	80.6 (79.8, 81.3)	75.3 (74.5, 76.2)	85.3 (84.6, 86)	86.2 (85.5, 86.9)	86.5 (85.8, 87.1)
211	Burke	GA	100 (100, 100)	89.3 (88.7, 89.9)	88.6 (88, 89.2)	88.2 (87.5, 88.8)	87.4 (86.7, 88)	89.7 (89.1, 90.3)	90 (89.4, 90.6)	90.2 (89.6, 90.7)
210	Screven	GA	99.5 (98.2, 99.9)	81.6 (80.8, 82.3)	81 (80.2, 81.7)	81.4 (80.6, 82.2)	81.7 (80.9, 82.4)	81.3 (80.5, 82.1)	92.2 (91.7, 92.7)	92.5 (92, 93)
83	Long	GA	99.4 (98.2, 99.9)	72.7 (71.9, 73.6)	72.6 (71.7, 73.5)	72.6 (71.7, 73.5)	61.8 (60.9, 62.8)	88.3 (87.6, 88.9)	88.1 (87.5, 88.7)	88.6 (87.9, 89.2)
97	Richmond	GA	99 (97.5, 99.6)	82.5 (81.8, 83.2)	82.7 (82, 83.4)	82.4 (81.7, 83.2)	78.5 (77.7, 79.3)	86 (85.3, 86.7)	86.3 (85.6, 86.9)	86.4 (85.7, 87)
76	Bibb	GA	97.3 (95.1, 98.5)	23.9 (23.1, 24.8)	23.8 (23, 24.6)	22.9 (22, 23.7)	24 (23.2, 24.9)	22.5 (21.7, 23.3)	53.2 (52.2, 54.1)	52.6 (51.7, 53.6)
181	Burke	GA	96.2 (93.9, 97.7)	55.1 (54.1, 56.1)	55.1 (54.1, 56.1)	55.4 (54.5, 56.4)	54.5 (53.6, 55.5)	56.4 (55.4, 57.4)	55.7 (54.8, 56.7)	57 (56, 58)
173	Tattnall	GA	96.1 (93.6, 97.5)	39.8 (38.8, 40.7)	40.4 (39.5, 41.4)	40.1 (39.2, 41.1)	38.5 (37.6, 39.5)	40.1 (39.1, 41)	40.4 (39.5, 41.4)	40.4 (39.5, 41.4)
31	Mitchell	GA	95.9 (93.6, 97.5)	72 (71.2, 72.9)	71.4 (70.5, 72.2)	71.7 (70.8, 72.5)	71.2 (70.3, 72)	72.2 (71.3, 73.1)	89.1 (88.4, 89.6)	89 (88.4, 89.6)
72	Stewart	GA	93.6 (90.6, 95.5)	36.2 (35.2, 37.1)	36.2 (35.3, 37.2)	34.6 (33.6, 35.5)	35.5 (34.6, 36.5)	36.4 (35.4, 37.3)	66.5 (65.6, 67.4)	66.9 (66, 67.8)
208	Screven	GA	86.8 (83.1, 89.7)	56 (55.1, 57)	55.9 (54.9, 56.9)	55.5 (54.6, 56.5)	56.3 (55.3, 57.2)	55.3 (54.4, 56.3)	73.1 (72.2, 74)	71.6 (70.7, 72.4)
143	Baker	GA	82.6 (78.5, 86)	62.9 (62, 63.9)	60.8 (59.9, 61.8)	60.8 (59.8, 61.8)	58.1 (57.1, 59)	65.7 (64.7, 66.6)	64.7 (63.8, 65.6)	64.6 (63.7, 65.6)
198	Effingham	GA	74.4 (69.7, 78.3)	41.2 (40.2, 42.2)	41.1 (40.2, 42.1)	39.8 (38.8, 40.8)	40.6 (39.7, 41.6)	40.9 (39.9, 41.8)	41.3 (40.4, 42.3)	64.9 (64, 65.9)
141	Decatur	GA	66.7 (62, 71.2)	17.2 (16.5, 17.9)	17.6 (16.9, 18.4)	17 (16.3, 17.7)	17 (16.3, 17.7)	16.9 (16.2, 17.7)	17.3 (16.6, 18.1)	40.3 (39.4, 41.3)
84	Tattnall	GA	54.8 (49.9, 59.6)	24.8 (24, 25.6)	25.7 (24.8, 26.5)	25.7 (24.8, 26.5)	25.1 (24.2, 25.9)	25.5 (24.7, 26.4)	24.8 (24, 25.7)	38.9 (37.9, 39.8)
174	Bryan	GA	48.9 (39.9, 58.3)	28.5 (27.7, 29.4)	28 (27.1, 28.8)	28.8 (27.9, 29.7)	25.9 (25.1, 26.8)	35.3 (34.4, 36.3)	35.3 (34.4, 36.3)	34.3 (33.4, 35.3)
82	Liberty	GA	48.9 (44.1, 53.9)	28 (27.1, 28.8)	28.5 (27.6, 29.4)	27.9 (27, 28.8)	24.9 (24, 25.7)	38.2 (37.3, 39.2)	38.4 (37.4, 39.3)	38 (37, 38.9)
176	Bryan	GA	44.8 (40, 49.6)	22.4 (21.6, 23.3)	22.2 (21.4, 23)	21.6 (20.8, 22.4)	19 (18.2, 19.8)	28.3 (27.5, 29.2)	28.6 (27.7, 29.5)	28.8 (27.9, 29.7)

29	Mitchell	GA	43.1 (38, 48.2)	20.9 (20.1, 21.7)	21.2 (20.4, 22)	21.4 (20.6, 22.2)	21 (20.3, 21.8)	21.8 (21, 22.7)	20.9 (20.1, 21.7)	20.6 (19.9, 21.4)
28	Miller	GA	41 (36.3, 45.9)	22 (21.2, 22.8)	21 (20.2, 21.8)	22.2 (21.4, 23)	20.8 (20, 21.6)	22.6 (21.8, 23.4)	21.7 (20.9, 22.5)	22.4 (21.6, 23.2)
98	McDuffie	GA	32.4 (28.1, 37.2)	14.1 (13.4, 14.8)	14.3 (13.6, 15)	13.9 (13.2, 14.6)	14.4 (13.8, 15.1)	13.8 (13.1, 14.5)	13.9 (13.2, 14.5)	14.7 (14, 15.4)
93	Burke	GA	26.8 (17.1, 39)	20.1 (19.3, 20.9)	19.3 (18.5, 20.1)	18.9 (18.1, 19.6)	18.5 (17.7, 19.3)	19.1 (18.4, 19.9)	18.5 (17.7, 19.3)	18.9 (18.1, 19.7)
170	Pulaski	GA	25.8 (18.2, 34.3)	9 (8.4, 9.6)	8.8 (8.3, 9.4)	9.2 (8.6, 9.8)	8.9 (8.3, 9.4)	8.5 (7.9, 9)	9.2 (8.6, 9.8)	8.8 (8.3, 9.4)
81	Coffee	GA	24.2 (20.3, 28.7)	11.1 (10.5, 11.7)	11.1 (10.5, 11.7)	10.9 (10.3, 11.5)	10.3 (9.7, 10.9)	12 (11.4, 12.7)	12.3 (11.7, 13)	11.9 (11.3, 12.5)
172	Dodge	GA	23.4 (19.6, 27.9)	7.3 (6.8, 7.8)	7.7 (7.1, 8.2)	7.9 (7.3, 8.4)	7.3 (6.8, 7.8)	7.2 (6.7, 7.7)	7.6 (7.1, 8.1)	7.5 (7, 8)
95	Jefferson	GA	15.1 (11.8, 18.8)	5 (4.6, 5.4)	5.2 (4.8, 5.7)	5 (4.6, 5.4)	5 (4.6, 5.5)	5 (4.6, 5.5)	5.3 (4.8, 5.7)	5.3 (4.9, 5.7)
85	Bulloch	GA	14.9 (11.8, 18.8)	6.9 (6.4, 7.4)	7.2 (6.7, 7.7)	7.1 (6.6, 7.6)	6.7 (6.3, 7.2)	7.1 (6.6, 7.6)	7.4 (6.9, 8)	7.3 (6.8, 7.8)
74	Bleckley	GA	7.5 (4.9, 11.6)	2.7 (2.4, 3.1)	2.6 (2.3, 2.9)	2.6 (2.3, 2.9)	2.7 (2.4, 3)	2.7 (2.4, 3)	2.4 (2.1, 2.7)	2.7 (2.4, 3.1)
177	Bryan	GA	7.2 (4.3, 12.7)	2 (1.7, 2.3)	2.3 (2, 2.6)	2 (1.7, 2.3)	2.1 (1.8, 2.4)	2.1 (1.8, 2.4)	2.1 (1.8, 2.4)	2.2 (1.9, 2.5)
178	Effingham	GA	5.9 (3.8, 9.3)	1.9 (1.6, 2.1)	2 (1.7, 2.3)	2 (1.7, 2.2)	2.2 (1.9, 2.5)	2.2 (1.9, 2.5)	2 (1.8, 2.3)	2.1 (1.8, 2.4)
168	Dougherty	GA	5.1 (1.1, 19.6)	2.7 (2.4, 3.1)	2.8 (2.5, 3.2)	2.5 (2.2, 2.9)	2.6 (2.3, 3)	2.6 (2.3, 2.9)	2.6 (2.3, 3)	2.9 (2.6, 3.2)
94	Burke	GA	4.7 (2.1, 9.7)	2.8 (2.5, 3.2)	2.8 (2.4, 3.1)	2.7 (2.4, 3)	2.7 (2.4, 3.1)	2.8 (2.5, 3.1)	3 (2.6, 3.3)	2.7 (2.4, 3)
175	Bulloch	GA	4.6 (2.8, 7.7)	1.7 (1.4, 1.9)	1.7 (1.4, 1.9)	1.7 (1.4, 1.9)	1.7 (1.5, 2)	1.7 (1.5, 2)	1.6 (1.4, 1.9)	1.4 (1.2, 1.6)
169	Stewart	GA	3.1 (1.9, 5.5)	1.4 (1.2, 1.6)	1.4 (1.2, 1.6)	1.1 (0.9, 1.3)	1.3 (1.1, 1.6)	1.6 (1.4, 1.9)	1.5 (1.3, 1.8)	1.4 (1.2, 1.6)
179	Effingham	GA	3 (1.7, 5.2)	0.8 (0.7, 1)	0.9 (0.7, 1)	0.7 (0.6, 0.9)	0.7 (0.5, 0.9)	0.8 (0.7, 1)	0.8 (0.6, 1)	1 (0.8, 1.2)
88	Screven	GA	2.6 (1.4, 4.7)	0.4 (0.3, 0.6)	0.5 (0.4, 0.7)	0.5 (0.4, 0.7)	0.6 (0.5, 0.8)	0.5 (0.4, 0.7)	0.6 (0.4, 0.7)	0.6 (0.4, 0.7)
90	Baldwin	GA	2.2 (1.2, 4.2)	0.4 (0.3, 0.5)	0.4 (0.3, 0.5)	0.4 (0.3, 0.5)	0.4 (0.3, 0.5)	0.4 (0.3, 0.6)	0.4 (0.3, 0.6)	0.4 (0.3, 0.5)
23	Decatur	GA	0.9 (0.1, 2.8)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)	0.2 (0.2, 0.3)	0.2 (0.2, 0.4)	0.3 (0.2, 0.4)	0.3 (0.2, 0.4)	0.2 (0.2, 0.3)
80	Irwin	GA	0.8 (0.1, 2.8)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.1 (0.1, 0.2)	0.2 (0.1, 0.3)	0.2 (0.1, 0.2)	0.3 (0.2, 0.4)	0.1 (0.1, 0.2)
171	Houston	GA	0.7 (0, 3.9)	0.2 (0.1, 0.3)	0.2 (0.1, 0.2)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)	0.2 (0.1, 0.2)
30	Early	GA	0.6 (0.1, 1.8)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)	0.2 (0.1, 0.3)	0.1 (0, 0.2)	0.1 (0.1, 0.2)	0.2 (0.1, 0.3)
127	Wilcox	GA	0.5 (0.1, 1.9)	0.1 (0.1, 0.2)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.2)	0.1 (0.1, 0.2)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)
26	Thomas	GA	0.5 (0.1, 1.8)	0.1 (0, 0.1)	0.1 (0, 0.2)	0.1 (0.1, 0.2)	0.1 (0, 0.2)	0.1 (0, 0.1)	0.1 (0, 0.2)	0.1 (0, 0.2)
87	Johnson	GA	0.3 (0, 1.4)	0.1 (0, 0.2)	0 (0, 0.1)	0.1 (0.1, 0.2)	0.1 (0, 0.1)	0.1 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.1)
91	Jefferson	GA	0.3 (0, 1.4)	0.1 (0, 0.2)	0.1 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.1)	0.1 (0, 0.1)
70	Ware	GA	0.2 (0, 1.4)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0)	0 (0, 0)	0 (0, 0.1)
218	Butts	GA	-	-	-	-	-	-	-	-
222	Camden	GA	-	-	-	-	-	-	-	-
223	Charlton	GA	-	-	-	-	-	-	-	-
9	Harrison	MS	2.8 (1.1, 6)	0.5 (0.4, 0.7)	0.5 (0.3, 0.6)	0.4 (0.3, 0.6)	0.5 (0.4, 0.7)	0.6 (0.4, 0.7)	0.5 (0.4, 0.6)	0.6 (0.5, 0.8)

10	Stone	MS	2.4 (1, 5.5)	0.5 (0.4, 0.7)	0.6 (0.5, 0.8)	0.5 (0.4, 0.7)	0.6 (0.4, 0.7)	0.6 (0.5, 0.8)	0.6 (0.5, 0.8)	0.6 (0.5, 0.8)
19	Forrest	MS	1.7 (0.9, 3.6)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)	0.3 (0.2, 0.5)	0.4 (0.3, 0.5)	0.3 (0.2, 0.5)
197	Harrison	MS	0.6 (0.1, 1.8)	0.1 (0, 0.1)	0 (0, 0.1)	0.1 (0, 0.2)	0 (0, 0.1)	0.1 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)
128	Harrison	MS	0.1 (0, 1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0.1)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
214	New Hanover	NC	100 (100, 100)	67.3 (66.4, 68.3)	68.4 (67.5, 69.3)	67.7 (66.8, 68.6)	65.7 (64.8, 66.6)	69.8 (68.9, 70.7)	70.1 (69.2, 71)	70.5 (69.6, 71.4)
117	Sampson	NC	100 (100, 100)	70.4 (69.5, 71.3)	70.1 (69.2, 71)	70.4 (69.5, 71.3)	70 (69.1, 70.9)	69.7 (68.8, 70.6)	90.5 (89.9, 91.1)	90.7 (90.1, 91.2)
215	Scotland	NC	100 (100, 100)	74.7 (73.8, 75.6)	73.3 (72.4, 74.2)	73.3 (72.4, 74.2)	73.4 (72.6, 74.3)	74.6 (73.8, 75.5)	74.4 (73.5, 75.2)	73.9 (73, 74.8)
194	Moore	NC	100 (100, 100)	85.2 (84.4, 85.8)	85.5 (84.8, 86.2)	84.8 (84.1, 85.5)	85 (84.3, 85.7)	84.3 (83.5, 85)	84.3 (83.6, 85)	84.8 (84.1, 85.5)
190	New Hanover	NC	97.7 (95.8, 98.8)	79.2 (78.4, 80)	78.6 (77.7, 79.4)	78.1 (77.3, 78.9)	77.5 (76.7, 78.3)	78.2 (77.4, 79)	93 (92.5, 93.5)	93.1 (92.5, 93.5)
204	Onslow	NC	96.1 (93.9, 97.7)	70 (69.1, 70.9)	69.1 (68.2, 70)	69.2 (68.3, 70.1)	50.6 (49.6, 51.6)	83.6 (82.9, 84.4)	83.7 (83, 84.5)	83.9 (83.2, 84.6)
121	Sampson	NC	94.2 (91.5, 96.1)	26.3 (25.4, 27.2)	26.2 (25.3, 27.1)	25.6 (24.8, 26.5)	25.5 (24.6, 26.3)	25.6 (24.8, 26.5)	46 (45, 47)	46.4 (45.4, 47.4)
189	Brunswick	NC	93.9 (91.2, 95.9)	77.8 (77, 78.6)	78.3 (77.5, 79.1)	78.2 (77.3, 79)	72.6 (71.7, 73.4)	83.2 (82.5, 83.9)	82.8 (82, 83.5)	82.9 (82.1, 83.6)
191	Pender	NC	89.6 (86.1, 92.1)	51.4 (50.5, 52.4)	50.8 (49.8, 51.7)	50.6 (49.6, 51.6)	49.7 (48.7, 50.7)	52.4 (51.4, 53.4)	51.9 (50.9, 52.9)	52.3 (51.3, 53.2)
110	Bladen	NC	86.3 (82.5, 89.3)	32.7 (31.8, 33.7)	33.4 (32.5, 34.4)	32.7 (31.8, 33.6)	33.6 (32.6, 34.5)	33.6 (32.7, 34.6)	51.3 (50.4, 52.3)	52.3 (51.4, 53.3)
113	Pender	NC	76.3 (71.8, 80.2)	46.2 (45.3, 47.2)	47.1 (46.1, 48.1)	46 (45.1, 47)	46.6 (45.6, 47.5)	45.7 (44.7, 46.6)	44.3 (43.4, 45.3)	66.9 (65.9, 67.8)
107	Brunswick	NC	63.9 (59.2, 68.6)	28.6 (27.7, 29.4)	28.2 (27.3, 29)	28.5 (27.7, 29.4)	27.5 (26.6, 28.4)	28.8 (27.9, 29.7)	28.7 (27.8, 29.6)	28.9 (28, 29.8)
201	Brunswick	NC	60.5 (55.6, 65.2)	15.5 (14.8, 16.2)	16.3 (15.6, 17)	16.3 (15.6, 17)	15.8 (15.1, 16.6)	15.7 (15, 16.4)	15.3 (14.6, 16)	41 (40.1, 42)
118	Duplin	NC	49 (44.1, 53.9)	11.6 (11, 12.3)	12 (11.4, 12.7)	11.8 (11.2, 12.5)	12.3 (11.7, 13)	12 (11.4, 12.7)	11.6 (11, 12.3)	12.1 (11.5, 12.8)
192	Bladen	NC	16.5 (13.2, 20.5)	11.1 (10.5, 11.7)	11.2 (10.6, 11.8)	11.3 (10.7, 11.9)	11.2 (10.6, 11.8)	11.3 (10.7, 12)	12.1 (11.5, 12.8)	11.6 (11, 12.2)
195	Cumberland	NC	16.2 (12.5, 20.6)	6 (5.5, 6.5)	6.4 (6, 6.9)	5.8 (5.4, 6.3)	6.1 (5.6, 6.6)	5.7 (5.3, 6.2)	6 (5.5, 6.5)	6.3 (5.8, 6.8)
116	Robeson	NC	12.8 (9.7, 17.3)	4.9 (4.4, 5.3)	5.1 (4.7, 5.6)	5.3 (4.8, 5.7)	4.8 (4.4, 5.2)	5 (4.6, 5.4)	5.1 (4.6, 5.5)	5 (4.6, 5.4)
193	Bladen	NC	12.6 (9.5, 16.3)	4.7 (4.3, 5.2)	4.6 (4.2, 5)	4.7 (4.3, 5.2)	4.8 (4.4, 5.2)	4.9 (4.5, 5.3)	4.9 (4.5, 5.4)	4.7 (4.3, 5.2)
203	Richmond	NC	10.4 (5.7, 20.2)	6 (5.6, 6.5)	6.1 (5.6, 6.6)	5.3 (4.9, 5.8)	6 (5.5, 6.4)	5.7 (5.3, 6.2)	6.1 (5.6, 6.6)	5.8 (5.3, 6.2)
109	Bladen	NC	7.8 (4.5, 12.6)	3.7 (3.3, 4.1)	3.8 (3.5, 4.2)	3.8 (3.4, 4.1)	3.8 (3.5, 4.2)	3.8 (3.5, 4.2)	4 (3.6, 4.4)	4 (3.7, 4.4)
115	Robeson	NC	7.5 (5.3, 10.7)	1.7 (1.5, 2)	1.8 (1.6, 2.1)	1.9 (1.7, 2.2)	2 (1.7, 2.3)	2 (1.7, 2.3)	2 (1.7, 2.3)	2 (1.7, 2.3)
111	Bladen	NC	7.1 (3.7, 12.6)	3.4 (3.1, 3.8)	3.8 (3.4, 4.2)	3.5 (3.1, 3.8)	3.3 (2.9, 3.6)	3.8 (3.4, 4.2)	3.4 (3, 3.8)	3.4 (3.1, 3.8)
114	Bladen	NC	5.2 (3.1, 8.7)	2.4 (2.1, 2.8)	2.6 (2.3, 3)	2.7 (2.4, 3)	2.9 (2.6, 3.3)	2.8 (2.5, 3.1)	2.5 (2.2, 2.9)	2.4 (2.1, 2.7)
202	Pender	NC	5.2 (3.5, 7.9)	1.7 (1.5, 2)	1.5 (1.2, 1.7)	1.8 (1.5, 2)	1.6 (1.3, 1.8)	1.5 (1.3, 1.8)	1.5 (1.3, 1.8)	1.9 (1.6, 2.1)
196	Cumberland	NC	4.2 (2, 7.7)	2.2 (1.9, 2.5)	2.2 (1.9, 2.5)	1.9 (1.7, 2.2)	1.8 (1.6, 2.1)	1.6 (1.4, 1.9)	2 (1.8, 2.3)	2.1 (1.9, 2.4)
124	Jones	NC	3 (0.8, 8.5)	1.3 (1.1, 1.5)	1.4 (1.2, 1.6)	1.3 (1.1, 1.5)	1 (0.8, 1.2)	1.6 (1.4, 1.9)	1.5 (1.3, 1.8)	1.6 (1.4, 1.8)
112	Pender	NC	2.5 (1.1, 5.1)	1.7 (1.5, 2)	1.5 (1.3, 1.8)	1.3 (1.1, 1.6)	1.6 (1.4, 1.9)	1.8 (1.5, 2)	1.5 (1.3, 1.7)	1.5 (1.3, 1.7)

119	Duplin	NC	1.8 (0.9, 3.6)	0.4 (0.3, 0.6)	0.6 (0.4, 0.7)	0.4 (0.3, 0.5)	0.4 (0.3, 0.6)	0.5 (0.3, 0.6)	0.4 (0.3, 0.6)	0.4 (0.3, 0.5)
120	Craven	NC	-	-	-	-	-	-	-	-
122	Moore	NC	-	-	-	-	-	-	-	-
123	Craven	NC	-	-	-	-	-	-	-	-
125	Wayne	NC	-	-	-	-	-	-	-	-
126	Wayne	NC	-	-	-	-	-	-	-	-
205	Carteret	NC	-	-	-	-	-	-	-	-
206	Craven	NC	-	-	-	-	-	-	-	-
219	Pitt	NC	-	-	-	-	-	-	-	-
220	Edgecombe	NC	-	-	-	-	-	-	-	-
221	Wake	NC	-	-	-	-	-	-	-	-
183	Berkeley	SC	100 (100, 100)	71 (70.1, 71.9)	70.4 (69.4, 71.2)	70 (69.1, 70.9)	53.2 (52.3, 54.2)	88.3 (87.6, 88.9)	87.5 (86.8, 88.1)	87.5 (86.8, 88.1)
212	Barnwell	SC	99.8 (98.6, 100)	88.2 (87.5, 88.8)	87.9 (87.2, 88.5)	87.8 (87.2, 88.4)	88.9 (88.3, 89.5)	87.8 (87.1, 88.4)	87.8 (87.2, 88.4)	88.4 (87.7, 89)
180	Jasper	SC	98.7 (97.1, 99.5)	45.4 (44.4, 46.4)	45.7 (44.7, 46.7)	45.2 (44.2, 46.1)	45.1 (44.1, 46.1)	46.4 (45.4, 47.3)	85.9 (85.2, 86.6)	84.8 (84, 85.5)
108	Chesterfield	SC	89.3 (85.8, 91.9)	56.8 (55.8, 57.8)	56.8 (55.8, 57.8)	56.8 (55.8, 57.8)	55 (54.1, 56)	59.4 (58.4, 60.3)	59.4 (58.4, 60.3)	59.4 (58.4, 60.4)
184	Aiken	SC	85.7 (82, 88.8)	16.6 (15.9, 17.3)	15 (14.3, 15.7)	14.8 (14.1, 15.5)	15.7 (15, 16.5)	15.6 (14.9, 16.3)	50.4 (49.5, 51.4)	51.2 (50.2, 52.1)
89	Hampton	SC	63.8 (58.9, 68.3)	22.1 (21.3, 23)	22 (21.2, 22.8)	22.3 (21.5, 23.2)	21.3 (20.5, 22.1)	22.2 (21.4, 23)	22.1 (21.3, 22.9)	52 (51, 53)
103	Aiken	SC	62.4 (57.7, 67.1)	41.7 (40.8, 42.7)	39.7 (38.7, 40.6)	38.4 (37.5, 39.4)	40.8 (39.8, 41.8)	39.9 (38.9, 40.8)	39.9 (39, 40.9)	53.6 (52.6, 54.5)
207	Jasper	SC	58.4 (45.2, 71.2)	41.3 (40.3, 42.3)	42 (41, 43)	41.3 (40.3, 42.3)	38.5 (37.6, 39.5)	44.2 (43.2, 45.1)	43.5 (42.5, 44.4)	42.5 (41.5, 43.5)
209	Allendale	SC	57.4 (51.6, 63.2)	35.8 (34.9, 36.8)	35.9 (35, 36.9)	36.1 (35.1, 37)	35 (34.1, 36)	36.4 (35.4, 37.3)	35.9 (34.9, 36.8)	51.1 (50.1, 52.1)
105	Sumter	SC	54.2 (49.4, 59.1)	35.6 (34.7, 36.6)	34.9 (33.9, 35.8)	35.3 (34.3, 36.2)	35 (34.1, 35.9)	35.7 (34.8, 36.7)	35.8 (34.9, 36.8)	35.4 (34.4, 36.3)
106	Richland	SC	52.2 (44.9, 59.7)	39.9 (39, 40.9)	39.6 (38.7, 40.6)	40.6 (39.7, 41.6)	40.1 (39.1, 41)	41.4 (40.5, 42.4)	40.5 (39.6, 41.5)	40.2 (39.3, 41.2)
186	Marion	SC	49.1 (44.1, 53.9)	31.8 (30.9, 32.7)	31.1 (30.2, 32)	31.8 (30.9, 32.7)	25.5 (24.7, 26.4)	41.5 (40.5, 42.4)	41.1 (40.2, 42.1)	41.5 (40.5, 42.5)
102	Berkeley	SC	31.3 (26.9, 36)	10 (9.4, 10.6)	11 (10.4, 11.6)	9.9 (9.3, 10.5)	10 (9.4, 10.6)	11.1 (10.5, 11.7)	11.3 (10.7, 11.9)	11.4 (10.8, 12)
188	Horry	SC	28.4 (24.3, 33.1)	10.1 (9.5, 10.7)	10.2 (9.6, 10.8)	9.7 (9.1, 10.3)	10.2 (9.6, 10.8)	10.6 (10, 11.2)	9.8 (9.2, 10.3)	10.1 (9.5, 10.7)
213	Georgetown	SC	23.3 (19.4, 27.6)	14.5 (13.8, 15.2)	14.4 (13.7, 15.1)	14.9 (14.2, 15.6)	11.4 (10.8, 12.1)	17.5 (16.8, 18.2)	17.2 (16.4, 17.9)	17.9 (17.2, 18.7)
187	Horry	SC	4 (2.5, 6.4)	1.9 (1.7, 2.2)	1.8 (1.6, 2.1)	1.5 (1.3, 1.8)	1.7 (1.4, 2)	1.7 (1.4, 2)	1.8 (1.5, 2.1)	1.7 (1.5, 2)
200	Horry	SC	3.5 (1.7, 7)	1.5 (1.3, 1.7)	1.4 (1.2, 1.6)	1.5 (1.3, 1.8)	1.4 (1.2, 1.7)	1.8 (1.5, 2.1)	1.7 (1.4, 1.9)	1.8 (1.5, 2)
182	Dorchester	SC	2.6 (1.5, 4.9)	0.9 (0.8, 1.1)	0.7 (0.6, 0.9)	0.9 (0.7, 1.1)	0.9 (0.7, 1)	0.8 (0.7, 1)	0.9 (0.8, 1.1)	0.9 (0.7, 1.1)
185	Aiken	SC	2.5 (1, 6.7)	1.2 (1, 1.4)	1.2 (1, 1.5)	1.4 (1.2, 1.7)	1.3 (1.1, 1.6)	1.1 (0.9, 1.3)	1.2 (1, 1.4)	1.2 (1, 1.5)
86	Beaufort	SC	2.3 (0.9, 5.9)	0.8 (0.6, 1)	0.7 (0.6, 0.9)	0.7 (0.5, 0.8)	0.7 (0.6, 0.9)	0.7 (0.6, 0.9)	0.9 (0.7, 1.1)	0.8 (0.6, 1)
92	Colleton	SC	1.9 (1, 3.9)	0.7 (0.5, 0.8)	0.6 (0.4, 0.7)	0.6 (0.4, 0.7)	0.5 (0.4, 0.7)	0.5 (0.4, 0.7)	0.6 (0.5, 0.8)	0.7 (0.5, 0.8)

100	Berkeley	SC	1.5 (0.7, 3.5)	0.3 (0.2, 0.4)	0.6 (0.4, 0.7)	0.5 (0.3, 0.6)	0.4 (0.3, 0.6)	0.7 (0.5, 0.8)	0.6 (0.5, 0.8)	0.6 (0.4, 0.7)
199	Charleston	SC	1 (0.2, 2.6)	0.2 (0.1, 0.3)	0.3 (0.2, 0.5)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)	0.3 (0.2, 0.4)	0.3 (0.2, 0.4)
104	Clarendon	SC	0.7 (0.2, 2.2)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)
99	Bamberg	SC	0.6 (0.1, 3)	0.1 (0, 0.2)	0.2 (0.1, 0.3)	0.1 (0, 0.2)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)
96	Bamberg	SC	0.6 (0.1, 1.8)	0.3 (0.2, 0.4)	0.2 (0.2, 0.3)	0.2 (0.2, 0.3)	0.3 (0.2, 0.4)	0.4 (0.3, 0.5)	0.4 (0.3, 0.5)	0.3 (0.2, 0.4)

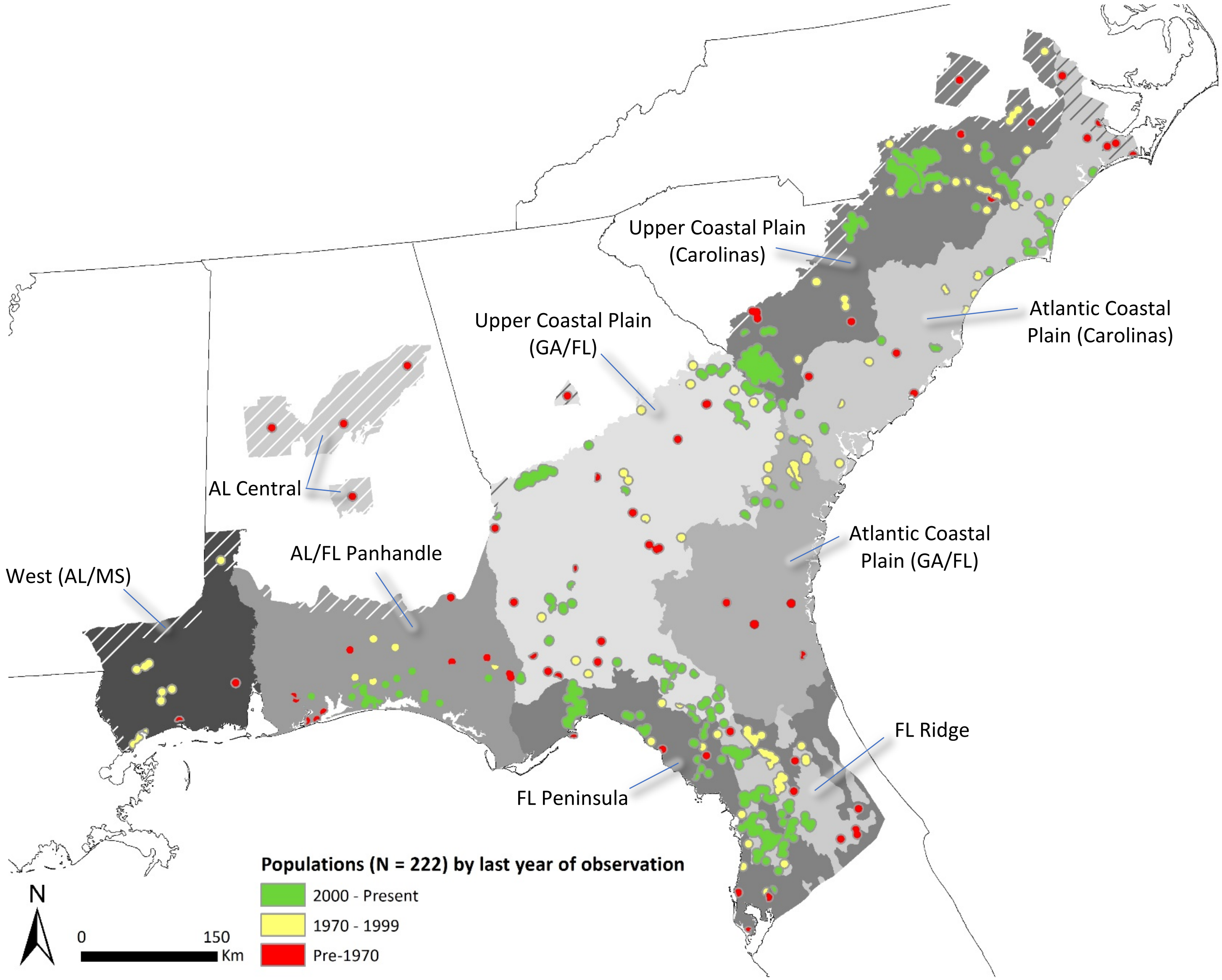

Figure B-1. Distribution of 222 southern hognose snake populations classified by last (most-recent) year of observation. Areas with diagonal lines fell within the species range but outside the analysis area. The grey representative units shown were clipped from the full species range (seen in the main SSA document) to only cover the analysis area. 204 populations occur in the analysis area.

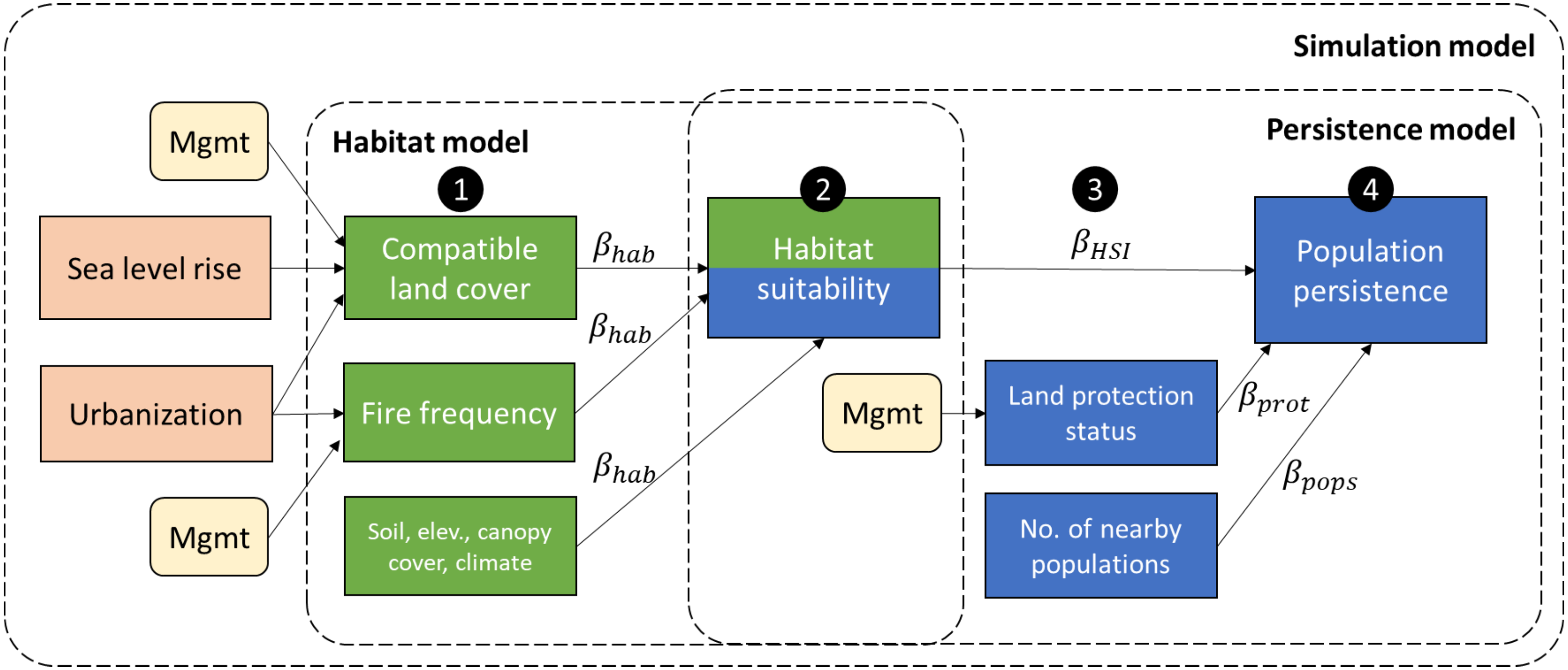

Figure B-2. Conceptual model linking components included in the habitat suitability model (green), current persistence model (blue), and impacts of stressors (orange) and management (yellow) in the simulation model for future conditions of the southern hognose snake. Numbers correspond to simulation model steps 1–4 discussed in Section 2.5.

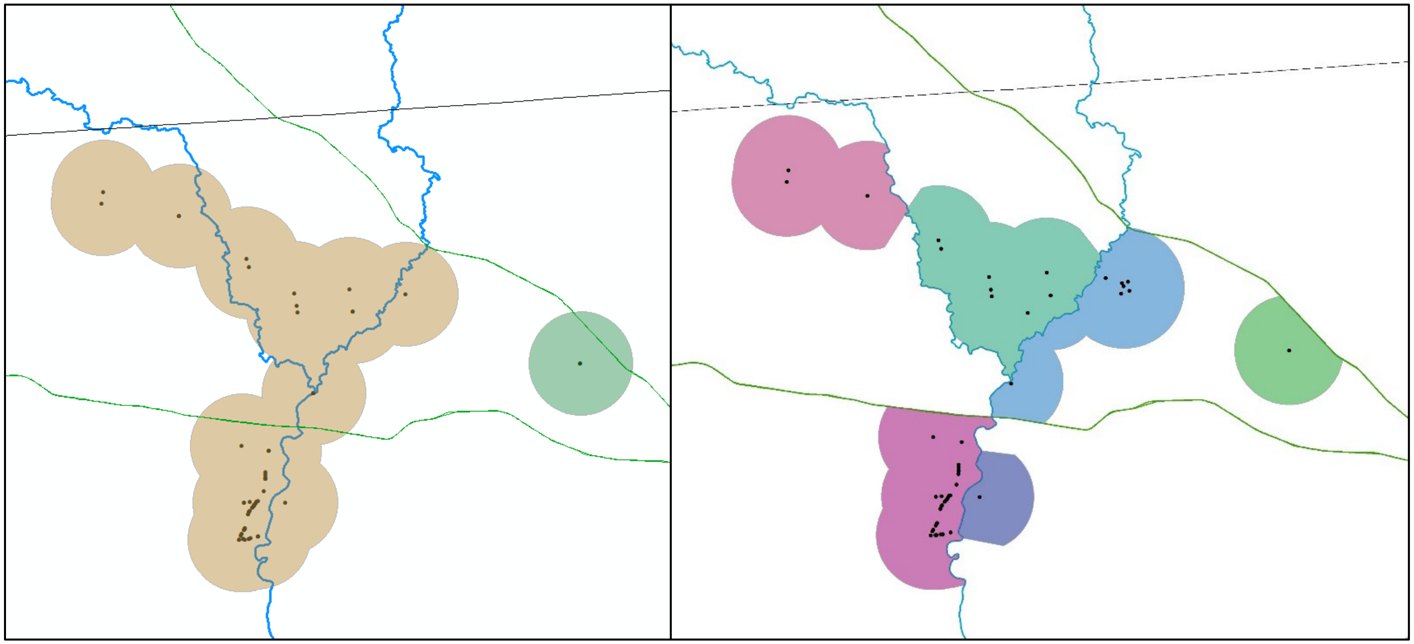

Figure B-3. Five-km buffers around all southern hognose records with different colors depicting different populations (left); same original buffers divided by major rivers (blue lines) and major highways (green lines) with final boundaries modified to reflect 5-km buffers around locations within a population (right).

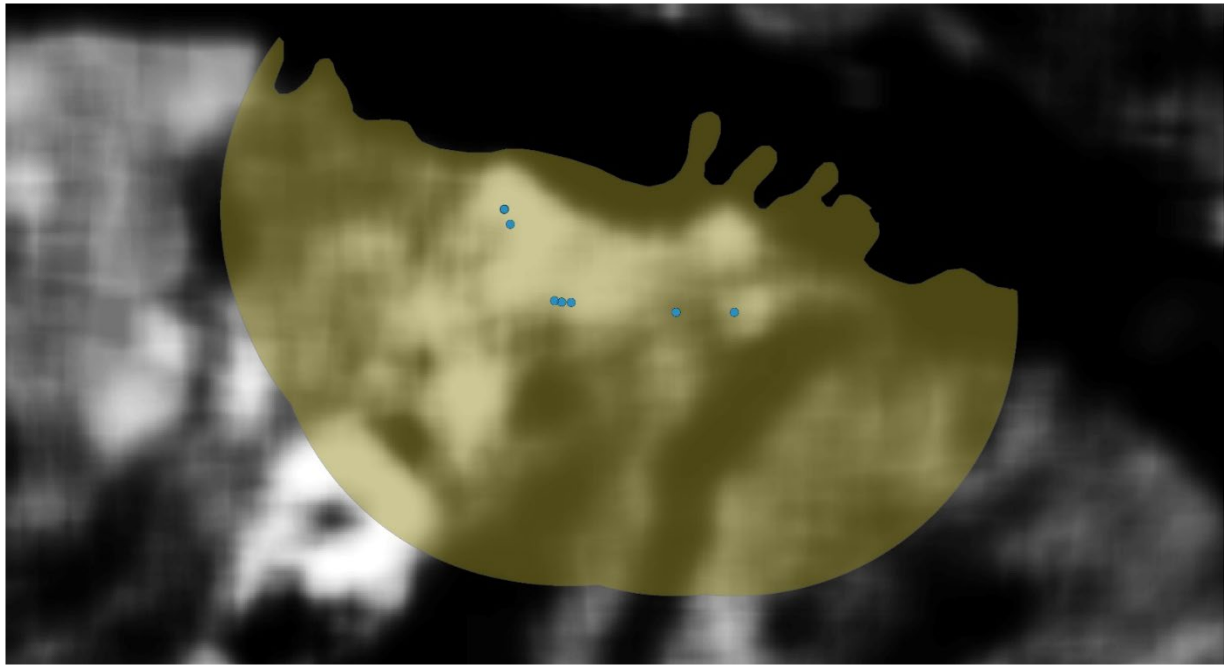

Figure B-4. Example of a population boundary around species locations (blue dots) that has been clipped by a 6th order river. The underlying raster shows the habitat suitability layer where lighter colors indicate higher suitability. We extracted mean conditions for habitat suitability and other metrics within each population's boundaries.

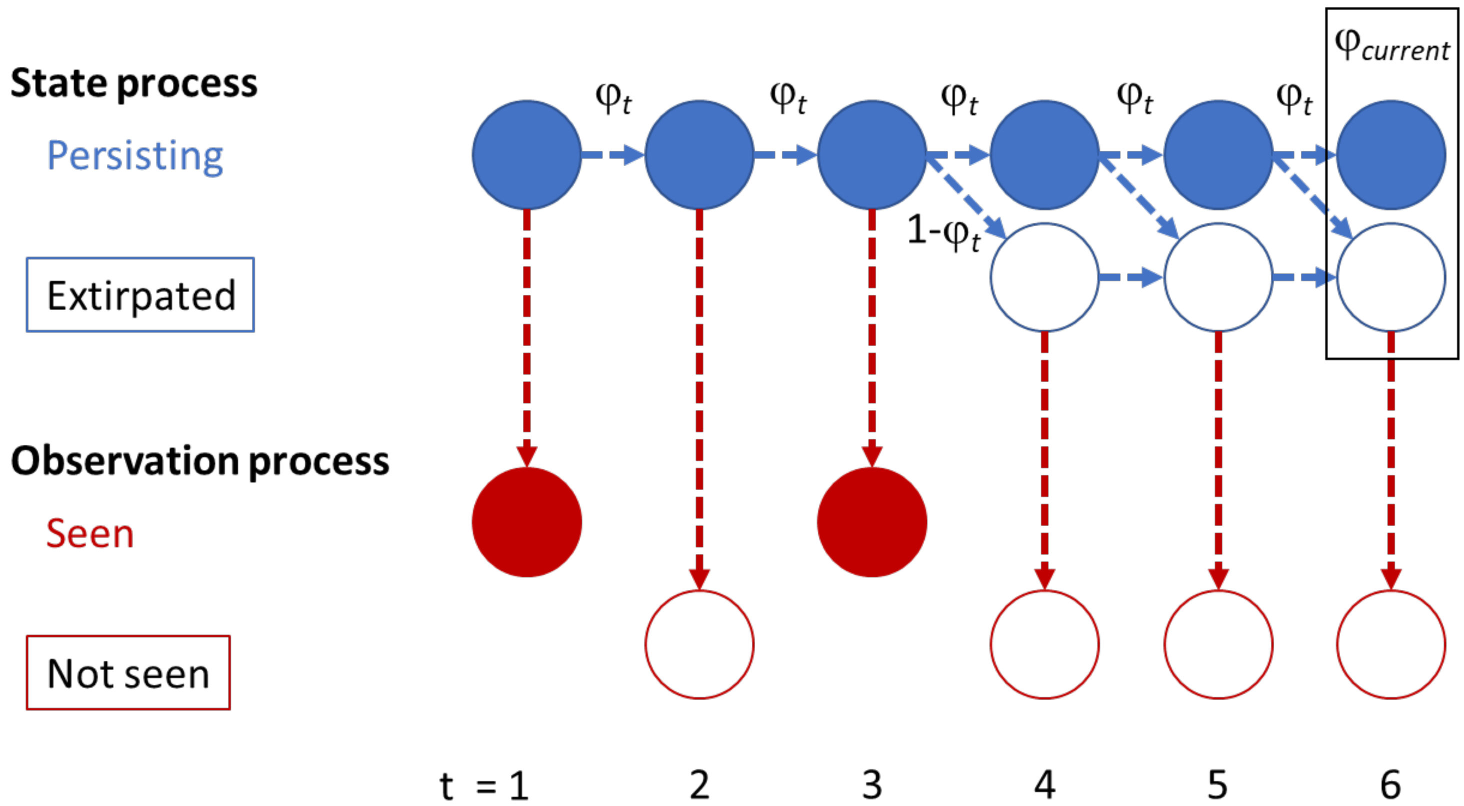

Figure B-5. Example of the state process (true state of the system) and observation process (what we observe) of a population over time for the persistence model. The population survives or becomes extirpated each year based on the annual persistence probability (φ_t) estimated in the model. This was used to derive the current persistence probability ($\varphi_{current}$) – i.e., the probability a site has survived over the entire time period modeled and is currently occupied in 2018. Its complement ($1 - \varphi_{current}$) is interpreted as the probability a population has become extirpated. If the population became extirpated in time period 4, then the sequence of the true state history would be z = [1, 1, 1, 0, 0, 0]. The observed capture history (when individuals were seen in this population) would be y = [1, 0, 1, 0, 0, 0]. Original source: Kery and Schaub (2012).

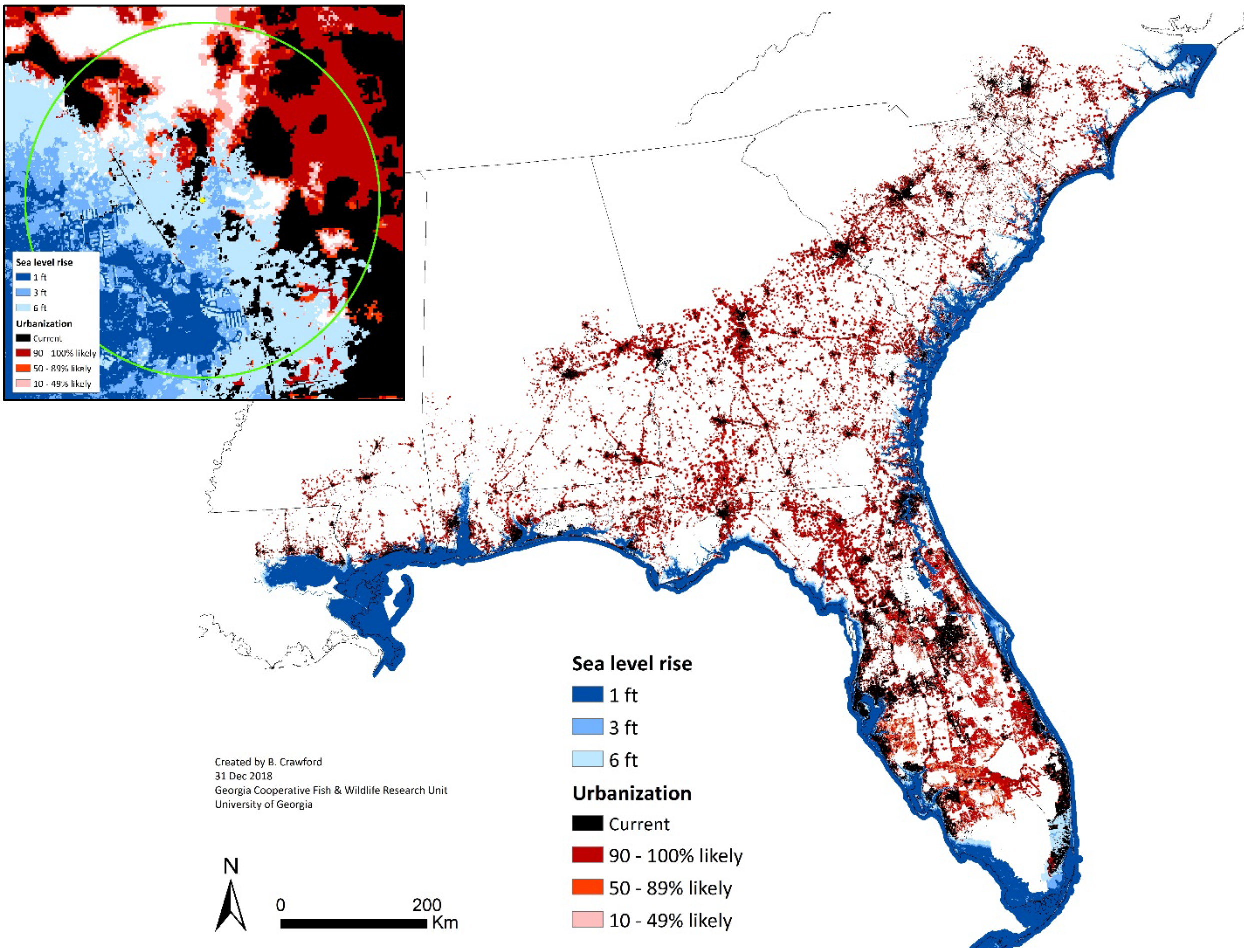

Figure B-6. Projected urbanization (black and red) and sea level rise (blue) for the year 2080 in the Southeast, United States. Certain southern hognose snake populations (green circle in inset) were predicted to experience substantial habitat loss due to urbanization and sea level rise.

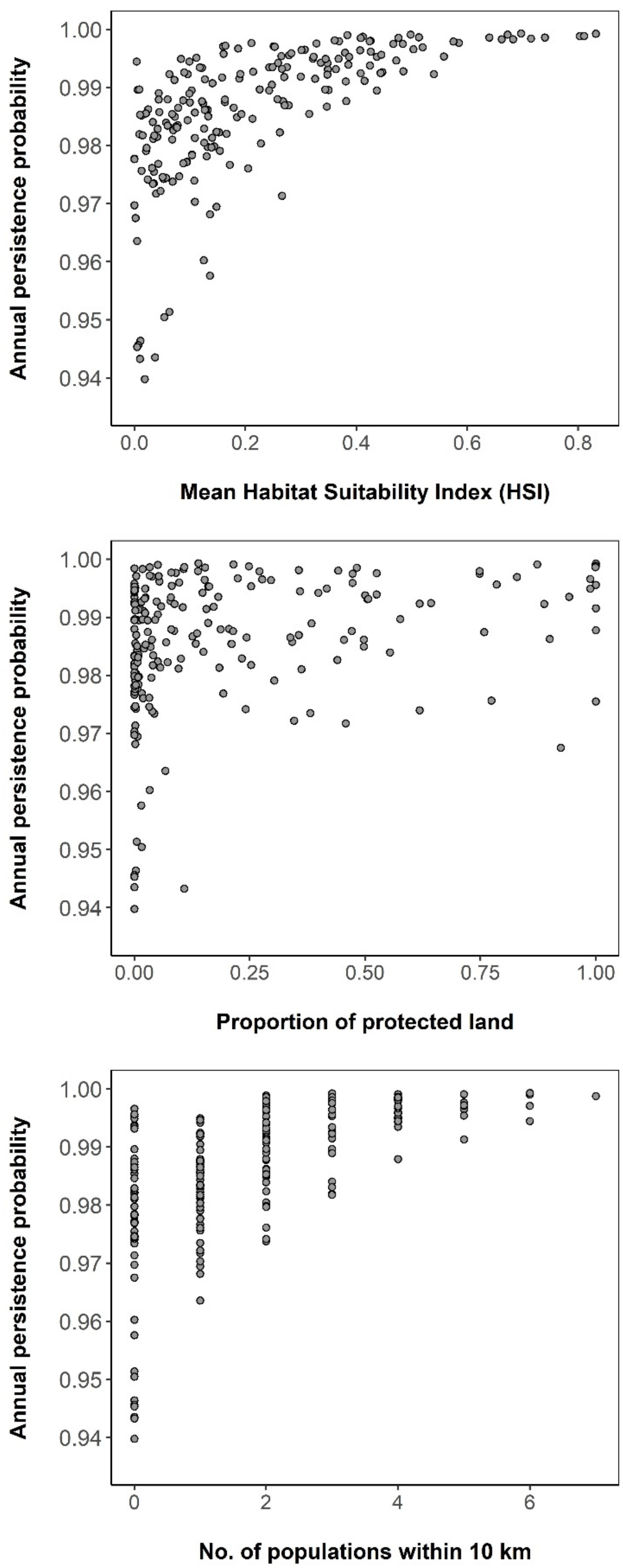

Figure B-7. Relationships between predicted probability of annual persistence and three metrics of site-level conditions for southern hognose populations (N = 204).

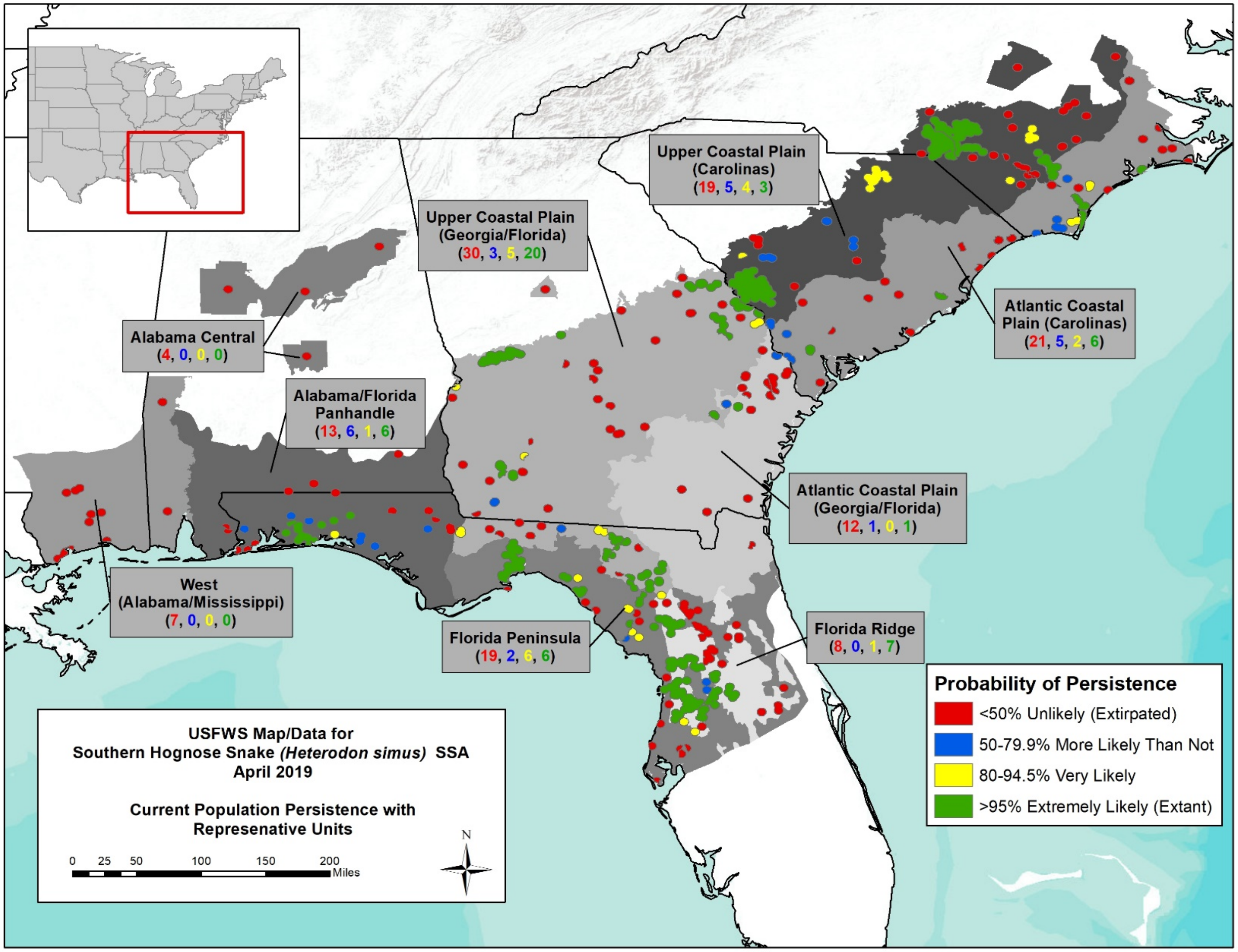

Figure B-8. Southern hognose snake populations across representative units based on probability of persistence. Green populations are extremely likely to currently occur on the landscape, or be extant, yellow populations are very likely, blue more likely than not, and red populations are unlikely to current exist, or are considered extirpated.

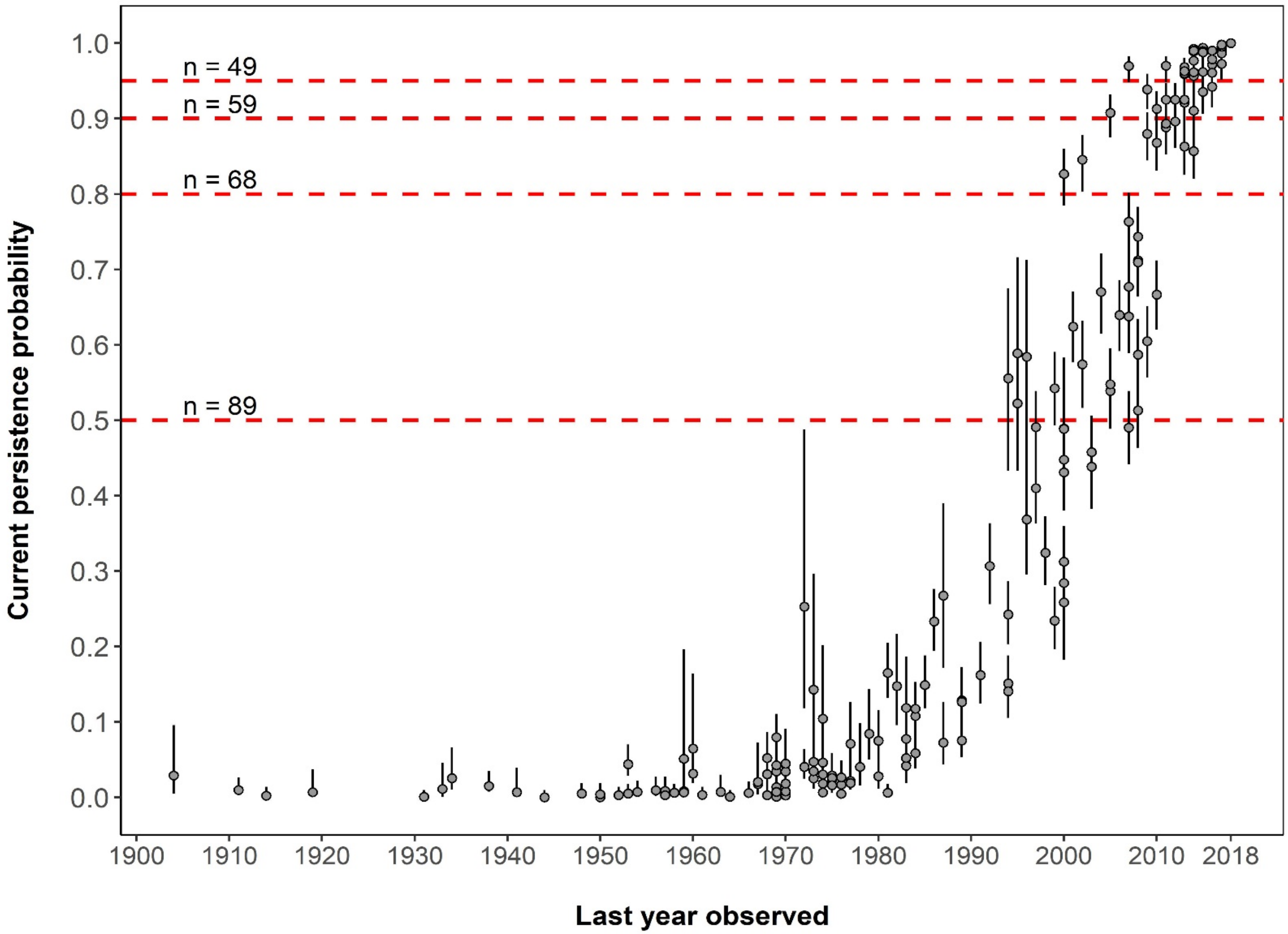

Figure B-9. Probability of persistence in the current year (2018) for southern hognose populations (N = 204) related to the last year an individual was observed in a population. Horizontal red dashed lines indicate persistence thresholds of 50, 80, 90, and 95%, and n values indicate the number of populations with mean current persistence probabilities above each threshold. Each point represents a population with the exception that the point with 100% persistence probability in 2018 represents 18 populations where snakes were observed that year.

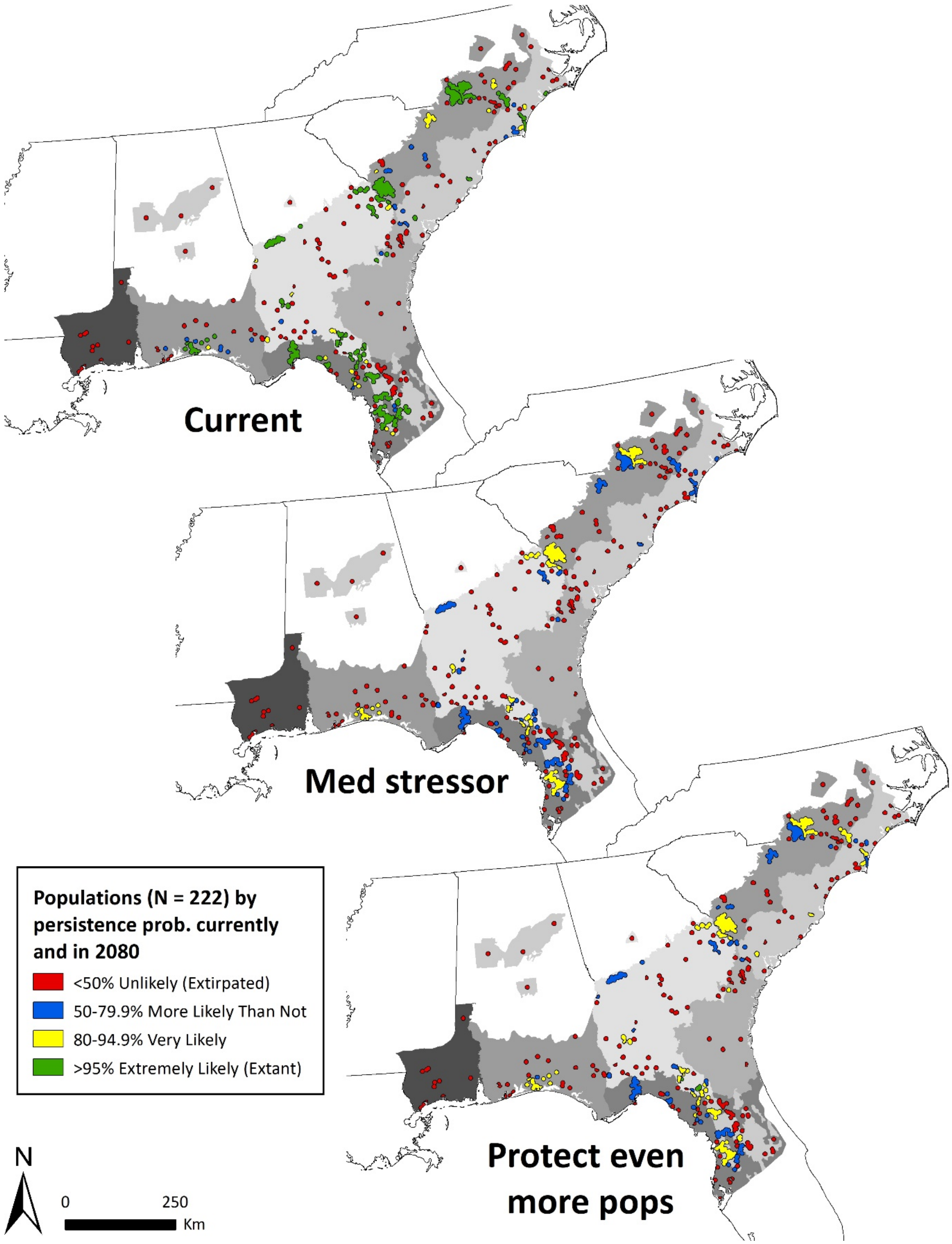

Figure B-10. Spatial distribution of southern hognose snake populations by category of persistence probability across the species' range under current conditions, the Medium Stressor scenario, and the Protect even more populations scenario.

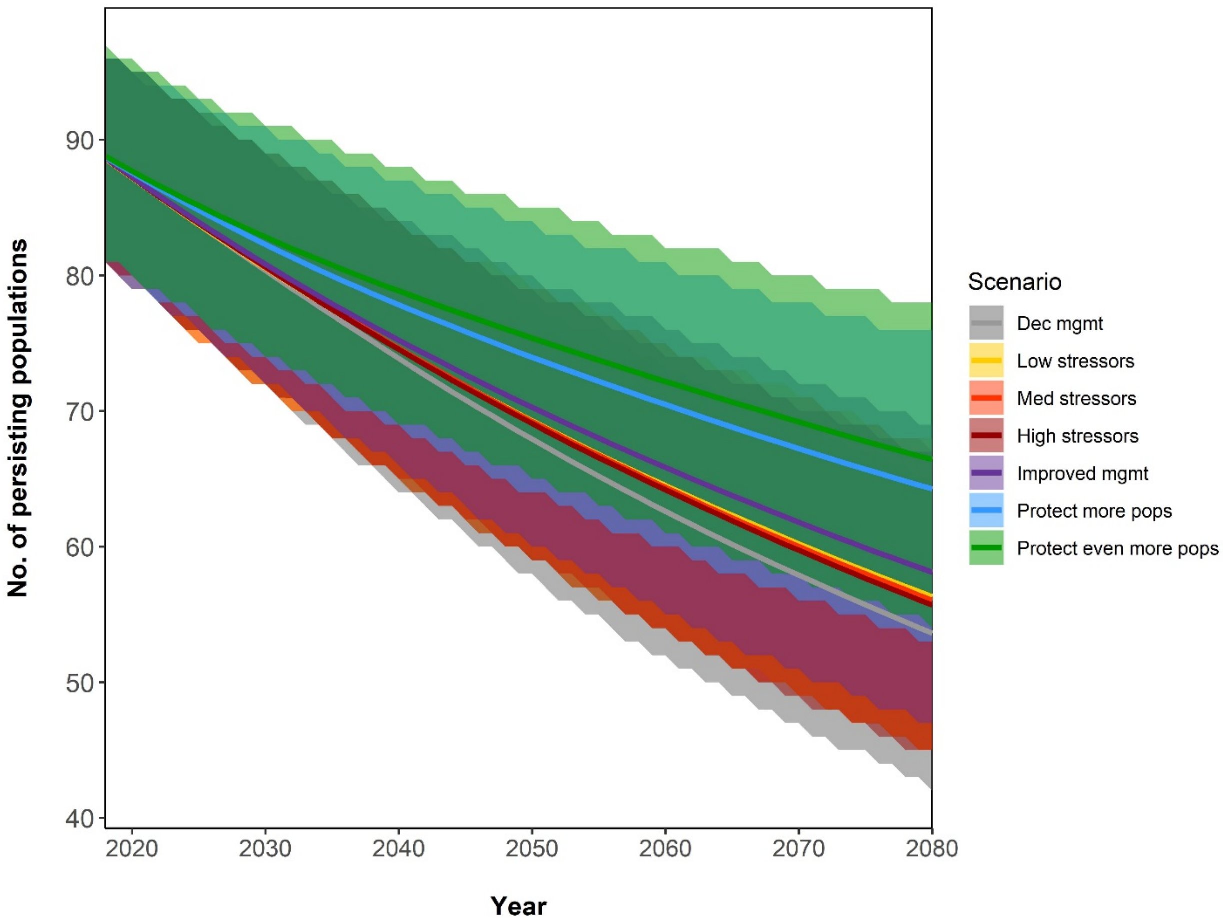

Figure B-11. Predicted mean (± 95% confidence intervals) number of persisting southern hognose snake populations between the present year (2018) and 2080, given seven scenarios of threats and management actions.

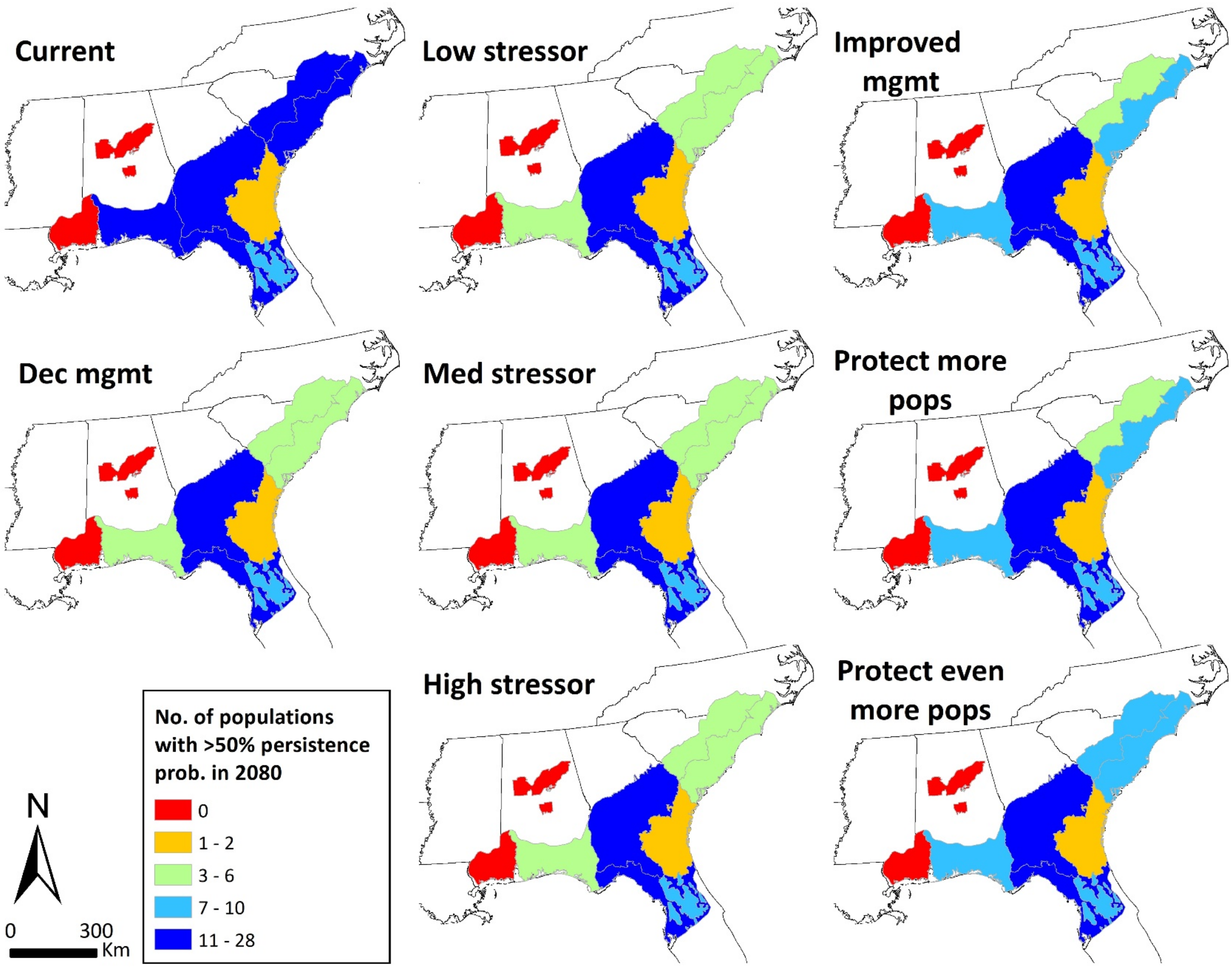

Figure B-12. Redundancy, measured by the number of populations above the 50% persistence probability threshold, within representative units for the southern hognose snake currently and in the year 2080 under threat and management scenarios.

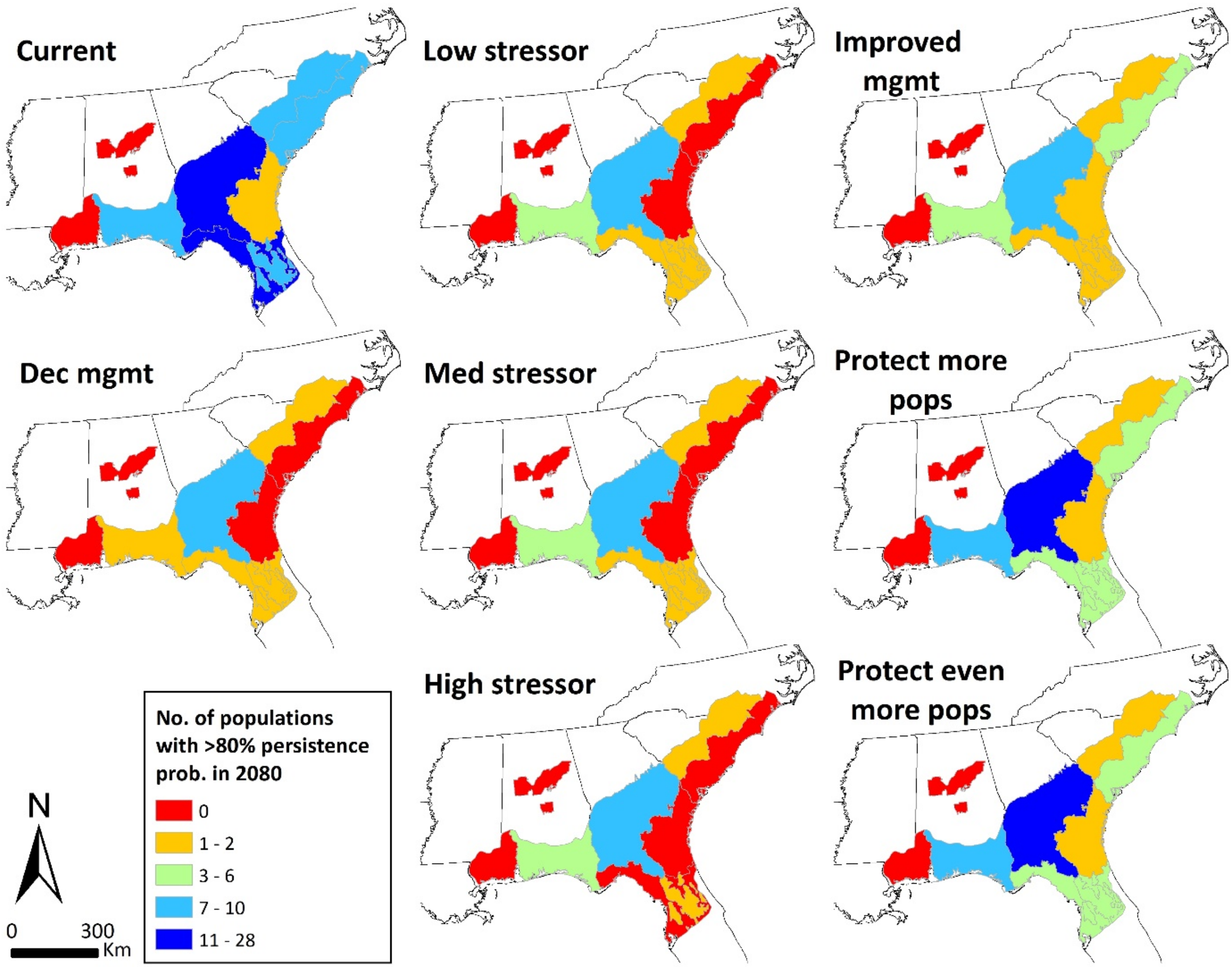

Figure B-13. Redundancy, measured by the number of populations above the 80% persistence probability threshold, within representative units for the southern hognose snake currently and in the year 2080 under threat and management scenarios.

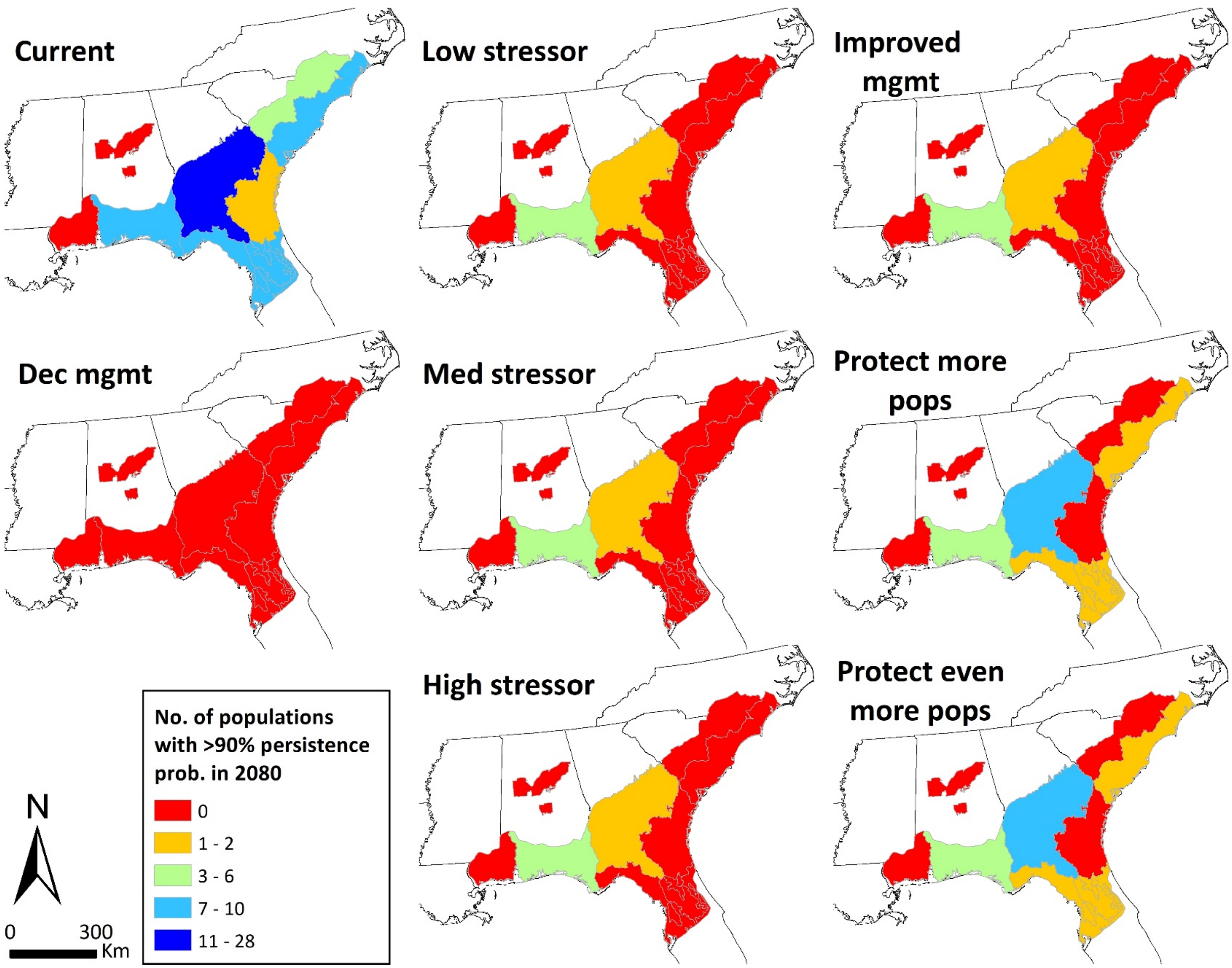

Figure B-14. Redundancy, measured by the number of populations above the 90% persistence probability threshold, within representative units for the southern hognose snake currently and in the year 2080 under threat and management scenarios.