Species Status Assessment (SSA) Report

for the

Eastern Indigo Snake

(*Drymarchon couperi*)

Version 1.1

July 8, 2019

Photo Credit: Dirk J. Stevenson

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

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Summary of Version Update

The changes from version 1.0 (November 2018) to 1.1 (July 2019) are minor and do not change the SSA analysis for the eastern indigo snake. The changes were:

1) Various editorial corrections were made throughout the document.
2) Added clarifying information in Sections 2.4 and 5.1 regarding eastern indigo snake records.
3) Revised Sections 2.2 and 4.4 to include additional relevant references and restructured to clarify content. References updated throughout report including References section.
4) Revised Section 6.1 and Appendix E to clarify content.

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EXECUTIVE SUMMARY

This Species Status Assessment (SSA) reports the results of a comprehensive review for the eastern indigo snake (*Drymarchon corais couperi*, hereafter recognized by its currently accepted name, *Drymarchon couperi*). The species was listed as threatened on March 3, 1978 (USFWS 1978) under the Endangered Species Act (ESA) due to threats from habitat modification, collections for the pet trade and gassing while in gopher tortoise (*Gopherus polyphemus)* burrows (USFWS 1978). This SSA provides a thorough assessment of the species' biology, its biological status and influencing factors, and assesses the species' resource needs in the context of determining the species' viability and risk of extinction. Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, representation and redundancy (together the 3Rs). This process used the best available information to characterize viability as the ability of the eastern indigo snake to sustain populations in its natural systems over time.

The eastern indigo snake is a large, non-venomous snake with populations occurring in portions of Florida and southeastern Georgia. Historically, the eastern indigo snake occurred throughout Florida and in the coastal plain of Georgia, Alabama and Mississippi. Although the eastern indigo snake is difficult to consistently locate in the field, important life history characteristics and species needs have been learned from numerous studies. The eastern indigo snake is a diurnal species. The species prefers upland habitat types (e.g. longleaf pine sandhills, scrub, pine flatwoods, tropical hardwood hammocks, and coastal dunes), but also uses a variety of lowland and human-altered habitats. They may move seasonally between upland and lowland habitats, especially in northern portions of their range. Throughout their range, eastern indigo snakes use below-ground shelter sites for refuge, breeding, feeding and nesting. They depend on gopher tortoise burrows in xeric sandhill habitats throughout the northern portion of the species' range for overwintering shelter sites. Adult eastern indigo snakes move long distances and have very large home ranges; from several hundred to several thousand acres (tens to over a thousand hectares). On average home range sizes are larger for males, and also vary by season and latitude. Home ranges in the northern portion of the range are larger than in the southern portion. Eastern indigo snakes may live for 8 to 12 years in the wild, become sexually mature around 3.5 years of age and breed October through January. They consume a wide variety of animals, including other snakes.

The primary negative factors influencing the viability of the species are from habitat fragmentation and loss due to land use changes, especially urbanization. Urbanization includes a variety of impacts which remove or alter available habitat or impact snakes directly including: residential and commercial development, road construction and expansion, direct mortality (e.g. road mortality, human persecution), invasive species, predation and inadequate fire management. Habitat loss for coastal populations due to sea level rise is also an increasing risk.

The cooperation of many partners to implement conservation efforts can help mitigate the negative factors and positively influence long-term viability of the species. To accelerate recovery, repatriation of eastern indigo snake populations in areas of extirpation is underway. Since listing under the ESA, wild collection of eastern indigo snakes for the pet trade is no longer believed to be a significant threat. Land conservation has increased in some areas, especially where there are on-going efforts to conserve gopher tortoise populations. These conservation efforts have diminished the threat of gassing gopher tortoise burrows, and will have lasting conservation benefits for the eastern indigo snake across much of its range.

Biological populations of eastern indigo snakes are unknown; thus, for this assessment we defined populations using species' movement and home range data from the literature (i.e. buffered occurrence data by 5 miles (8 kilometers)). To maintain species viability, resilient eastern indigo snake populations need large habitat patches (>10,000 acres (> 4,046 hectares)) of good quality habitat (diverse, unfragmented, few roads), with adequate shelter sites (e.g. gopher tortoise burrows), and connectivity among one or more populations for genetic exchange. The species needs genetic and ecological diversity (representation) to maintain adaptive potential and, multiple populations (redundancy) across representative units to withstand catastrophic events. To assess current condition we measured population and habitat factors and assigned resiliency classes to populations based on the best available information on the species' biology. We then considered the representation and redundancy of populations across the species' range. To assess future conditions, we used models to forecast habitat fragmentation and loss due to urbanization and sea level rise at two future times, at years 2050 and 2070. We also considered the potential of targeted conservation action (i.e. habitat conservation and population repatriation) to improve species viability.

The current distribution for the eastern indigo snake has contracted from its historical distribution. Some of the range contraction has occurred since listing under the ESA, particularly in the Florida Panhandle (currently no resilient populations) due to the decline of gopher tortoise populations (Enge *et al.* 2013); however conservation efforts are underway to repatriate gopher tortoise and eastern indigo snake populations in this region. The overall current population resiliency is medium to low and is predicted to be low to very low in the future without targeted conservation efforts. The eastern indigo snake faces a variety of negative influencing factors from habitat fragmentation and loss, and direct mortality that are predicted to be exacerbated by urbanization and sea level rise. At least seven island populations are predicted to be extirpated due to sea level rise and many decline in resiliency as a result of urbanization. Future ecological and genetic representation decreases due to loss of resilient populations in the North Florida region, lowering the species' potential to adapt to changing environmental conditions. Low (in Southeast Georgia and Peninsular Florida) to no (in Panhandle and North Florida) redundancy in representative areas increases the species' risk to catastrophic events. One population is predicted to remain highly resilient without targeted conservation efforts aimed to protect and repatriate populations. On-going conservation efforts (e.g. gopher tortoise conservation, habitat conservation and repatriation) are positively influencing the eastern indigo snake and are key to mitigating negative factors and ensuring long-term viability of the species. The following table provides a summary of the current and future conditions of the eastern indigo snake organized by the 3Rs.

The 3Rs Population and Species Needs	**Current Condition**	**Future Condition (Viability):** Projections based on future urbanization and sea level rise scenarios at years 2050 and 2070:
Resiliency (population level): • Large populations able to withstand stochastic events **Needs** • High habitat quantity • Habitat diversity • Low habitat fragmentation • Adequate shelter • Population connectivity	• 53 (of 83) extant populations • Population resiliency: 4 High 13 Medium 28 Low 8 Very Low 30 Extirpated	• 46 (of 83) extant populations. Seven lost to sea level rise, and 44 to 47 very low or extirpated. • Low urbanization rates: One highly resilient population and 6 to 10 medium resilient populations at 2050 and 2070, respectively. • Moderate urbanization rates: One highly resilient population and 5 to 6 medium resilient populations at 2050 and 2070, respectively. • High urbanization rates: One highly resilient population and 4 to 5 medium resilient populations at 2050 and 2070, respectively. • Targeted Conservation: Moderate urbanization rates are mitigated via habitat conservation & repatriation. By 2070, 6 highly resilient populations, 16 medium resilient and 2-4 populations repatriated.
Representation (species level): • Genetic and ecological diversity to maintain species adaptive potential **Needs** • Genetic variation exists between populations • Ecological variation exists across geographic gradient	Compared to historical distribution: • 3 of 4 regions represented, but considerable declines in occupancy across the regions (Panhandle* 97% loss, North Florida 56% loss, Southeast Georgia 32% loss and Peninsular Florida 42% loss) • Genetic and ecological variation retained but with losses in key areas needed for connectivity	• 3 of 4 regions continue to be represented but with declines across all scenarios. • All scenarios exhibit declines in representation due to population declines across genetic and ecological gradients. • Low, Moderate and High Urbanization scenarios: No highly resilient and 2-7 medium resilient populations remain in Peninsular Florida; no high or medium resilient populations remain in the North Florida (by 2070) or occur in the Panhandle and one highly resilient and 2 medium resilient populations in Southeast Georgia. • Island populations are mostly lost across all scenarios due to seal level rise. • Targeted Conservation: Number of highly resilient populations increase in Southeast Georgia (3), and are maintained in Peninsular Florida (3). North Florida populations are maintained at medium levels and 2-4 Panhandle populations are repatriated.

The 3Rs Population and Species Needs	**Current Condition**	**Future Condition (Viability):** Projections based on future urbanization and sea level rise scenarios at years 2050 and 2070:
Redundancy (species level): • Number and distribution of populations to withstand catastrophic events **Needs** • Multiple resilient populations in each area of representation	• 30 of 83 historical populations extirpated • Overall 48% decline in population extent • 4 highly resilient populations: Panhandle*: 0 North Florida: 0 Southeast Georgia: 1 Peninsular Florida: 3	• Low, Moderate and High Urbanization: Low (Southeast Georgia 2, Peninsular Florida 2-7) to no redundancy (North Florida, Panhandle) of medium resilient populations. No redundancy of highly resilient populations, only one remains in Southeast Georgia. • Targeted Conservation: 6 highly resilient populations, 16 medium resilient populations retained in key areas and some populations restored (but at medium to low levels) Panhandle: 0 High, 2-4 repatriated North Florida: 0 High, 2 Medium Southeast Georgia: 3 High, 6 Medium Peninsular Florida: 3 High, 6 Medium

* Panhandle Region includes portions of Alabama, Florida, Mississippi and Georgia. See report for detail.

CHAPTER 1 – INTRODUCTION

The eastern indigo snake (*Drymarchon corais couperi*, hereafter recognized by its currently accepted name *Drymarchon couperi* [Collins 1991, p.43, Wüster *et al*. 2001, p.163, Crother 2012, p.59]) is a large, iridescent-black, non-venomous snake in the Colubridae Family with natural populations occurring in portions of Florida and southeastern Georgia. Historically, the eastern indigo snake occurred throughout Florida and in the coastal plain of Georgia, Alabama and Mississippi. The species was listed as threatened on March 3, 1978 under the Endangered Species Act (ESA) due to threats from habitat modification, collections for the pet trade and gassing while in gopher tortoise (*Gopherus polyphemus*) burrows (USFWS 1978). A Recovery Plan was published in 1982 (USFWS 1982). Since listing under the ESA, wild collection of eastern indigo snakes for the pet trade and gassing of gopher tortoise burrows are no longer believed to be significant threats; however, habitat modification remains a significant influencing factor. The current distribution for the eastern indigo snake has contracted from its historical distribution. Some of the range contraction has occurred since listing under the ESA, particularly in the Florida Panhandle due to the decline of gopher tortoise populations (Enge *et al.* 2013); however conservation efforts are underway to repatriate gopher tortoise and eastern indigo snake populations in this region.

Since listing under the ESA, a lot has been learned about the biology and ecology of the eastern indigo snake, and the U.S. Fish and Wildlife Service (Service) has worked closely with partners to make progress towards recovery of the species. The Species Status Assessment (SSA) framework (Smith *et al*. 2018, entire) summarizes the information compiled and reviewed by the Service, incorporating the best available scientific and commercial data, to conduct an in-depth review of the species' biology, evaluate its biological status and influencing factors, and assesses the resources and conditions needed to maintain long-term viability. The intent is for the SSA to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from Listing to Consultations to Recovery. This first version of the eastern indigo snake SSA will be used to inform the upcoming Five Year Review (in 2019) of the species and then to revise the species' Recovery Plan (to include measurable recovery criteria), and the Recovery Implementation Strategy. This SSA provides a review of the available information strictly related to the biological status of the eastern indigo snake and its viability

Using the SSA framework (Figure 1), we consider what the eastern indigo snake needs to maintain viability by characterizing the status of the species in terms of its resiliency, representation and redundancy (together the 3R's) (Smith *et al*. 2018, entire). For the purpose of this assessment we generally define viability as, the ability of the species to sustain populations in its natural systems over time.

The definitions of the 3Rs are:

- **Resiliency** describes the ability of a population to withstand stochastic disturbance. Resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations.
- **Representation** describes the ability of a species to adapt to changing environmental conditions over time as characterized by the breadth of genetic and environmental diversity within and among populations.
- **Redundancy** describes the ability of a species to withstand catastrophic events by spreading risk among multiple populations across a large area.

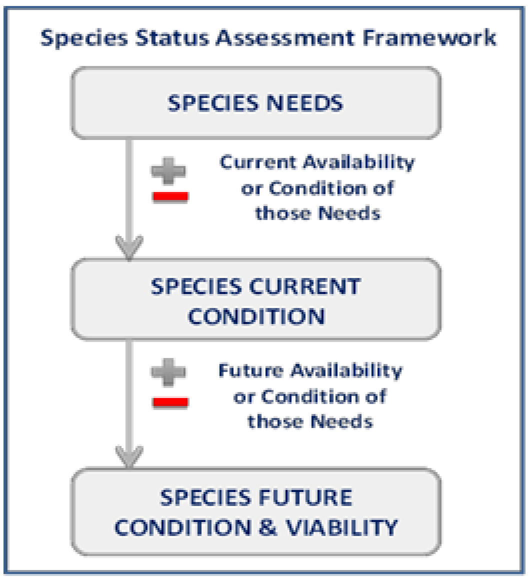


Figure 1: Species Status Assessment Framework

To evaluate the biological status of the eastern indigo snake, both currently and into the future, we assessed a range of conditions that allowed us to consider the species' resiliency, representation and redundancy. This SSA provides a thorough assessment of 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 species.

The format for this SSA includes: species biology, species needs, influences on viability, current conditions and future conditions. This document is a compilation of the best available scientific and commercial information, and a description of past, present, and likely future risk factors to the eastern indigo snake.

CHAPTER 2 – SPECIES INFORMATION AND INDIVIDUAL NEEDS

2.1 Species Description

The eastern indigo snake was originally described by J.E. Holbrook in 1842 from a specimen collected near the Altamaha River, Wayne County, Georgia (McCranie 1980). Eastern indigo snakes are moderately heavy-bodied and almost entirely iridescent bluish-black in color, belly included; the pigment of the chin and sides of the head may be reddish, orange-brown or cream (Conant and Collins 1998, Stevenson *et al.* 2008, p.339). The extent and intensity of the pigment is highly variable (Figure 2), lacking on many specimens, and typically most extensive on juveniles and adult males (Layne and Steiner 1996, p.11). The intensity and extent of red-orange pigment may be pronounced on adult male specimens from southern Florida.

Figure 2: Variability of the coloration on the chin and side of head. Photos by Dirk Stevenson.

Scales are fairly large and smooth, except for sexually mature males which develop faint keels on the dorsal scale rows along the middle of the back (Figure 3) (Layne and Steiner 1984).

Figure 3: Faint keels on dorsal scales of mature male eastern indigo snake. Photo by Dirk Stevenson.

Mature adult eastern indigo snakes weigh from 2 pounds to over 10 pounds (1 to 4 kilograms). The eastern indigo snake is the longest species of snake native to the United States and reaches up to 8.6 feet (ft) (2.63 meters (m)) in total length (Conant and Collins 1998, Stevenson *et al.* 2008, p.339). They exhibit sexual dimorphism in size, with adult males reaching significantly greater sizes and commonly attaining a total length of 6.5 to 7.0 ft (1.98 to 2.13 m) (Layne and Steiner 1996, Stevenson *et al.* 2009). Generally, adult females only reach a total length of 4.0 to 6.0 ft (1.22 to 1.83 m) (Layne and Steiner 1996, Stevenson *et al*. 2009, Knafo *et al*. 2016).

2.2 Taxonomy and Genetics

At the time of listing under the Endangered Species Act in 1978, the eastern indigo snake was considered a subspecies of indigo snake, *Drymarchon corais couperi* (USFWS 1978). Post-listing, Collins (1991, p.43) elevated this lineage to species status based on geographic isolation and morphology. Subsequent work supported this designation and the eastern indigo snake was accepted by the scientific community as its own species, *Drymarchon couperi* (Wüster *et al*. 2001, p.163, Crother 2012, p.59). The Service adopted this change in nomenclature in 2008 (USFWS 2008, p.23). In addition to the eastern indigo snake, other common names include blue indigo snake and blue gopher snake.

Ongoing genetic studies further evaluating taxonomic classification have only recently been conducted. Shamblin *et al*. (2010, entire) used 22 nuclear microsatellite markers to successfully differentiate individual snakes from Fort Stewart, Georgia, and suggested the technique used in their genetic analysis could also prove valuable in conducting population level studies. Krysko *et al*. (2016b, entire) evaluated the genetic diversity of 20 eastern indigo snakes across Florida and southern Georgia using mitochondrial DNA (mtDNA) derived from tissue samples. Krysko *et al*. (2016b, entire) described a divergence of the species into two genetic lineages, an Atlantic lineage occupying southeastern Georgia and northeast Florida and a Gulf lineage occupying southern Florida, the central Lake Wales Ridge of Florida, the Gulf Coast drainage of Florida, and the panhandle region of western Florida (Figure 4). The authors hypothesized that these two lineages represent two different species of indigo snakes (Krysko *et al*. 2016a, b, entire), and described differences in scalation which they assert provide a method to morphologically distinguish between the two species. These two lineages illustrate a similar biogeographic pattern previously identified for other plants and animals that have come in and out of contact with each other many times during historic sea level changes. Nevertheless, in certain areas of Florida, this potential classification would place the two eastern indigo snake lineages in close enough proximity that no barrier to gene flow would exist between them (Figure 4). This region was described by Krysko *et al.* (2016b, p. 566) as a hybrid zone between the two lineages.

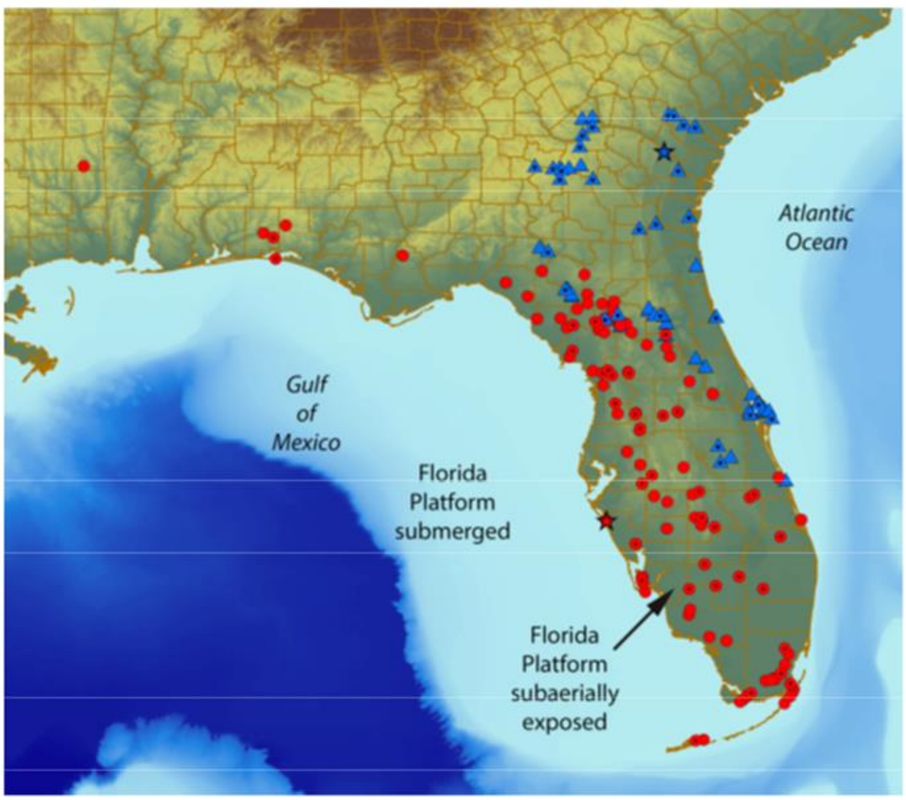


Figure 4. Distribution of Indigo Snake (*Drymarchon*) samples on the subaerially exposed Florida Platform in Florida and Georgia. Atlantic Lineage (blue triangles; with dots = genetic samples, without dots = this study using morphology based on cluster analysis); Gulf Lineage (red circles; with dots = genetic samples, without dots = this study using morphology based on cluster analysis); and stars represent holotype specimens for *D. couperi* (blue) and *D. kolpobasileus* (red). Genetic data from Krysko *et al.* (2016a). Figure borrowed from Krysko *et al.* (2016a, p. 561).

More recent data bring into question the validity of splitting the eastern indigo snake into two species. Genetic diversity was further evaluated by Folt *et al.* (2019) using microsatellite (nuclear) DNA (nDNA) from 428 tissue samples of eastern indigo snakes from across the species range, including the 20 samples used by Krysko *et al.* (2016a). These genetic analyses supported multiple populations within eastern indigo snakes; however the geographic pattern suggested a north-south orientation rather than a Gulf-Atlantic orientation and the contemporary gene flow was widespread across this geographic pattern (Figure 5) (Folt *et al.* 2019). Genetic distance was strongly correlated with geographic distance across the range when samples were separated into both north-south clusters and Gulf-Atlantic clusters. Folt *et al.* (2019) concluded that genetic structure among populations is best described as continuous isolation by distance along a north-south geographic axis within a single species.

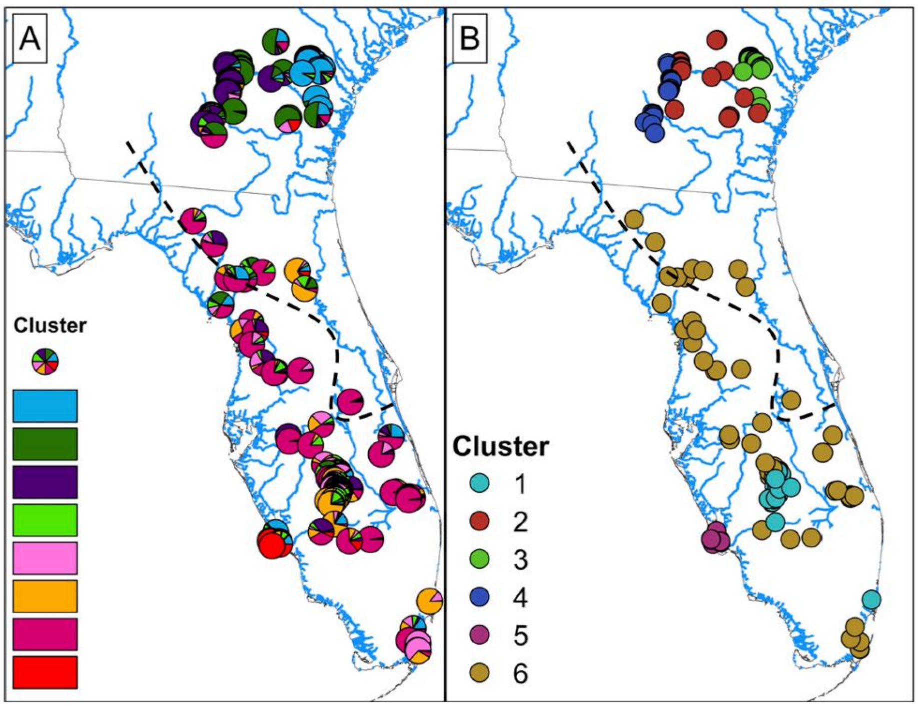


Figure 5. Maps of *Drymarchon couperi* (*sensu* lato) sampling sites represented as (A) pie charts of percent ancestry within population clusters identified by Structure analysis $K = 8$ populations, and (B) cluster membership from the Geneland analysis with $K = 6$ populations. For both panels, percent ancestry and/or cluster membership was assigned given the number of populations K that received the highest support during the analysis. The black dashed lines indicates the boundary between the Atlantic and Gulf lineages from Krysko *et al.* (2016b). Figure borrowed from Folt *et al*. (2019).

In addition, Folt *et al*. (2019) suggest that this high level of contemporary gene flow between eastern indigo snakes and the inconsistent patterns between mtDNA and nDNA may be driven by high dispersal of male snakes relative to females. Since female eastern indigo snakes move over much smaller distances than males, it would follow logically that results from a study of mtDNA (Krysko *et al.* 2016b, entire), which passes maternally, would show population sub-structuring among females that may not be reflected in contemporary patterns of nDNA. The differences in movement and home ranges between male and female eastern indigo snakes are well documented (see Section 2.3.1), with males on average having larger home ranges, moving more frequently and over longer distances. This type of life history limits the utility of mtDNA alone to reveal novel species (Folt *et al.* 2019).

Because of the differences in inheritance and mutation rates, mtDNA is often used to determine species phylogeny and systematics, while patterns in nDNA illustrates more contemporary gene flow and population subdivision (Sunnucks 2000, p. 200). Folt *et al*. (2019) suggest that even if a historical climatic event may have separated *D. couperi* into two populations described by Krysko *et al.* (2016a,b, entire) using mtDNA, that the observed levels of contemporary gene flow (nDNA) erase any historical differentiation. Furthermore, there has not been adequate analysis to determine if the pattern of scale differences described by Krysko *et al*. (2016a, entire) occurs consistently throughout the eastern indigo snake range to support separate diagnosable species based on morphology.

A similar pattern of a species separated and re-joined during cycles of glaciation has occurred in the North American pitvipers of the *Agkistrodon* genus (cottonmouths) (Burbrink and Guiher 2015, Strickland *et al.* 2014). Burbrink and Guiher (2015) provided statistical support for the separation of Florida cottonmouths from continental cottonmouths into two separate species. Strickland *et al.* (2014) provided statistical support that cottonmouths are a single species with gene flow across the Gulf Coastal Plain. These reported taxonomic differences may be the result of markers that reflect different time scales, contemporary versus historic (Strickland *et al.* 2014). It is possible that the data from eastern indigo snake lineages may be explained by the same pattern; mtDNA reflect historical patterns in female eastern indigo snake genetics and nDNA provides a contemporary perspective of genetic diversity and gene flow in the species.

Until further research provides additional clarity or the scientific community has examined and accepted the eastern indigo snake taxonomic change suggested by Krysko *et al.* (2016a b, entire), the Service maintains the eastern indigo snake, *Drymarchon couperi* (Collins 1991), as one species.

2.3 Historical Range and Distribution

Historically, the eastern indigo snake occurred throughout Florida and in the coastal plain of Georgia, Alabama and Mississippi (Figure 6) (Löding 1922, Haltom 1931, Carr 1940, Cook 1954, Diemer and Speake 1983, Lohoefener and Altig 1983, Moler 1985a, Enge *et al*. 2013, entire). Although there are unsubstantiated reports of eastern indigo snakes from South Carolina, the species was removed from South Carolina's state list of native reptiles and amphibians in 2009 because of a lack of evidence that it ever occurred there as a part of the native fauna. In addition, the lack of any historic or recent records within the Savannah River Drainage in

Georgia, adjacent to South Carolina, supports this contention (Enge *et al*. 2013, p.295).

2.4 Current Range and Distribution

The current distribution of the eastern indigo snake has a reduced geographic area compared to its historic range (Figure 6). Enge *et al.* (2013, entire) described current extant populations (records post year 2000) to occur in much of its historical range in Georgia and Florida but records are lacking or scarce in portions of that range. Eastern indigo snakes are extirpated or are very rare in the Florida Panhandle and Southwest Georgia. Naturally occurring populations are probably no longer extant in Alabama and Mississippi based on lack of recent records (Enge *et al*. 2013, p. 296). As part of the current recovery strategy, repatriation of eastern indigo snakes back into former parts of its range is ongoing in Alabama and the Florida Panhandle (see section 4.8 below). In summary, the majority of recent records for the eastern indigo snake are from southeastern Georgia and peninsular Florida. The eastern indigo snake may persist in the panhandle of Florida, but only in low numbers.

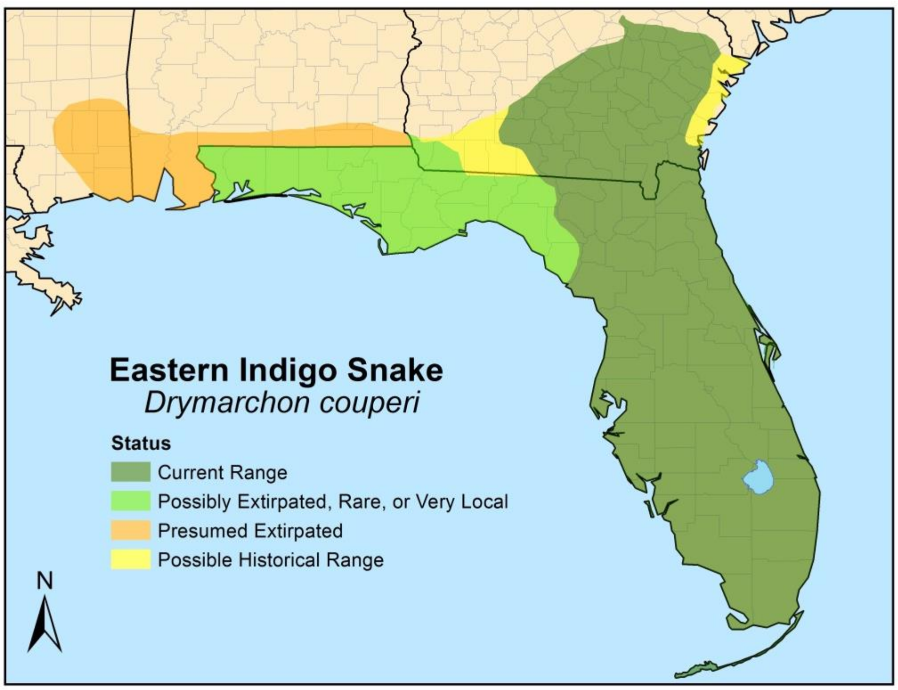


Figure 6. Historical and current range of the eastern indigo snake. Map by Javan Bauder.

We divided the distribution of the eastern indigo snake into the following four regions: the Panhandle, North Florida, Peninsular Florida and Southeast Georgia (Figure 7). These regions were delineated along state and county boundaries that represent the geographic (east-west and north-south) distribution of the species. This geographic distribution represents the both the ecological and genetic diversity of the species. Eastern indigo snake behavior, such as home range size, movement and dependence on gopher tortoise burrows for cool-season shelter has been documented to vary across a north to south gradient likely due to climatic differences (Hyslop *et al.* 2009a, entire, Bauder *et al.* 2018, entire). The Panhandle, North Florida and

Southeast Georgia regions all represent the "northern populations" and Peninsular Florida represents the "southern populations." The north-south gradient also represents a genetic gradient described by Folt *et al.* (2019). Southeast Georgia and North Florida regions generally align with the Atlantic-Gulf (east-west) genetic gradient described by Krysko *et al.* (2016a,b). The Panhandle region represents the western portion of the species range and is disjunct from the eastern regions because of the paucity of recent eastern indigo records due to habitat degradation and losses of gopher tortoise populations from harvest for human food (Enge *et al*. 2013, p. 289). The North Florida region geographically connects the east-west and north-south regions. This regional breakdown provides a framework to assess the species' ecological and genetic diversity (representation).

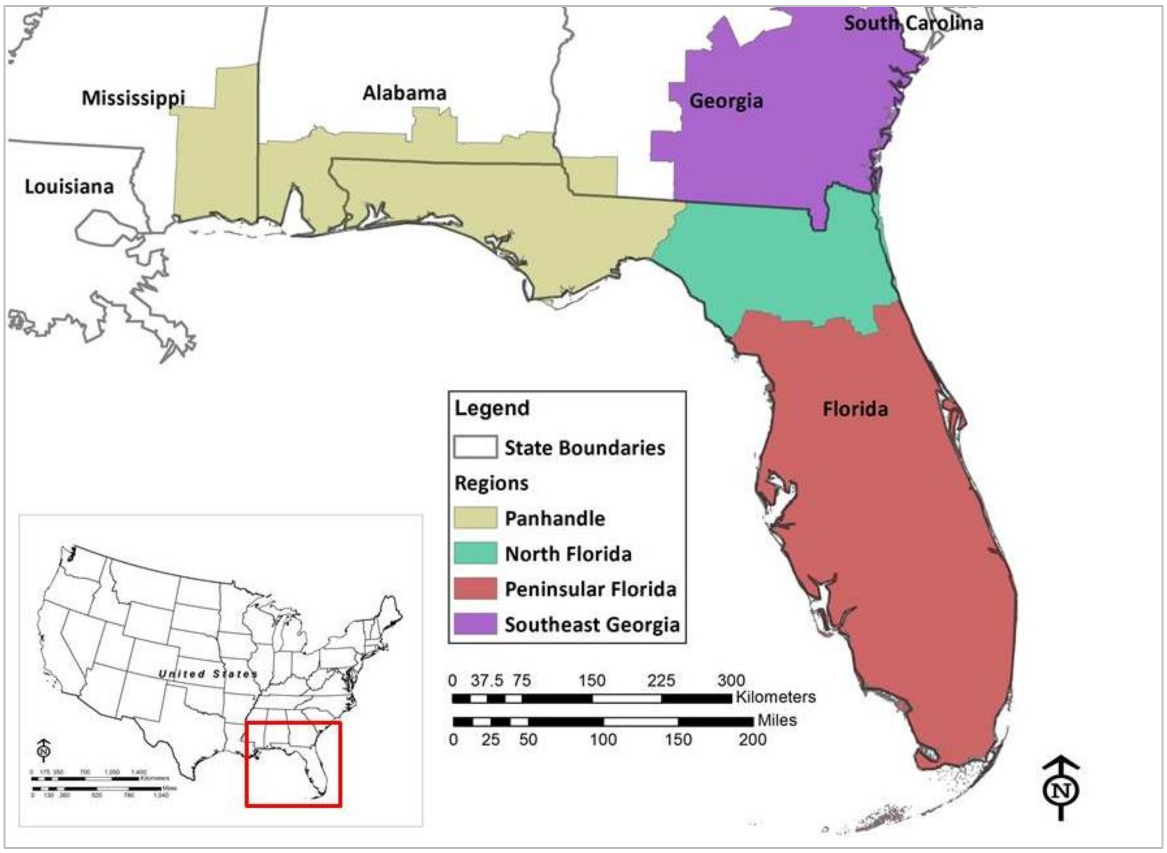


Figure 7: Delineation of four regions, the Panhandle, North Florida, Peninsular Florida and Southeast Georgia, within the range of the eastern indigo snake.

For each region we mapped the number of eastern indigo snake records to depict the known distribution of the species. Records are element occurrence data collected over time (a few very early 1800's records, but most records occurred between the years 1936-2017). These records are documented as geographic coordinates (latitude, longitude) that can be displayed in a Geographic Information System (GIS) and represent unique observations of eastern indigo snakes at specific locations on specific dates in time. Range-wide species occurrence data used in this report are from Enge *et al*. (2013, entire), which includes records up to the year 2012. Post 2012 to 2017 records were obtained directly from State Natural Heritage Programs, State Herpetologists and conservation organizations in Florida and Georgia. It is important to note that survey and monitoring efforts are not evenly distributed across the range. The number of records varies across the range with some areas having many records from research and monitoring efforts to other areas having no or few records which could represent lower numbers of snakes or that the area is under-surveyed. In addition, records may represent the same individual snake documented at multiple points in time. Numerous records are from observations on roads (dead or alive). The "heat maps" that are provided for each region in the following section show where we know the species to have occurred historically compared to current. Current distribution is represented by records from 2001-2017, similar to the distribution described by Enge *et al.* (2013, entire). A total of 2,272 records were used in this report, of which about half (1,239) are considered current. See section 5.1 below for more detail on how records are used in this report.

2.4.1 Panhandle

The Panhandle represents the western-most distribution of the species and includes extreme south Alabama and southeastern Mississippi, the Florida Panhandle (west of the Aucilla River in Florida) and two southwestern counties in Georgia (Figure 8). This region has experienced significant declines in eastern indigo snake populations and the species is believed to be extirpated in Alabama and Mississippi, and very rare in the Florida Panhandle.

Alabama

Four historical (1954 or earlier) eastern indigo snake records are known from three counties in Alabama (Covington (Neil 1954), Baldwin (Haltom 1931) and Mobile (Löding 1922) counties) (Enge *et al*. 2013, p. 294). Three additional recent records are reported from Mobile County in 2000 and 2001; however these records are Type II records (Enge *et al*. 2013, p.290) and are not supported by photos or specimens (see section 5.1). It is possible, though, that the species was more abundant than former records indicate because herpetologists studying the reptiles of Alabama in the early 1900's did not mention that eastern indigo snakes were rare (Blanchard 1920, Löding 1922). Nevertheless, by the mid-1970's herpetologists were concerned that the species had disappeared from Alabama (Mount 1975).

In an effort to repatriate the species, 537 eastern indigo snakes (adults, juveniles, and hatchlings) were released at about 20 sites across Alabama, Mississippi, Georgia, Florida and South Carolina beginning in 1976 and continuing through 1987 through a project conducted by Auburn University (Speake 1990, entire). A captive breeding colony at Auburn University was used to produce snakes for the repatriation efforts (Speake 1990, entire). A preliminary assessment of survival of released snakes was conducted from 1986 through 1989; captures or sightings of eastern indigo snakes occurred at five of the 16 release sites evaluated (Speak 1990, entire). No recent records of eastern indigo snakes are known from these areas and the repatriation effort is considered unsuccessful (Hart 2002, Irwin *et al.* 2003, Smith *et al.* 2006, Stevenson *et al.* 2008). In 2002, a study was completed in Alabama to determine if evidence of the species could be verified (Hart 2002). In 2000, sites of experimental repatriation from the 1980s (Hart 2002) were visited and landowner contacts were made. In addition, recent anecdotal sightings and reports were researched and attempts made to determine their accuracy; none could be verified as eastern indigo snake records. No eastern indigo snakes were observed by Hart (2002) during the study, and he concluded that if eastern indigo snakes still occur in Alabama, they occur at such low densities that detection is improbable.

In 2010 an eastern indigo snake repatriation project was launched at a site located on the Conecuh National Forest (CNF), Covington County, Alabama (Godwin *et al*. 2011). Thirty-eight eggs of wild-caught gravid females from southeastern Georgia were hatched and reared in captivity through approximately two years of age (until they reached a size of 3 to 4 ft (0.97 to 1.22 m)) and released on the CNF. These 38 snakes were intensively monitored via radio telemetry during 2010-2011 and 13 were reported to have died, 12 were not relocated, and 13 were reported alive at the conclusion of the study. Mortality was due to a combination of vehicular strikes, predators and unknown factors (Godwin *et al*. 2011, entire). The first indication that this reintroduction may prove to be a success is evidence of successful breeding at the site; two females tracked via radio telemetry were captured in 2012, laid eggs that produced nine offspring (Stiles *et al.* 2013, p. 40). Since 2011, 116 additional snakes have been released (154 total) on the CNF most of them reared at the Orianne Center for Indigo Conservation (OCIC), located in central Florida. Post radio telemetry monitoring, at least 10 confirmed observations of eastern indigo snakes near the release sites have been reported between 2012-2018 (Godwin 2018). No unmarked eastern indigo snakes have been captured, which would be an indicator of survival of offspring from repatriated snakes (Stiles *et al.* 2013, p. 40). Over the next five to seven years at CNF, it is anticipated that about 150 more snakes will be released at the CNF to reach a target of about 300 snakes released (Godwin and Steen 2017, entire).

Mississippi

Cook (1954) reported three specimens from Mississippi; one specimen is in the Mississippi Museum of Natural Science collected from Wayne County, Mississippi in 1939. The most recent credible record for the species in this state is from two eastern indigo snake sightings reported from the mid-1950's on DeSoto National Forest, Perry County, Mississippi (C. Finch, Governor of state of Mississippi *in litt*. 1977, Lohoefener and Altig 1983) and a 1955 observation from Forrest County. Due to the lack of confirmed recent records for the eastern indigo snake in Mississippi, it is likely extirpated in the state.

Florida Panhandle

The Florida Panhandle includes counties that are west of the Aucilla River. While the species is known throughout Florida, few or no recent records exist from the panhandle (Gunzburger and Aresco 2007, Enge *et al.* 2013, p. 292). In the 1980's, Moler (1985a) conducted a distributional survey of the eastern indigo snake in Florida by compiling records from 32 institutions and obtaining sightings from interviews with 95 biologists and other individuals familiar with the species. Museum specimens were available from 44 counties and sightings from 63 of Florida's 67 counties. Moler (1985a) concluded that the eastern indigo snake was "distributed widely, though not necessarily commonly throughout Florida, including the panhandle." Enge *et al*. (2013) documented 578 recent (2001–2012) eastern indigo snake records from 47 counties in Florida, however, they concluded that eastern indigo snakes are now rarely observed and have a restricted distribution in the Florida panhandle. The most recent verifiable eastern indigo snake record for the region was at Eglin Air Force Base in 1999; a credible (but not verified by photo or specimen) eastern indigo snake sighting was reported from close to the Base boundary in 2011 (Enge *et al*. 2013). The decline of eastern indigo snakes in this region may have resulted from a dramatic decline in gopher tortoise populations, going back to the mid 1900's and coinciding with a period of heavy human predation on tortoises. In 2017, a repatriation project was launched at the Nature Conservancy's Apalachicola Bluffs and Ravines Preserve in Liberty County where 32 snakes were released in 2017-2018, with future releases planned. Prior to this, the last confirmed eastern indigo snake on the Preserve was in 1982.

In extreme southwestern Georgia (Decatur and Seminole counties) at least one small population may still occur. This population is close to the Florida state line and may be a northerly extension of the Florida population inhabiting the sandhills along the Apalachicola River (Enge *et al.* 2013, p. 297); therefore, is included as part of the Panhandle region described in this report.

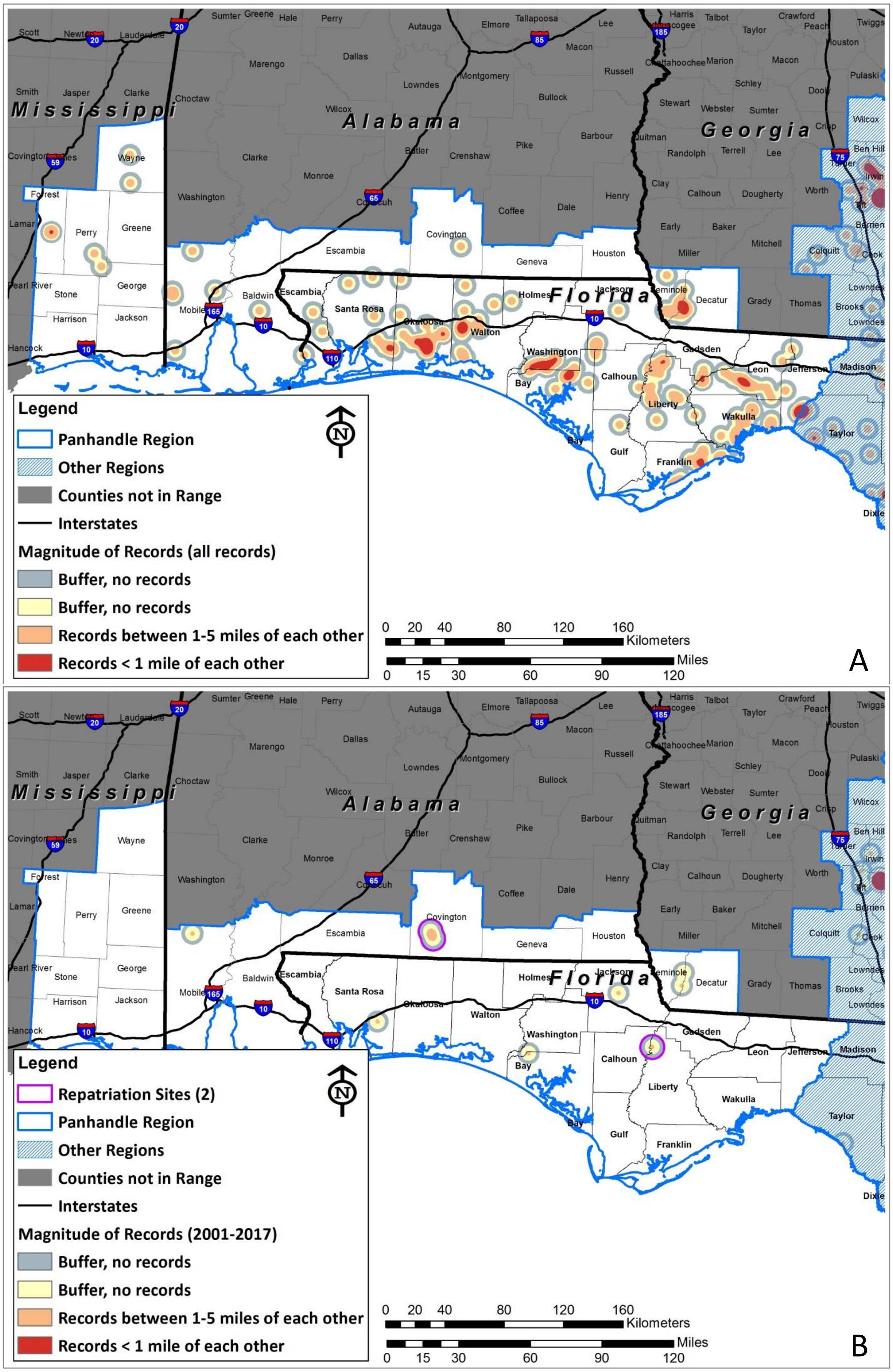


Figure 8: Historical (A) and current (B) distribution of eastern indigo snake records across the Panhandle region. Historical includes all eastern indigo snake records. Current includes records from 2001-2017.

2.4.2 North Florida

The North Florida region includes counties east of the Aucilla River (Jefferson County) and north of the latitude of Gainesville, Florida, where the eastern indigo snake is dependent on gopher tortoise burrows for overwintering shelter (Enge *et al*. 2013, p. 297) (Figure 9). A total of 222 records are reported for this region with 83 recent records (2001-2017) (Enge *et al.* 2013 and unpublished data). While once widely distributed across this region, recent eastern indigo snakes sightings are mostly documented in upland areas along the Suwannee River in Alachua, Columbia, Gilchrist, Lafayette, and Suwannee counties. Eastern indigo snakes are also recently documented in Clay and Putnam counties, including on Camp Blanding Joint Training Center and Etoniah Creek State Forest. A few records are from the coastal areas in this region, such as Guana River Wildlife Management Area. This region links the western region (Panhandle) where recent eastern indigo snake records are very rare and the north (Southeast Georgia) and south (Peninsular Florida) regions where the majority of recent records occur. This region represents the only part of Florida that currently supports "northern" populations of eastern indigo snakes.

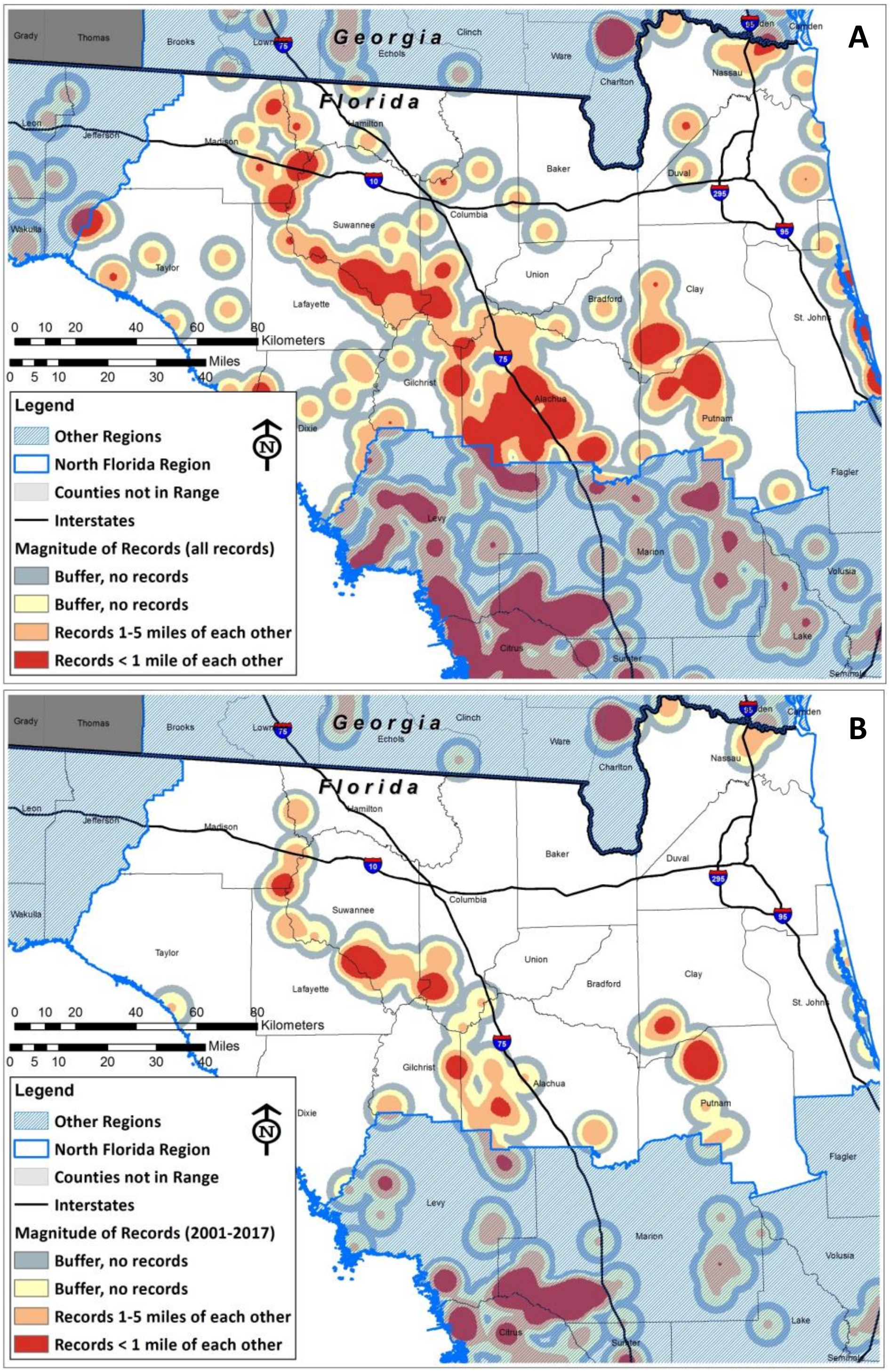


Figure 9: Historical (A) and current (B) distribution of eastern indigo snake records across the North Florida region. Historical includes all eastern indigo snake records. Current includes records from year 2001-2017.

2.4.3 Peninsular Florida

The Peninsular Florida region includes central and south Florida counties south of the latitude of Gainesville, Florida where eastern indigo snakes are less dependent on gopher tortoise burrows for overwintering shelter (Figure 10). A total of 1,107 records are reported for this region with 533 recent records (2001-2017) (Enge *et al.* 2013 and unpublished data). Eastern indigo snakes remain widespread and more commonly observed in central and south Florida, except for parts of the urbanized southeastern coast in Palm Beach and Broward counties. In the peninsula, they are more widely distributed, across different habitat types, than in other parts of their range although they continue to prefer upland habitats (Bauder *et al.* 2018). They are known from the Ocala area where they are widely distributed but not common. Eastern indigo snakes are also widespread in the Osceola Plain and along the Lake Wales Ridge on large unfragmented habitats (including large ranchlands) (Enge *et al.* 2013, p. 293). Given the species' preference for upland habitats, eastern indigo snakes are not commonly found in the wetland complexes of the Everglades region even though they have been found in pinelands, tropical hardwood hammocks, and mangrove forests in extreme south Florida (Duellman and Schwartz 1958, Steiner *et al*. 1983, Metcalf 2017). Eastern indigo snakes occur on some islands in Florida. Along the Atlantic Coast, populations occur on Merritt Island in Brevard and Volusia counties. Along the Gulf Coast in Lee County, the species still occurs on Cayo Costa, North Captiva, Big Pine, and Little Pine islands, but the population on the more developed Sanibel Island may have been extirpated (Enge *et al.* 2013, p. 293). Historically, the eastern indigo snake also occurred across the Florida Keys from Key Largo to Sugarloaf Key. The species may persist on Little Knockemdown Key (validated sighting in 2009 and a skeleton found in 2018), but the species is likely extirpated from most of the Keys.

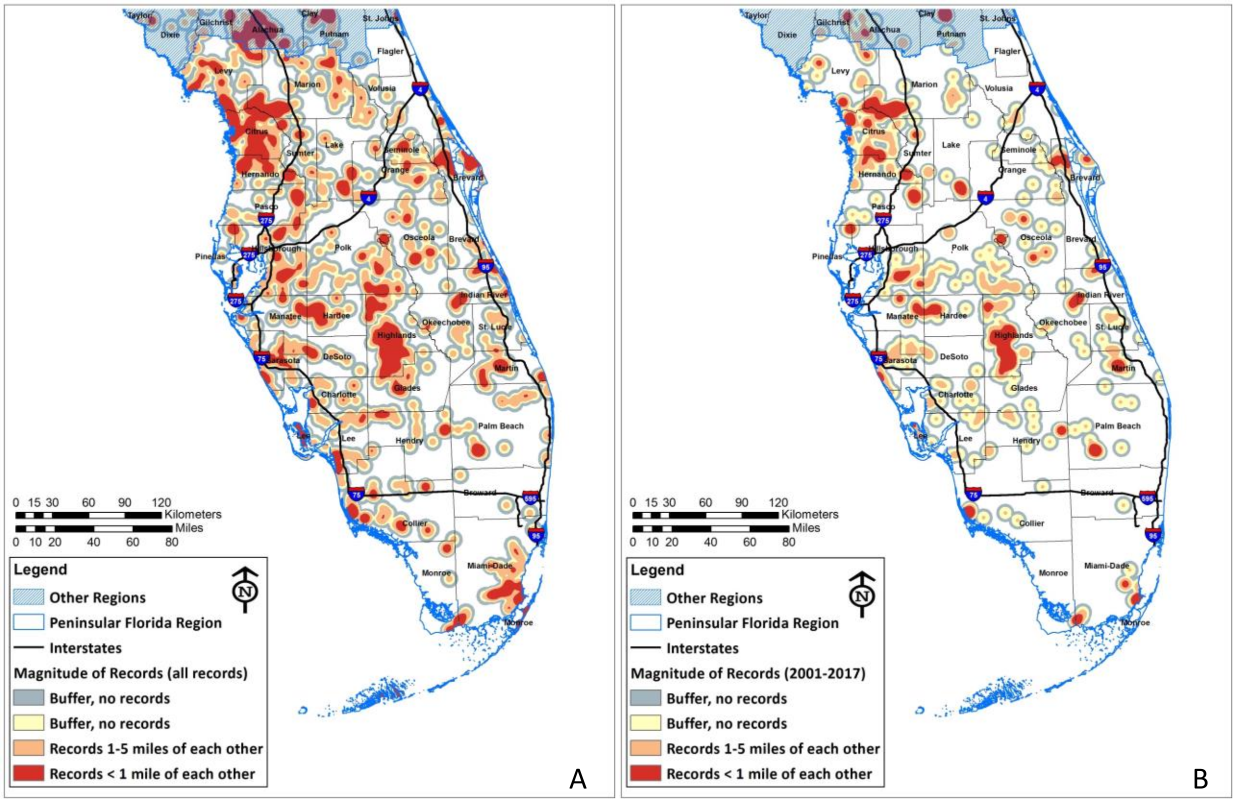


Figure 10: Historical (A) and current (B) distribution of eastern indigo snake records across the Peninsular Florida region. Historical includes all eastern indigo snake records. Current includes records from years 2001-2017.

2.4.4 Southeast Georgia

In Georgia, the first extensive effort to survey the distribution of the eastern indigo snake, as well as characterize and delineate its habitat, was conducted by Diemer and Speake (1983) between 1978 and 1980. Results of this study indicated that the stronghold for the snake was in a contiguous block of approximately 41 southeastern and south-central Georgia counties. Undeveloped sand ridges of coarse white sands lying along the northeastern sides of blackwater streams in the Atlantic Coastal Plain are prime eastern indigo snake habitat (Stevenson *et al.* 2008, p. 340). In a recent review completed by Enge *et al*. (2013), the eastern indigo snake was found to remain widespread in the lower and middle Coastal Plain of southeastern and south-central Georgia and it is regularly observed in sandhill habitats along the major river systems in this area (Figure 11). A total of 763 records are reported for Georgia with 614 recent (2001–2017) records for 29 Georgia counties (Enge *et al*. 2013 and unpublished data). However, recent records (2001-2017) indicate that the range has contracted to south of Interstate 16 and east of Interstate 75 (Figure 11), except for a recent record just west of Interstate 75 near Reed Bingham State Park (Enge *et al.* 2013, p. 291). Despite localities mapped by Diemer and Speake (1983) based upon "credible sightings," the occurrence of eastern indigo snakes in the following areas of Georgia has never been substantiated by photographs or specimens: (1) the Fall Line Sandhills region, including the Ft. Valley plateau; (2) the Fall Line Red Hills; and (3) the Tallahassee Hills (i.e. Tallahassee Red Hills) (physiographic regions follow Wharton 1978). Records are absent from the Savannah area in Chatham County, although suitable habitat occurs (at least historically) in the form of xeric sandhills along the Ogeechee River. Valid records are also lacking from any barrier island in Georgia. From Glynn County northward, records are absent from the coastal province adjacent to the mainland coast except for a single, old record for Glynn County (no date, no precise locality data, labeled from "Brunswick," not mapped in Figure 11). The historic and current status for upland islands within the interior of the vast Okefenokee Swamp is poorly known; there are old, credible sightings but no recent records (Diemer and Speake 1983, Stevenson 2006, Enge *et al*. 2013).

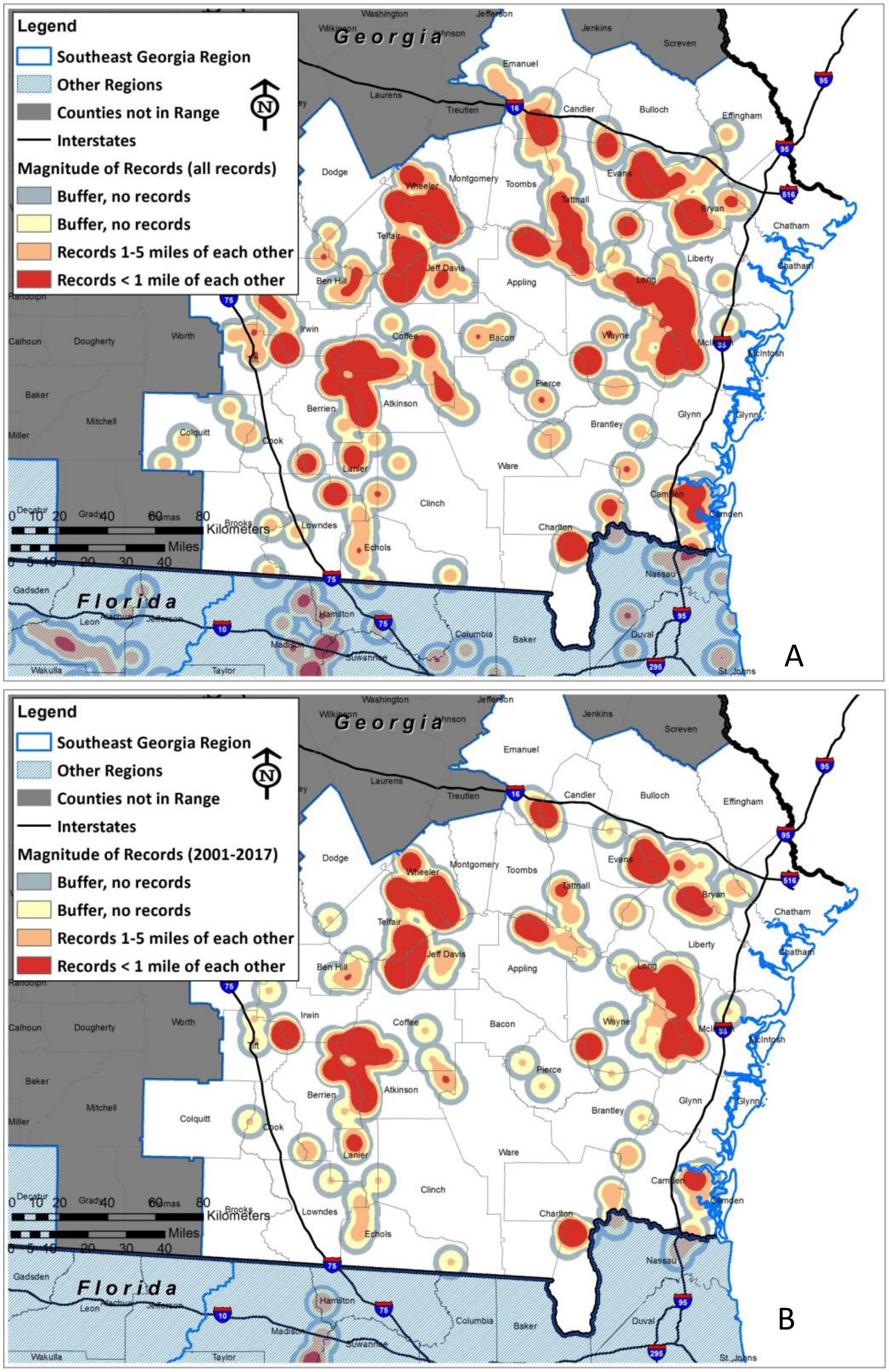


Figure 11: Historical (A) and current (B) distribution of eastern indigo snake records across the Southeast Georgia region. Historical includes all eastern indigo snake records. Current includes records from years 2001-2017.

2.5 Individual Needs

2.5.1 Life History

Reproduction and Development

Although the eastern indigo snake is a diurnal (active during the day) species (Stevenson *et al.* 2008) it is not amenable to standard population survey and mark/recapture methods like most snake species (Steen 2010, entire), and a robust, inexpensive survey technique has not been found (Enge 1997, Smith and Dyer 2003, Stevenson *et al.* 2003 p. 394, Alessandrini 2005, Ford and Ford 2005, Bolt and Weiss 2006, Mason *et al.* 2007, Stevenson *et al.* 2009, Hyslop *et al.* 2009b, Stevenson *et al.* 2010b, Rothermel 2017, p.15). However, even though the eastern indigo snake is difficult to consistently locate in the field we have learned important life history characteristics from numerous studies.

Several estimates of sex ratios are documented from studies on wild populations. Three studies of hatchlings/juveniles (Moulis 1976, Steiner *et al*. 1983, Godwin *et al*. 2011, p. 32) reported sex ratios not differing from 1 male to 1 female. However, it appears that sex ratios become more male biased in adult snakes. Layne and Steiner (1996) reported an adult sex ratio of 1.54 males to 1 female for eastern indigo snakes in south Florida. Stevenson *et al.* (2009) reported a ratio of 2.1 males to 1 female (63 males, 29 females), with no significant difference in recapture rates between sexes, in a study at Fort Stewart, Georgia. Maturity in wild snakes has been estimated to be attained at about 5.0 ft (1.52 m) total length (Speake *et al*. 1987, Layne and Steiner 1996).

Eastern indigo snakes breed during the autumn and winter months, October through February. Males are often aggressive during this time competing for mates (Figure 12). Few nest sites have been observed but they have been found in open-canopied sandy habitats associated with gopher tortoise burrows (Stevenson *et al.* 2008, p. 340, Newberry *et al.* 2009, p. 97). Hyslop (2009a, p. 461) found females using upland sandhills in early spring, after males had mostly dispersed to lowland habitats, specifically using a higher proportion of abandoned gopher tortoise burrows during what was assumed to be just prior to nesting. Some reproductive data can be gleaned from captive populations. Speake *et al*. (1987) reported that two females, captive since birth, bred at 40 and 41 months of age (about 3.5 years). The clutch size of 21 females, removed from the wild and laying eggs in the spring following their capture ranged from 6 to 12 (average = 8.5), number of hatchlings ranged from 0 to 11 and clutch viability ranged from 0-100% (Godwin *et al.* 2011, pp. 25-26). Moulis (1976) reported a range of 4 to 12 eggs for captive females and estimated their sexual maturity to be reached at 3 to 4 years of age based on their rate of growth. Captive female eastern indigo snakes typically lay eggs between April and June that hatch in August to September. Several studies indicate that annual reproduction is possible. Speak *et al.* (1987) reported 20 of 21 females captured during the spring were gravid and Hyslop (2007) reported that all females (9) examined in the spring were gravid. In a two-year study of a wild population, 3 of 5 females studied were gravid in both years (Bolt 2006). Eastern indigo snakes hatched in captivity are on average 1.4 ft (41.2 centimeters (cm)) and grow to about 2.6 ft (79.5 cm), 3.7 ft (113.9 cm), and 4.0 ft (121.9 cm) by years 1, 2, and 3, respectively (Hoffman 2018). Twelve individuals recaptured in Georgia indicate faster growth rates for subadult and small adult snakes than for large adults (Stevenson *et al*. 2003, p. 397). The lifespan of eastern indigo snakes is not well-understood. The maximum reported longevity for a captive eastern indigo snake of unknown sex was 25 years and 11 months (Shaw 1959); a study of wild eastern indigo snakes in Georgia reported that individual snakes often reach ages of 8 to 12 years (Stevenson *et al.* 2009).

Figure 12: Male combat before breeding (left) and female just after oviposition (right) at the Orianne Center for Indigo Conservation. Photos by Fred Antonio.

<u>Diet</u>

The diet of the eastern indigo snake reflects the species' large home range and movement between uplands, lowlands, and other landscapes in which it occurs. The eastern indigo snake is an active forager (Stevenson *et al.* 2008, p. 341) seeking out its prey rather than sitting and waiting on its prey. A review of prey records indicates that the eastern indigo snake consumes a wide variety of animals, but the primary prey are rodents, anurans, snakes and small turtles (Stevenson *et al.* 2010a). While eastern indigo snakes depend on gopher tortoises for their burrows they are also known to eat small tortoises (Stevenson *et al.* 2010a, p.3). In south Florida, eastern indigo snakes have been documented to consume non-native species such as a walking catfish (*Clarius batrachus*) (Metcalf and Herman 2018, p.341) and a hatchling Burmese python (*Python bivittatus*) (Andreadis *et al.* 2018, pp.341-342). Nevertheless, more than half of the 47 different vertebrate prey species documented by Stevenson *et al.* (2010a, p.6) were snakes, including venomous snakes (Figure 13) and other eastern indigo snakes.

Figure 13: Eastern indigo snake eating a copperhead (*Agkistrodon contortrix*) (left) and a rat snake (*Pantherophis alleghaniensis*) (right). Photos by Jim Godwin

<u>Home Range and Movement</u>

Adult eastern indigo snakes have very large home ranges; most estimates of home ranges vary from several hundred to several thousand acres (ac) (tens to over a thousand hectares (ha)) (Speake *et al*. 1978, Moler 1985b, Dodd and Barichivich 2007, Hyslop 2007, Breininger *et al*. 2011, Hyslop *et al*. 2014, Jackson 2013, Metcalf 2017, Bauder *et al.* 2018). On average the home ranges of adult male eastern indigo snakes are substantially larger than the home ranges of adult females (Appendix A). Male and female eastern indigo snake home ranges are considerably larger compared to other large North American snakes such as those summarized by Hyslop *et al.* (2014, p.107): the eastern coachwhip (*Masticophis flagellum*) < 250 to 450 ac (<100 ha to 183 ha), snakes of the genus *Pituophis* (Pine and Bullsnakes) averaged 195 ac (79 ha), the eastern diamond-backed rattlesnake (*Crotalus horridus*) male home ranges are between 69 and 197 ac (28 and >80 ha) and the timber rattlesnake male home range averaged around 276 acres (112 ha).

Movement between habitat types varies between northern and southern portions of the species' range, possibly based on location above and below the frost line (near the latitude of Gainesville, Florida) and a need for more winter protection from the cold above the frost line. In the more northern parts of the species' range (i.e., Georgia and North Florida), habitat use often varies seasonally between upland and lowland areas, especially where the snakes habitually overwinter in gopher tortoise burrows in xeric sandhill habitats (Hyslop *et al.* 2009a). Northern winter home ranges tend to be small (less than 25 ac (10 ha)), in spite of evidence of breeding activity, when compared to home ranges in spring through autumn (up to 3,700 ac (1,500 ha)) when more diverse habitats are occupied (Speake *et al.* 1978, Stevenson *et al.* 2009, Hyslop *et al.* 2014). In more southern parts of their range in Peninsular Florida, eastern indigo snakes become more habitat generalists and move among the available habitat types but maintain a strong affinity to upland habitats (Bauder *et al.* 2016b, Bauder *et al.* 2018). Unlike in northern regions, male eastern indigo snakes take longer, more frequent movements and have larger home ranges during the winter breeding season, although both male and female home ranges tend to be smaller overall than those in the north (Bauder *et al.* 2016b, p.221). A comparison of Peninsular Florida mean annual home range size with mean annual home range size in Southeast Georgia, using data from Hyslop *et al.* (2014), is described in Bauder *et al.* (2016b, p.223): male home range of 369 ac (149 ha) in Peninsular Florida versus 1,260 ac (510 ha) in Southeast Georgia; female home range of 121 ac (49 ha) in Peninsular Florida versus 252 ac (102 ha) in Southeast Georgia. A comparison of annual home range data for eastern indigo snakes collected in specific locations from various studies using radio telemetry to track snake movements is provided in Appendix A.

In addition, Peninsular Florida movements reported in Bauder (*et al.* 2016b, p.223) did not indicate seasonal movements between winter and summer habitats as described for Southeast Georgia (Hyslop *et al.* 2014). Home range overlap of male and female eastern indigo snakes in Peninsular Florida was significantly greater than overlap between individuals of the same sex, although female home ranges overlapped more frequently in the nonbreeding season (Bauder *et al.* 2016a, p.221). Male home ranges often completely encompassed female home ranges but rarely overlapped each other (Bauder *et al.* 2016a, p.221). A somewhat different pattern was described by Hyslop *et al.* (2014) for eastern indigo snakes in Southeast Georgia. All eastern indigo snake home ranges in that study overlapped those of multiple other eastern indigo snakes and the two largest male home ranges overlapped each other year-round (Hyslop *et al.* 2014).

Adult eastern indigo snakes, especially males, can move considerable distances. An adult male in Georgia was recaptured over 13.5 miles (mi) (22 kilometers (km)) linear distance from its original capture (Stevenson and Hyslop 2010, entire), but maximum long distance linear movements for males of 3-5 mi (5-8 km) are more common (Hyslop *et al.* 2014, p. 105). In central Florida long range distance linear movements are shorter than recorded in Georgia. An adult male in central Florida was recorded to travel 4.3 mi (7 km) (Breininger and Bolt unpublished data), but maximum long distance linear movements of about 2.4 mi (3.9 km) are more common (Bauder *et al.* 2018 p. 747). Large home ranges and long distance movements indicate that the species is especially vulnerable to habitat fragmentation and road mortality (Breininger *et al*. 2004, Breininger *et al*. 2011, 2012; Hyslop *et al*. 2011, Hyslop *et al*. 2012). Large areas of natural habitats, protected from roads and the fragmentation associated with development are needed to maintain viable snake populations (Layne and Steiner 1996, Breininger *et al*. 2004, Dodd and Barichivich 2007, Breininger *et al*. 2011, 2012; Hyslop *et al*. 2012, Enge *et al*. 2013).

2.5.2 Habitat

The eastern indigo snake occurs in a wide range of upland and lowland habitat types including mesic pine flatwoods, scrubby flatwoods, longleaf pine sandhills, oak scrub, sand pine scrub, dry prairie, tropical hardwood hammocks, freshwater and saltwater marshes and swamps, coastal dunes, and some human-altered habitats (USFWS 1982, Moler 1992, Stevenson *et al*. 2008, Hyslop *et al.* 2009a, Enge *et al*. 2013) (Figure 14). They may move seasonally between upland and lowland habitats, especially in northern portions of their range. However, across its range eastern indigo snakes exhibit a strong preference year-round for upland habitat types (Bauder *et al*. 2018 pp. 754-755, Hyslop *et al.* 2014, p. 108)).

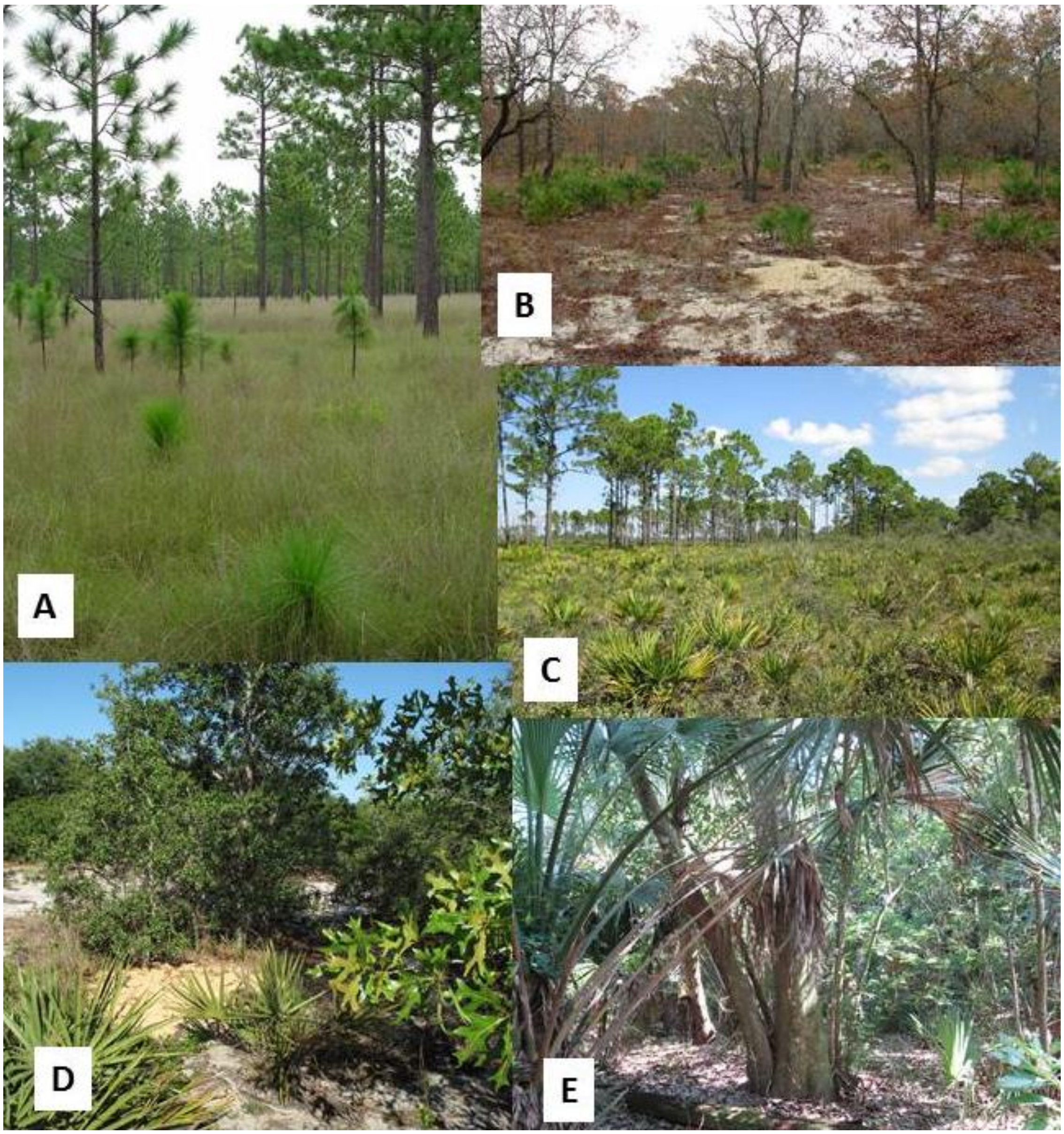


Figure 14: Examples of eastern indigo snake habitat (A) Longleaf Pine Sandhill, GA; (B) Sandhill Scrub, GA; (C) Scrubby Flatwoods, FL; (D) Oak Scrub, FL; and (E) Tropical Hardwood Hammock, FL. Photos A & B by Dirk Stevenson, Photo C by Lance Paden/Orianne Society and Photos D & E by Javan Bauder/Orianne Society. Additional habitat photos provided in Appendix A (Figure A1).

Throughout their range, eastern indigo snakes may also use below-ground shelter sites for refuge, breeding, feeding and nesting (Speake *et al*. 1978, Stevenson *et al*. 2003 p. 395, Hyslop *et al*. 2009a, Stevenson *et al*. 2010b). In the northern part of their range, burrows are used to protect against the cold. In summer, eastern indigo snakes use burrows as protection from heat and dry conditions since they have been shown to be susceptible to desiccation (Bogert and Cowles 1947). Reliance on xeric sandhill habitats throughout the northern portion of the eastern indigo snake's range in Georgia and northern Florida is due to the dependence on gopher tortoise burrows for shelter during winter (Stevenson *et al*. 2003 & 2009, Hyslop *et al*. 2009, Bauder *et al*. 2017, p. 78) (Figure 15). However, presence of gopher tortoise burrows alone is not a sufficient predictor of suitable overwintering habitat for eastern indigo snakes (Bauder *et al.* 2017, p. 78). Eastern indigo snakes use both active and inactive gopher tortoise burrows. In Georgia, eastern indigo snakes have been documented to have den site fidelity, returning to the same sandhills and sometimes the same burrows over multiple winters (Stevenson *et al*. 2003 p. 401, Hyslop et al. 2009a p 460, Hyslop *et al*. 2017 p. 105). In wetter habitats that lack gopher tortoises, eastern indigo snakes may take shelter in hollowed root channels, hollow logs, stump holes, or the burrows of rodents, armadillo (*Dasypus novemcinctus*), or land crabs (*Cardisoma guanhumi*) (Lawler 1977, Moler 1985b, Layne and Steiner 1996, Hyslop 2007, Hyslop *et al*. 2009a). Juvenile and subadult eastern indigo snakes are very difficult to detect in the wild, thus there is a poor understanding of the ecology of these age classes. In Georgia Hyslop *et al.* (2009b, p. 97) captured 4 subadults, including a hatchling, using box traps. Bauder *et al*. (2012, p. 343), observed 13 juvenile snakes in the xeric sandhills of Georgia and suggest that lower detection rates of juveniles may be due to more cryptic behavior, low densities, and rare use of gopher tortoise burrows as shelter because of the threat of cannibalism.

Figure 15: Eastern indigo snake basking near a gopher tortoise burrow (left) and approaching gopher tortoise burrow (right) during winter in Southeast Georgia sandhill habitat. Photos by Dirk Stevenson.

Throughout Peninsular Florida, the eastern indigo snake may be found in almost all terrestrial habitats except in areas with high-density urban development (Moler 1992, Enge *et al*. 2013). From the latitude of around Gainesville, Florida, south, they are less tied to longleaf pine sandhills and become more habitat generalists, although they still require below-ground shelter sites and commonly use gopher tortoise burrows and sandy xeric habitats when these are available (Layne and Steiner 1996, Enge *et al*. 2013, Bauder *et al*. 2016b). Eastern indigo snakes can be common in some hydric hammocks (Moler 1985a, Bauder *et al.* 2018). On the sandy central ridge (i.e., Lake Wales Ridge) of south Florida, eastern indigo snakes may use gopher tortoise burrows more (62 percent) than other underground shelter (Layne and Steiner 1996). In extreme southern Florida, they are typically found in pine flatwoods, pine rocklands, tropical hardwood hammocks, and in most other undeveloped areas (Kuntz 1977, Enge *et al*. 2013). Below-ground shelter sites used in these areas include burrows of armadillos, hispid cotton rats (*Sigmodon hispidus*), and land crabs; burrows of unknown origin; natural ground holes; hollows at the base of trees or shrubs; ground litter; trash piles; and crevices of rock-lined ditch walls (Layne and Steiner 1996).

Eastern indigo snakes are also known to utilize human-altered habitats. In Florida, agricultural sites, such as sugar cane fields, improved pasture sites, citrus groves, and canal banks created in drained wetland areas are sometimes occupied by eastern indigo snakes (Enge *et al*. 2013, O'Bryan 2017 p. 1, Bauder *et al*. 2018 p. 756). Additional habitat photos are provided in Appendix A.

CHAPTER 3 – POPULATION AND SPECIES NEEDS

3.1 Population Resiliency

Resiliency *describes the ability of a population to withstand stochastic disturbance. Resiliency is positively related to population size and growth rate and may be influenced by connectivity among populations. Generally speaking, populations need abundant individuals within habitat patches of adequate area and quality to maintain survival and reproduction in spite of disturbance.*

For the eastern indigo snake to maintain species viability, its populations need be resilient enough to withstand stochastic events. Stochastic events that have the potential to affect eastern indigo snakes include temperature changes, drought, hurricanes and flooding, disease, etc. which can impact individuals or the habitat they require for critical life functions such as breeding, feeding and sheltering.

To be resilient to stochastic events, populations of eastern indigo snakes need to have adequate number of individuals (abundance) including all lifestages (breeding adults, juveniles, and hatchlings). The population extent should be large enough such that localized events do not cause extirpation. Populations need connectivity within populations (demographic connectivity) to be able to re-colonize sites after a stochastic event or local extirpation (source-sink dynamics) as well as connectivity between populations (genetic connectivity) to reduce inbreeding (genetic rescue) and contribute to adaptive evolution.

Population level characteristics (population extent, population connectivity and abundance) that influence resiliency are influenced by habitat conditions. Due to the species' relatively low densities and its cryptic behavior we have limited range-wide information of what defines a biologically distinct population of eastern indigo snakes (see section 5.1 for additional discussion), including population sizes and trends. However, important information on the life history and habitat use for this species has been gained from research studies. Adequate population connectivity, population extent and abundance are influenced by habitat quality (habitat type, fragmentation [including presence of roads and urbanization] and presence of shelter sites) and habitat quantity (Figure 16).

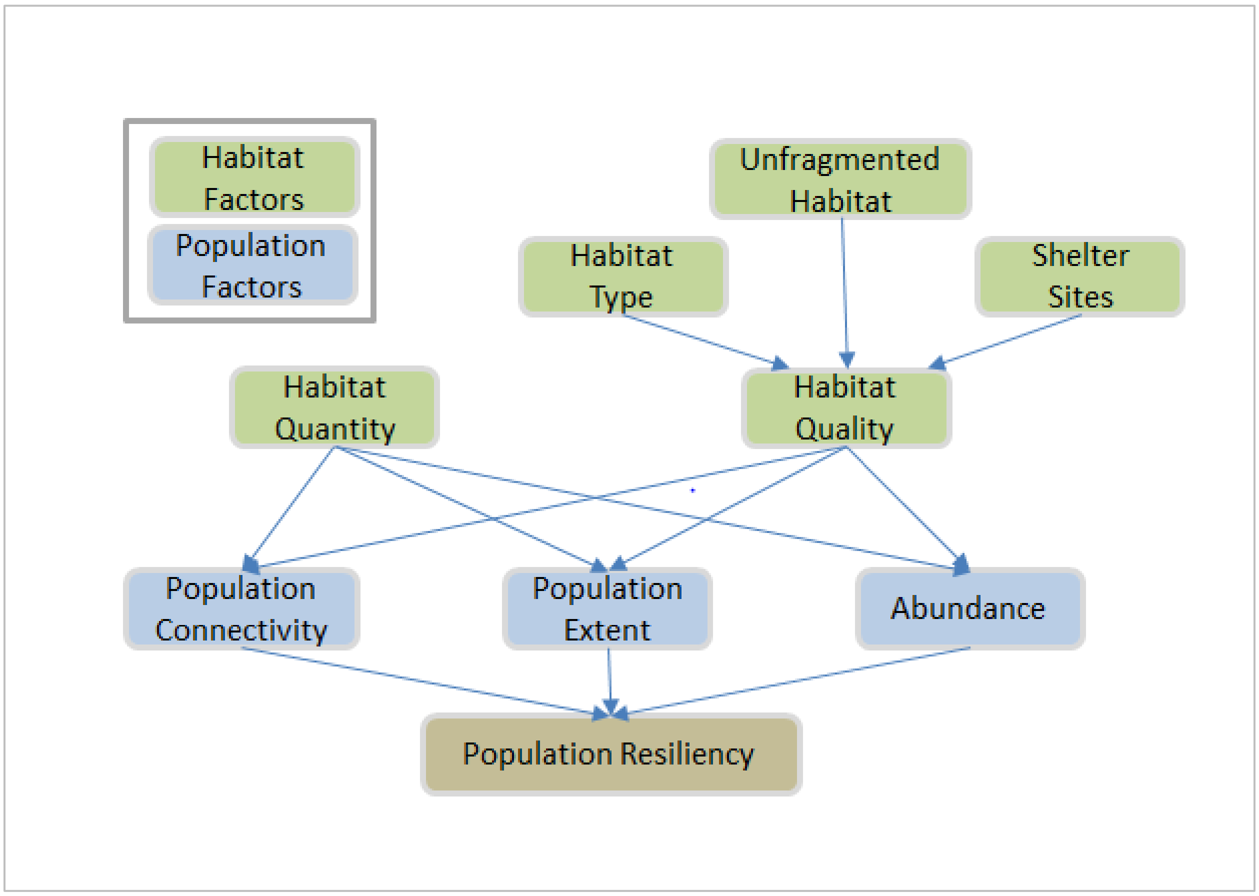


Figure 16: Basic population and habitat needs for eastern indigo snake population resiliency.

Habitat Quality

Resilient eastern indigo snake populations need good habitat quality of sufficient size with connectivity among populations. While they occupy a wide range of natural and human-altered habitat types (see section 2.5.2), eastern indigo snakes need a diversity of natural habitat types (e.g. scrubby flatwoods, longleaf pine sandhills, oak scrub, sand pine scrub, dry prairie, tropical hardwood hammocks, agricultural fields, coastal dunes, etc.) to support essential life functions of breeding, feeding, and sheltering. It is believed that a combination of both natural upland (primary habitat) and lowland (secondary habitat) habitat provides the best matrix of habitat types to support resilient eastern indigo snake populations. Most of these upland habitat types depend on periodic fire to maintain good quality. Throughout its range, shelter sites are needed year-round by eastern indigo snakes for thermoregulation, foraging, nesting, and mating. In Georgia and northern Florida, eastern indigo snakes depend on upland xeric sandhill habitats and the availability of gopher tortoise burrows for thermal shelter during winter.

Habitat fragmentation is a critical factor affecting eastern indigo snake population resiliency and persistence. Breininger *et al*. (2012 p. 364) suggest that snake survival is highest in "conservation cores" that are not fragmented by roads and that survival decreases with increasing fragmentation and presence of roads. Increased exposure to roadways likely increases road mortality due to the species' large home range (largest in North America, ranging from several hundred to several thousand acres, see section 2.5.1), active foraging behavior, conspicuous body size, and high movement potential (Bauder *et al.* 2018 p.757). Numerous studies have documented direct mortality of eastern indigo snakes on roads (Breininger *et al.* 2011, 2012, Hyslop *et al.* 2014, Ceiley *et al.* 2014, Godwin and Steen 2017) and many eastern indigo snake records are from sightings on roads (see section 4.2). Bauder *et al.* (2018, p.751) found that probability of crossing roads decreased with increasing distance from roads and this distance was greatest for breeding males (who may move long distances in search of females). Habitat fragmentation also negatively impacts eastern indigo snakes by reducing fire spread and disrupting the ability to conduct prescribed fire which is necessary for maintaining good quality habitat throughout much of the species' range.

Degraded habitat quality has the potential to impact population resiliency by inducing stress on individuals (e.g. reduced shelter and foraging habitat), impacting breeding and reproductive success, causing direct mortality and limiting connectivity and the ability to re-colonize areas after stochastic events. Therefore, extensive tracts of land with diverse, unfragmented habitat are important to support viable eastern indigo snake populations (Diemer and Speake 1983, Breininger *et al*. 2004, Dodd and Barichivich 2007, Breininger *et al*. 2011, 2012, Hyslop *et al*. 2012). Lastly, degraded habitat quality can negatively impact the ability for long-distance movement and reduce genetic exchange among populations increasing the risk of extinction due to inbreeding and reduced capacity for evolutionary adaptation (Carlson *et al.* 2014, p. 523).

Habitat Quantity
In addition to large home ranges, eastern indigo snakes exhibit a low degree of home range overlap, especially among adult males (Hyslop *et al.* 2014, Bauder *et al*. 2016a). And, although some species may expand their home range when habitat quality declines (Van Horne 1983, entire), studies on eastern indigo snakes in central Florida found that home ranges in urban and fragmented landscapes were significantly smaller than those snakes in more natural landscapes (Breininger *et al.* 2011, entire, Bauder *et al.* 2018, p. 755). Although the authors lacked data to test these conclusions, Breininger *et al.* (2011, p. 488) suggest smaller home ranges may be because snakes in suburban areas moved less due to the abundance of food, or they altered their behavior to reduce mortality risk, or that they are able to occupy less pristine settings due to their general habitat preferences (in central Florida) and variable diet. However, smaller and fragmented habitat may reduce the snake's ability to find mates, disrupt gene flow and alter availability of prey (Breininger *et al.* 2011, p. 489), unless the snake moves further distances which increases mortality due to roads and predation. Therefore, eastern indigo snake populations need large tracts of good quality habitat to sustain reproducing populations (Moler 1992, Breininger *et al.* 2004, Breininger *et. al.* 2011, Breininger *et al.* 2012, p. 366).

3.2 Species Representation

***Representation** describes the ability of a species to adapt to changing environmental conditions over time. It is characterized by the breadth of genetic and environmental diversity within and among populations.*

Identifying and evaluating representative units that contribute to a species' adaptive potential are important components of assessing overall species viability (Smith *et al.* 2018, entire). This is because having populations that are distributed throughout multiple representative units may safeguard a species' ability to adapt to environmental changes overtime. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. Representation of the eastern indigo snake can be described in terms of ecological (latitudinal) and genetic variability and are assessed by using the four (4) regions (Panhandle, North Florida, Southeast Georgia, and Peninsular Florida) described in section 2.4 above, as our representative units.

Ecologically, eastern indigo snakes are known to differ markedly between northern and southern populations in seasonal activity. The southern populations (Peninsular Florida) do not depend upon gopher tortoise burrows for winter shelter sites, likely because of milder winter temperatures, but are closely associated with gopher tortoises where they co-occur. The northern populations (North Florida, Southeast Georgia, and the Panhandle) are dependent on gopher tortoise burrows for overwintering shelter (Enge *et al.* 2013, p. 297). Genetic variability has been documented within a north-south gradient (Folt *et al*. 2019) as well as an east-west (Atlantic-Gulf) gradient (Krysko *et al.* 2016b, entire). The north-south genetic gradient is generally the same as the ecological gradient.

For the eastern indigo snake to exhibit adequate representation, resilient populations should occur across the ecological gradient which represents the ecological setting in which the eastern indigo snake has evolved. Furthermore, genetic patterns and variability that exists within the species should be maintained to enable the species' adaptive potential.

3.3 Species Redundancy

Redundancy *describes the ability of a species to withstand catastrophic events. Redundancy is characterized by having multiple, resilient populations distributed within the species' ecological setting and across the species range.*

Redundancy reduces the species' extinction risk if a portion of the species' range is negatively affected by a natural or anthropogenic catastrophic disturbance. Species that have resilient populations spread throughout their historical range are less susceptible to extinction (Carroll *et al.* 2010, entire, Redford *et al.* 2011, entire). Redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode (e.g. disease) involving many populations). Redundancy is measured by the number of populations, their resiliency, and their distribution (and connectivity). Thus, high redundancy for the eastern indigo snake is defined as multiple resilient populations distributed throughout representative areas (ecological and genetic) of the species' historical range. Maintaining connectivity among redundant populations is important for allowing immigration and emigration between populations and increases the likelihood of recolonization should a population become extirpated.

CHAPTER 4 – FACTORS INFLUENCING VIABILITY

The eastern indigo snake was listed under the ESA as threatened in 1978 throughout its range due to population declines caused by habitat modification, over-collecting for the pet trade and mortality from gassing gopher tortoise burrows (USFWS 1978). Based on the eastern indigo snake's life history and habitat needs (section 2.5 above), we identified the potential negative and positive influencing factors and contributing sources of those influences that are likely to affect current and future species viability (Figure 17). In the following sections we discuss the specific influences most affecting the species.

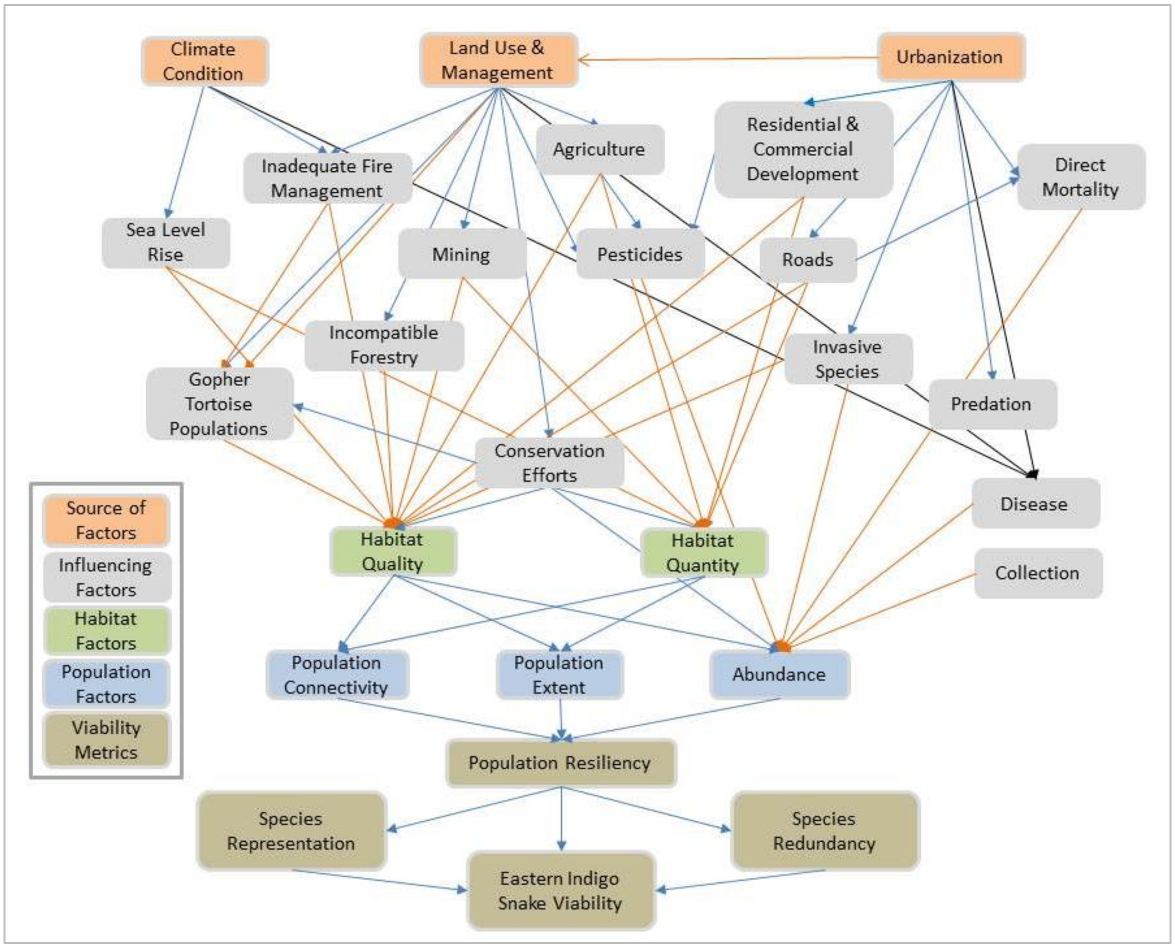


Figure 17: Factors influencing the viability of the eastern indigo snake. Factors connected by blue arrows have positive relationships. Factors connected by orange arrows have negative relationships. Factors connected by black arrows have neutral or unknown relationships.

4.1 Habitat Modification and Destruction

Habitat Fragmentation

Eastern indigo snakes have large home ranges and move long distances (especially males); thus, habitat connectivity needs to be maintained. Urbanization creates habitat fragmentation by reducing habitat patch sizes. Primary and secondary roads (such as interstates and highways) are prominent features of urbanized areas and can contribute to isolation and fragmentation of eastern indigo snake populations because they often avoid these type of roads (Bauder *et al.* 2018, p.751), but they may eventually cross these road types in search of food and mates when habitat patch sizes decrease (Breininger *et al*. 2004, 2011, and 2012).

As urbanization of natural areas progresses, the size of fragmented habitat patches become smaller sustaining fewer snakes and creating islands of fragmented habitat with little or no connectivity within a landscape of unsuitable habitat. However, eastern indigo snakes will likely persist in localities where large, contiguous patches of natural habitat remain. It has been suggested that eastern indigo snake populations that occur on federal, state, or other privately managed conservation lands with multiple patches of at least 2,500 ac (1,000 ha) (i.e. multiple patches is >5,000 ac (>2,023 ha)) may increase long-term viability (Moler 1992). However, high edge-area habitat patches (e.g. edges created by roads or human-altered habitats) have greater extinction risk due to direct mortality (Breininger *et al*. 2004, 2011, and 2012, entire). A recent study suggested 2,500 ac is too small to support even a single pair of eastern indigo snakes and suggested about 12,000 – 22,000 ac (5,000 – 9,000 ha) of unfragmented habitat is needed to sustain eastern indigo populations in central Florida (Bauder 2018, p. 160). Sytsma *et al.* (2012, pp. 39–40) estimated a reserve size of 10,000 ac (4,047 ha) could support a small population of eastern indigo snakes. However, Hyslop *et al.* (2014, p.109) reported that the collective extent of eastern indigo snakes studied (n=31) near Fort Stewart in Southeast Georgia, where the snakes are believed to travel the farthest distance, was about 20,000 to 35,000 ac (8,000 to 14,000 ha). These patch sizes reported in the literature provide insight to the degree of habitat fragmentation suitable for eastern indigo snakes.

<u>Habitat Destruction</u>

Throughout the eastern indigo snake's current range (i.e. Florida and Georgia), the increasing trend of urbanization and agricultural development continues to destroy and degrade habitat. Because of its relatively large home range and low degree of home range overlap (Hyslop *et al.* 2014, Bauder *et al*. 2016a), the eastern indigo snake is especially vulnerable to habitat loss (Lawler 1977, Moler 1985b, Breininger *et al*. 2004, 2011, and 2012; Hyslop *et al*. 2012, Bauder *et al.* 2018).

Habitat impacts due to urbanization are increasing across the species range, particularly in Florida. In 1977, Lawler reported that the loss of natural habitat in Florida was increasing and eastern indigo snake habitat was being lost at a rate of 5 percent per year. Zwick and Carr (2006, p.2) predicted that by 2060 nearly 3 million acres of natural habitat in Florida would be lost to urbanization. In a more recent study Carr and Zwick (2016) projected Florida's population to grow from about 18.8 million to approximately 33.7 million by 2070. The projected population growth is not evenly distributed and may be accommodated by more compact pattern of development and increased protected lands (Carr and Zwick 2016). Generally, central Florida is projected to experience much greater growth and therefore have the greatest increase in developed lands while the Panhandle region is predicted to have the lowest rate of development with significant open space predicted to remain (Zwick and Carr 2006, Carr and Zwick 2016). Although eastern indigo snakes may occupy areas of low density residential housing in the southern portions of its range in Florida, this also represents a potential negative influence to the species since there is increased likelihood of snakes being killed by humans and domestic pets (Breininger *et al.* 2012, p. 364). The effects of habitat destruction on the eastern indigo snake are likely most substantial along the Florida coasts, in the Keys, and along the high ridges of central Florida, where human population growth is expected to continue to accelerate. In

Southeast Georgia, urbanization also is increasing but not as rapidly compared to Florida. Georgia is mostly forested (>57% in 2012), followed by agricultural land (>18% in 2012) and developed land (>12% in 2012); however developed land continues to increase (USDA 2016, p.3).

Solar energy developments can destroy or degrade habitat for eastern indigo snakes. Solar developments on sand ridges are a factor that is increasing significantly in both Georgia and Florida in recent years (EIA 2018a). In 2010 Florida produced approximately 80,000 Megawatts (MW) increasing to 870,000 MW in 2017. In Georgia, solar development has increased to almost 2.5 times more than Florida, having only produced only 3,000 MW in 2012 increasing to 2,137,000 MW in 2017. By the end of 2016, Georgia ranked 8th in the nation in solar (EIA 2018b). Some solar utility developers and companies recognize the potential impact this type of development may have on rare species and their habitat and have begun working with conservation organizations to reduce impacts via strategic siting assessments (NASA Develop 2018).

Although to a lesser extent than urbanization, conversion of suitable, natural eastern indigo snake habitat to agricultural land uses (including crop, pasture and timber land) also contributes to habitat destruction and degradation throughout much of Georgia and Florida (Enge *et al.*2013, USDA 2016 entire, Carr and Zwick 2016). These anthropogenic land uses have variable influences on eastern indigo snakes, but may provide important habitat for eastern indigo snakes (e.g. Ceilley *et al.* 2014, GDNR 2017). However, these land uses are subject to relatively frequent alteration (e.g. herbicides, plowing) and heavy equipment as a result of various production needs (harvesting, planting, ditching, etc.) that may negatively influence eastern indigo snakes (e.g. Godley and Moler 2013, p. 363, Enge *et al.* 2013). Nevertheless, eastern indigo snakes are known to inhabit extensive canal systems in central and south Florida. Efforts to restore natural wetlands at these agricultural sites may adversely impact eastern indigo snakes (Ceilley *et al.* 2014). Agricultural land use practices (e.g. heavy herbicide use, bedding, planting dense stands of *Pinus* sp.) can reduce herbaceous groundcover and negatively influence gopher tortoise populations (CCA 2012, Enge *et al.* 2013) and the availability of gopher tortoise burrows as shelter sites for eastern indigo snakes. Loss of thermally stable, below-ground shelter sites can negativity influence eastern indigo snakes, especially in the northern portion of its range (Enge *et al*. 2013). While agricultural lands present some risk to eastern indigo snake populations, negative impacts may be offset by conservation of agricultural lands. For example, conserved agricultural land (e.g. conservation easements, Sustainable Forestry Initiative) may reduce impacts from urbanization, improve wildlife habitat, and maintain connectivity among eastern indigo snake populations.

Mining for resources such as sand, limestone, phosphate and heavy metals continues to increase in Georgia and Florida (GEPD 2017, FDEP 2018) and adversely impact eastern indigo snake habitat. In Georgia, multiple sand and heavy metal mines within the range of the eastern indigo snake have been permitted since 2008 (GEPD 2017). In Florida, mining is widespread across eastern indigo snake habitats; for example, phosphate mines disturb between 3,000 and 6,000 acres (1,200- 2,400 ha) annually in Florida (FDEP 2003). Generally, resource mining causes intensive land disturbance over relatively large areas over time. In an effort to reduce overall environmental impacts from mining, mitigation and reclamation of mined lands are often implemented. Land protection (mitigation) in strategic areas may help offset impacts to habitat loss; however, effectiveness of reclaiming retired mines and restoring habitat suitability for eastern indigo snakes is not known.

Habitat modification from any of the above activities can lead to direct mortality from impacts due to equipment and/or hazardous materials. Heavy equipment can kill or injure snakes. Construction debris can also cause harm to individuals. For example, snakes are particularly vulnerable to entanglement in plastic netting that is often used in matting for erosion control on construction projects (Stuart and Watson 2001, pp. 162-164) and eastern indigo snake entanglement has been documented (Enge *et al.* 2018).

Habitat Degradation (inadequate fire management)

Eastern indigo snakes use a variety of habitats, and patterns of habitat use may shift seasonally. However throughout its range, eastern indigo snakes show a strong affinity for upland habitat types, especially longleaf pine habitats. Most of these upland habitat types depend on reoccurring periodic fire to maintain good quality. Natural fires are now often suppressed, and many habitats are degraded from inadequate fire management (Wear and Greis 2002), however the number of states offering education and training to certify prescribed fire managers has increased over time increasing the capacity for prescribed fire (Melvin 2015, p. 1). The inability to meet prescribed fire goals is likely to be influenced with expanding urbanization and climate change. Changes in climate are predicted to increase wildfire risk and limit the number of suitable burn days due to warming temperatures and regional drying via evapotranspiration regardless of changes in precipitation (Ingram *et al*. 2013, p. 166). In addition, to reduce "non-essential" carbon emissions, the possibility of additional air quality restrictions (PM 2.5) further limit prescribed fire. In 2014, state forestry agencies in the southeast United States ranked air quality/smoke management and wildland urban interface/population growth higher than the national percentage as impediments limiting prescribed fire (Melvin 2015, p. 17).

4.2 Direct Mortality

Human population growth will increase the potential of eastern indigo snake mortality from both intentional and unintentional killing. This will likely occur from direct mortality by people and their domestic animals, from the use of chemicals to control disease and pests, and from road mortality. Deliberate killing of snakes is common (Andrews *et al.* 2008). Life history traits such as the snake's diurnal nature, large body size and their large home range size (that often results in the necessity of crossing roads), make them more susceptible to being observed and deliberately killed.

An increase in the number of mortalities from vehicles on roads may result in declines or extirpation of populations. At a study site in Florida, researchers compared the catch-per-unit-effort in 1981-1983, and 2005-2009, and found that the eastern indigo snake population had declined by greater than 95 percent (Godley and Moler 2013). The potential eastern indigo snake habitat did not appear to substantially decline or change in quality over the three decades of the study. The researchers suggested evidence supported cumulative, unsustainable mortality from vehicular traffic as a primary factor in the population decline (Godley and Moler 2013).

Because of the cryptic nature of eastern indigo snakes and the difficultly surveying for them, many of our records are from sightings on roads, either Dead on Road (DOR) or Alive on Road (AOR) (Figure 18). A preliminary summary of DOR/AOR data by Enge, Stevenson, Chandler and Elliott (unpublished data), in Georgia and Florida indicate over 200 snakes were observed on roads since the year 2000 with most of these sightings as DORs (unpublished data). These 200 snakes are likely only a very small fraction of the actual DOR/AORs since many go unreported and DORs are often scavenged by other animals.

Eastern indigo snakes will cross roads, but telemetry data indicate they prefer areas away from roads (Breininger *et al.* 2012, Hyslop *et al.* 2014, p. 105, Bauder *et al.* 2018). Breininger *et al.* (2012) found that eastern indigo snakes had relatively high survival in conservation core areas, but along roads and in suburbs their survival was greatly reduced. They found study animals dead along roads, including individuals intentionally killed by humans (Hyslop *et al.* 2009c, Breininger *et al.* 2012). Hyslop *et al.* (2014, p. 105) did not record any radio-tracked study snakes outside boundaries created by paved roads, but found 2 eastern indigo snakes not included in the telemetry study dead on these roads. The radio-tracked snakes were found to regularly cross unpaved roads. Bauder *et al.* (2018, p. 751), suggest eastern indigo snakes avoid larger paved roads (primary and secondary roads such as interstates and highways), but readily cross smaller paved roads (tertiary roads such as two-lane rural county roads). In populations with low numbers of individuals, any additional negative influencing factors to populations could cause local extirpations. This is especially true in long-lived snakes, such as the eastern indigo snake, that make long-distance movements, and have low reproductive rates, and low natural densities. Models have demonstrated that protection of adult eastern indigo snakes, which are the age class most likely to be killed on roads, is the most important factor in survival of a population (Hyslop *et al*. 2012).

Figure 18. Eastern indigo snake dead on road (DOR), likely killed by vehicular strike (left) and eastern indigo snake alive on road (AOR) (right). Photo by Dirk Stevenson (left) and Matt Moore (right)

4.3 Climate Conditions

Changing climate conditions are likely to have an effect on eastern indigo snakes. Sea level rise, due to climate change**,** will impact the coastal populations due to inundation of habitat and increased saline environments. Florida has undergone drastic changes in size and shape over long geologic periods due to sea level changes that influenced the distribution and genetic diversity of the eastern indigo snake (Kyrsko *et al*. 2016b, p. 112). While some eastern indigo snakes have been observed in saline habitats (mangrove swamplands), the species' salinity tolerance is unknown (Metcalf 2017, p. 53). Habitat loss and degradation of today's landscape reduces connectivity and creates movement barriers. For example, Metcalf (2017, p. 53) suggests for the coastal population at Rookery Bay Reserve, a heavily trafficked road (SR 951) may block their escape inland from rising sea levels.

Impacts of shifting temperatures and rainfall due to climate change are variable but may cause indirect effects, such as dependence on gopher tortoise burrows for winter shelter sites and shifts in prey base. However, since the eastern indigo snake has a diverse diet, dietary needs for the snake will likely be met. Shifting temperature and rainfall can negatively affect the ability to conduct prescribed fire (Melvin 2015, p.1) which is an important management tool for maintaining good quality habitat (see Habitat Degradation section above). To minimize risk of habitat loss from sea level rise and variable effects from changing weather, maintaining connectivity among habitat patches so that snakes can move in response to changing climate conditions will be essential for long-term viability.

4.4 Disease

A health assessment has been completed of 61 wild eastern indigo snakes captured in southeastern Georgia (Knafo *et al.* 2016). Similar to a south-central Florida study (Layne and Steiner 1996), they found that a high percentage of snakes examined during the winter months had scabrous boils and skin lesions varying from superficial wounds to ones extending down to muscle tissue. Based on mark-recapture and health assessment studies, snakes seem to commonly recover from the boil-lesion condition that generally disappears in the summer months (Stevenson *et al*. 2009, Knafo *et al*. 2016). Healthy eastern indigo snakes commonly harbor a wide variety of endoparasites; however, these organisms are generally common in wild snakes and may not negatively affect the species (Foster *et al*. 2000, Knafo *et al*. 2016). However, Metcalf *et al.* (2018) documented one eastern indigo snake in Collier County, Florida where parasite load from *Kiricephalus coarctatus* was determined to be a contributing factor to the snake's death.

Snake fungal disease (SFD) (*Ophidiomyces ophiodiicola*) is an emerging disease that has infected snakes throughout the eastern United States, including eastern indigo snakes in Georgia, and has been implicated in the population declines of several snake species (Lorch *et al.* 2015, Chandler *et al*. 2019, entire). Snake fungal disease is a fungal pathogen of endemic and captive snakes in North America and can persist in soil as well as colonize living hosts (Allender *et al.* 2015). In Georgia, an on-going study by The Orianne Society documented 117 positive SFD (positive DNA qPCR test) infections of 786 sampled snakes with positive results for 22 species, with water snakes (genus *Nerodia*) and the eastern indigo snake exhibiting the highest rates of infection (43.9%) (Chandler *et al.* 2018, 2019 entire). In some cases minimal to extensive scabbing and lesions may be noticeable on the snake (Figure 19), however snakes with presence of scabbing or lesions do not always test positive for SFD (Chandler *et al*. 2018, p.19). No reports of SFD in eastern indigo snakes from Florida have been documented (Enge 2018, Rothermel 2017, p. 23) but few specimens of eastern indigo snakes from Florida have been examined for SFD. Eastern indigo snakes may exhibit a high prevalence of SFD during winter months when the snakes are often hibernating underground (e.g. in tortoise burrows) in humid environments that make them more susceptible to developing SFD than at other times of the year. Eastern indigo snakes may be able to rid themselves of SFD by shedding. The long-term prognosis for SFD and eastern indigo snakes is unknown and research is on-going to collect additional samples to better understand its effects on the eastern indigo snake and other snake fauna (Chandler *et al*. 2018, p. 20).

Figure 19. Photo of eastern indigo snake from southeast Georgia with extensive scabbing from snake fungal disease. Photo by John Jensen/Georgia Dep. Natural Resources

The protozoa *Cryptosporidium* spp. are a significant cause of parasitic disease in snakes. The two most significant species in snakes are *Cryptospordium serpentis*, which has a gastric tropism and *Cryptosporidum varanii*, which has a small intestinal tropism (Lock and Wellehan 2015 entire, Wellehan and Stahl 2015, entire). Symptomatic snakes infected with *C. serpentis* often have poor growth, weight loss, regurgitation, and gastric hypertrophy leading to a visible mid-body swelling. The most common clinical sign, regurgitation, leads to chronic weight loss and muscle wasting. Snakes infected with *C. varanii* usually have wasting, poor growth, and diarrhea, with no symptoms of regurgitation (Wellehan and Stahl 2015, entire). It has been proposed that reptiles that are immunosuppressed by stress or concurrent illness are more likely to develop clinical signs. Snakes infected with *C. serpentis* can enter a chronic carrier state where they do not show clinical signs, and intermittent shedding of organisms does occur.

Reported prevalence and fate of snakes with *C. serpentis* in captive and wild populations is not well studied. An extensive survey of over 500 wild and captive reptiles over three continents found a 3% prevalence of infection with *Cryptosporidium* (Upton *et al*. 1989, entire). However, it seems there is a higher prevalence rate in captive populations (Sevá *et al.* 2011, entire) and infection may be more common in the zoological collections than traditionally thought. Partners in Georgia and Florida are currently expanding surveys to research the occurrence of *C. serpentis* in wild snake populations to better understand the distribution and prevalence of this disease in the wild.

To reduce the spread of disease, a handling protocol has been developed by the Service to decrease the risk of infectious disease transfer when multiple snakes are handled by researchers studying eastern indigo snakes. This protocol is provided to all Federal 10(a)(1)(A) recovery permits (USFWS 2016, entire).

4.5 Gopher Tortoise Populations

Across the species' range, eastern indigo snakes use gopher tortoise burrows for breeding, feeding, sheltering and nesting. In the northern part of their range, eastern indigo snakes depend on gopher tortoise burrows for winter shelter sites. Past declines in gopher tortoise populations are suspected to have negatively affected eastern indigo snake populations, especially in the northern areas of the snake's range (Enge *et al*. 2013). The practice of gassing, introducing gasoline into animal burrows, such as gopher tortoise burrows, to expel rattlesnakes, is usually fatal to tortoises, eastern indigo snakes and other commensal species (Speake 1978, Speake and McGlincy 1981). Gassing of gopher tortoise burrows, one of the factors for listing the eastern indigo snake as threatened under the ESA (USFWS 1978) is now illegal in both Florida and Georgia, but still occurs to some extent (e.g. Dozier 2010, p. 10). Although still a factor, it is unlikely that gassing is currently having a large negative impact on most eastern indigo snake populations (Enge *et al*. 2013). In the panhandle of Florida, it is suspected that eastern indigo snakes populations declined due to the impact of past human harvest of gopher tortoises for food (Enge *et al*. 2013, p. 289). Gopher tortoise populations have declined throughout much of their range due to human impacts from gassing and harvest, habitat conversion and habitat degradation. However, in an effort to reverse the decline of the gopher tortoise, conservation efforts are on-going to protect, manage and restore tortoise populations (see Conservation Efforts section 4.8 below) which will support conservation and recovery of the eastern indigo snake.

4.6 Collection

Collection of eastern indigo snakes from the wild for the pet trade was a primary reason for listing the species under the ESA. Furthermore, there was concern at the time of listing, that publicity from the listing of the eastern indigo snake would generate increased demand for this species, resulting in more collection from the wild. However, for activities that will contribute to the species' recovery by enhancing their survival such as propagation and educational animals, interstate commerce of captive eastern indigo snakes and other recovery actions are permitted under Section 10 the ESA. Although some unauthorized wild collection of eastern indigo snakes may still occasionally occur, it is thought to have negligible impacts on wild populations (Enge *et al*. 2013). However, the high price of adult eastern indigo snakes in pet trade may incentivize unauthorized activities associated with take and sale (e.g. adult snakes retail for $1,200). Some eastern indigo snakes from south Florida have especially extensive, bright red-orange pigment on their heads and necks (a condition found on some adult male snakes and termed "high-red" by herpetoculturists); snakes with this type of coloration are coveted by some breeders and hobbyists, making wild eastern indigo snakes from the south Florida region potentially attractive to some unauthorized collection. Wild collection remains a concern for the species, and still occurs to some extent (e.g. Roebuck 2014). Nevertheless, collection for commercial, recreational, scientific, or educational purposes is not considered to be a significant threat to the species, at this time.

4.7 Other

Predation and Invasive Species

In captive populations, hatchlings do not all emerge at the same time (Alessandrini 2001). There may be periods as long as 2 weeks between the beginning of hatching of the first and last neonates of a single clutch. During this period of time, the odors present at the initiation of the hatching process could attract predators such as fire ants (*Solenopsis*), skunks (*Mephitis*), coyotes (*Canis*), foxes (*Vulpes*), opossums (*Didelphis*), raccoons (*Procyon*), crows (*Corvus*), and even other snakes. Newberry *et al.* (2009, p. 97) reported evidence of depredation of eastern indigo snake eggs by a raccoon in a xeric sandhill near an active gopher tortoise burrow in southeast Georgia. Laboratory studies have demonstrated that red imported fire ants (*Solenopsis invicta*) can penetrate the eggs of another colubrid snake, the yellow rat snake [sic] (eastern ratsnake: *Pantherophis alleghaniensis*) (Diffie *et al.* 2010) and likely caused the mortality of eggs of the rough green snake (*Opheodrys aestivus)* in the wild (Conners 1998). It is likely that eggs of the eastern indigo snakes can be penetrated, damaged and/or the embryos killed by fire ants. As a result, the red imported fire ant has the potential to be a factor in the decline of eastern indigo snake populations; however at present, we have no information on actual effects on populations.

Burmese pythons (*Python bivittatus*), native to Southeast Asia, are one of the largest snakes in the world. They have been introduced into southeast Florida, where they are rapidly expanding their range and becoming a serious concern for the greater south Florida ecosystem including areas such as Everglades National Park (Harvey *et al*. 2010, p.2, NPS 2016). Although the American alligator (*Alligator mississippiensis*) is the only reptile documented as Burmese python prey (Harvey *et al*. 2010, p.11), the python is a generalist predator and it may be possible that if it comes into contact with an eastern indigo snake in areas of habitat overlap; for example, along canal levees in south Florida, eastern indigo snakes may be taken as prey, but there is no evidence that this has occurred. Conversely, American alligators are also known to kill pythons and recently, an eastern indigo snake was documented to have preyed upon a hatchling python in Collier County, FL (Andreadis *et al.* 2018, pp. 341-342). However, predator-prey interactions with pythons and population effects are not well-understood. Burmese pythons also represent a competitive threat in these areas due to their broad dietary preferences (Reed 2005, p. 763). Burmese pythons are known to carry novel pathogens and parasites that have been documented to spillover to native snakes in Florida (Miller *et al.* 2017, entire). Due to the eastern indigo snake's frequent movement and large home ranges, they may have increased exposure to encounter Burmese pythons and their exotic pathogens (Reed 2005, p.761).

Increasing human population growth will also increase predation from direct mortality by people and their domestic animals (see section 4.2). Although disease and predation are negative factors faced by eastern indigo snakes, the effects on populations are not well understood. Further investigation is needed to determine the significance of these factors.

Pesticides

Because the eastern indigo snake is an apex predator, pesticides that bioaccumulate through the food chain may present a potential hazard (Lawler 1977). For example, secondary exposure to rodenticides used to control black rats may result in mortality to eastern indigo snakes in developed areas (Speake 1993). Although Knafo e*t al.* (2016) found that organochlorine pesticides and their by-products were all below detection limits in their eastern indigo snake blood samples, Lawler (1977) examined body fat where high accumulation of these compounds were detected. Both blood and fat samples may be needed to more accurately document variable levels of OC exposure (Rainwater 2005). Herbicides used on crops or for silviculture may have negative effects on eastern indigo snake populations (Speake 1993).

4.8 Conservation Efforts

4.8.1 Existing Regulatory Mechanisms

Endangered Species Act (ESA***)***

Since the listing of the eastern indigo snake in 1978, the Service has entered into many formal and informal consultations with other Federal agencies pursuant to section 7(a)(2) of the ESA. Examples include interagency consultations on proposed housing developments, golf courses, and roads that involve wetland fill, timber harvest activities, military activities, and other activities within the current and historic range of the species. Federal agencies involved in these consultations with the Service have included the Federal Highway Administration, U.S. Forest Service, Department of Defense and Army Corps of Engineers. These consultations resulted in measures to avoid or reduce impacts to eastern indigo snakes, including upland habitat acquisition and preservation by Federal agencies. In addition, section 7(a)(1) of the ESA requires that Federal agencies use their authorities to further the conservation of listed species.

Under section 10(a)(1), permits may also be issued to non-federal entities. Section 10(a)(1)(A) permits may be issued for scientific purposes or for other purposes that enhance the survival and recovery of the species (e.g. captive propagation, see Conservation Efforts section 4.8). For development projects that do not have a federal nexus (addressed under Section 7 of the ESA), but may cause incidental take of the eastern indigo snake, under section 10(a)(1)(B), an incidental take permit may be issued provided the applicant submits a Habitat Conservation Plan (HCP) that specifies the impact of the taking, minimization and mitigation measures, alternatives to the taking, adequate funding for the plan, and that the taking will not appreciably reduce the likelihood of the survival and recovery of the species in the wild. HCPs for eastern indigo snakes have been developed for several types of projects such as commercial and residential development, and timber and mining operations. There also is some interest in the development of eastern indigo snake HCPs for solar and agricultural developments. HCPs provide the applicant legal coverage under the ESA should take occur of a listed species, however the decision to develop an HCP is voluntary and there are likely developments impacting eastern indigo snakes that are unaccounted for.

State Protections

Each state within the historical range of the eastern indigo snake provides some protection for the species. In Alabama, the eastern indigo snake is listed as endangered and is a nongame species protected by regulation (Alabama Department of Conservation and Natural Resources (ADCNR) 2018); in Florida and Georgia it is listed as threatened (FWC 2017, Georgia Department of Natural Resources (GDNR) 2018), and in Mississippi as endangered (Mississippi Natural Heritage Program 2015). The protections provided by each state vary. However, most state laws focus on prohibitions against taking eastern indigo snakes from the wild and possessing, killing, exporting, or selling them, although Georgia regulations protect the habitat of listed species on public land (GDNR 2018).

Other Considerations

There are few existing regulatory mechanisms for the protection of the upland habitats where eastern indigo snakes spend much of their lives. The National Forest Management Act requires the U.S. Forest Service (Forest Service) to manage habitats to provide the ecological conditions that contribute to the conservation of species. Development and implementation of additional provisions that would contribute to the conservation of specific species are included in Forest Management Plans for individual states. Forests within the range of the eastern indigo snake include provisions for prescribed burning and habitat management that benefit the eastern indigo snake. However, because multiple-use is the guiding principal on most public land, protection of the eastern indigo snake may be one of many management goals including timber production, and military and recreational use.

Section 404 of the Clean Water Act is the primary Federal law that has the potential to provide some protection for the wetland sites on private land which are occupied seasonally by eastern indigo snakes. The success of protecting eastern indigo habitat by implementing this regulation is unknown.

4.8.2 Federal Lands Agency Conservation Measures

Under section 7(a)(1) of the ESA Federal agencies are required to use their authorities to further the conservation of listed species. The Service, the Forest Service and the Department of Defense all play important roles in recovery efforts for the eastern indigo snake.

Fish and Wildlife Service (Service)

Because most species spend at least part of their lifecycle on non-federal lands, the Service implements conservation tools and programs that aid in the conservation of listed and at-risk species, including the eastern indigo snake, on non-federal lands. The Cooperative Endangered Species Conservation Fund (aka. Section 6 Grants) is a tool that provides grants to states to participate in a wide array conservation projects for listed species and species identified in State Wildlife Action Plans, which include the eastern indigo snake. These grants are State Wildlife Conservation Grants, Recovery Land Acquisition Grants, Habitat Conservation Planning Assistance and Land Acquisition Grants. Additionally conservation programs such as the Safe Harbor Program and Partners for Fish and Wildlife Program provide resources and financial assistance to private landowners to further conserve wildlife and their habitat. To date more than 100 Partners for Fish and Wildlife Project have been implemented across Alabama, Florida and Georgia that potentially benefit the eastern indigo snake

Several National Wildlife Refuges (NWR) (e.g. Okefenokee NWR, Merritt Island NWR, Chassahowitzka NWR) provide important habitat for eastern indigo snake populations. Much of the prescribed burning and mechanical upland habitat restoration conducted NWRs have benefited the eastern indigo snake and made significant contributions to the survival and recovery of the species. Habitat improvements, including ecosystem restoration, enhancement, and protection, also support eastern indigo snake recovery.

Forest Service

National Forests in Alabama, Florida and Mississippi within the range of the eastern indigo snake have active prescribed burning programs for longleaf pine. This habitat management supports recovery efforts for the species. A multi-agency effort is occurring on the Conecuh National Forest to repatriate the eastern indigo snake to southern Alabama, as discussed below. The Forest Service has coordinated on this project with ADCNR, GDNR, Auburn University, The Orianne Society, Zoo Atlanta, Fort Stewart Military Reservation, and the Service (ADCNR 2014).

Department of Defense

As part of implementation of the Sikes Act 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. Those written for installations where the eastern indigo snake occurs include specific guidelines for conservation of the species. Eastern indigo snakes are known from at least seven military installations; 3 in Florida (Avon Park Air Force Range, Camp Blanding Military Reservation and Eglin Air Force Base [historical]) and 4 in Georgia (Fort Stewart Military Reservation, Kings Bay Navy Base, Moody Air Force Base [historical], and Townsend Bombing Range). An active prescribed burning program is implemented on these military installations to manage for longleaf pine ecosystems which benefits conservation and recovery of the eastern indigo snake. Many installations include specific eastern indigo snake habitat and population management prescriptions and goals within their INRMPs. In southeastern Georgia, research and management efforts have been on-going at the Fort Stewart Military Reservation where several populations of eastern indigo snakes are protected. In addition, ongoing environmental awareness training programs for soldiers include instruction on identification and protection of eastern indigo snakes. The Department of Defense's (DoD) Readiness and Environmental Protection Integration (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 additional eastern indigo snake habitat in Georgia and Florida.

4.8.3 State Wildlife Agency Conservation Measures

Alabama, Florida, and Georgia wildlife agencies, often in coordination with the Service, have conducted surveys, longleaf pine ecosystem restoration projects, land acquisition, prescribed burning, and other activities to benefit the recovery of the eastern indigo snake on state and private lands. Specifically, GDNR is conducting annual mark-recapture monitoring across the eastern indigo snake range in Georgia. The program to repatriate eastern indigo snakes to Alabama and Florida (discussed below) was initiated by the ADCNR and the Florida Fish and Wildlife Conservation Commission (FWC) and supported by GDNR. The work of GDNR nongame staff resulted in the conversion in 2012 of an annual rattlesnake "roundup", within the range of the eastern indigo snake, to a snake-friendly and education-oriented "festival" event with a focus on environmental education. This roundup, where, historically, rattlesnakes were ultimately killed (there is one remaining roundup within the range of the eastern indigo snake in Whigham, GA (Adkins 2017)), has changed to a festival where snakes of many species, including eastern indigo snakes, are displayed and information related to snake ecology and conservation is disseminated.

Initial efforts to create an eastern indigo snake habitat model for the state of Florida were made by Cox and Kautz (2000). The FWC has built on that effort by creating a revised potential habitat map for this species in Florida based on soil type, habitat fragment size, and other habitat characteristics as well as revising the Florida GAP (Gap Analysis Project) analysis of gopher tortoise habitat, since eastern indigo snakes rely on gopher tortoise burrows when available (Bock and Enge 2014). GDNR has put together a similar habitat model for the eastern indigo snake in Georgia (Elliott 2009). A team of federal, state and other partners led by the Georgia Cooperative Fish and Wildlife Research Unit at the University of Georgia has developed a draft habitat suitability model for gopher tortoises across its range (Crawford and Maerz, 2017, entire). This gopher tortoise suitability map helps to highlight potential areas for eastern indigo snake suitability in the northern portion of its range. The data developed through these projects provide useful information on sites likely to support eastern indigo snake populations.

The state of Florida has protected more than 2.4 million ac (1.2 million ha) through its Preservation 2000 and Florida Forever programs (FDEP 2016). In 1998, Florida voters amended the state constitution by ratifying a constitutional amendment that reauthorized bonds for land acquisition. The Florida Forever Act, implemented in 2000, reinforced Florida's commitment to acquire and conserve natural and cultural habitats and better manage these lands. This legislation benefits the recovery of the eastern indigo snake. In section 5.5 of this report we estimate the amount of occupied eastern indigo snake habitat that occurs on protected lands.

In 2012, the FWC updated their Gopher Tortoise Management Plan for the state of Florida (FWC 2012). The overarching conservation goal of this management plan is no net loss of gopher tortoises from the time of plan approval in 2012 through 2022. Objectives of the plan include: minimizing the loss of gopher tortoises; increasing and improving gopher tortoise habitat; enhancing and restoring gopher tortoise populations where the species no longer occurs or has been severely depleted on protected, suitable lands; and maintaining the gopher tortoise's function as a keystone species. Eastern indigo snakes in Florida should benefit from these actions taken on behalf of the gopher tortoise. In addition, the plan proposes gopher tortoise burrow commensal conservation actions, which if implemented, would support conservation and recovery of the eastern indigo snake.

4.8.4 Conservation Efforts by Private Organizations and Multi-organizational Cooperation

The Orianne Society

The Orianne Society (Orianne) is a non-profit wildlife conservation organization founded in 2008 to help conserve the eastern indigo snake through research, environmental education, land acquisition, and habitat management. At their field preserve (Orianne Indigo Snake Preserve), along the Ocmulgee River in Telfair County, Georgia, eastern indigo snake and gopher tortoise studies are on-going, including population monitoring. Habitat management activities conducted by Orianne place an emphasis on the use of prescribed fire to maintain or restore native longleaf pine–wiregrass sandhill communities.

In coordination with State and Federal agencies, Orianne has studied the distribution of the eastern indigo snake (Enge *et al*. 2013) and tested eastern indigo snake survey methods including the use of a specially-trained wildlife detector dog (Stevenson *et al*. 2010b). Orianne has also conducted research on the diet, nutrition (Stevenson *et al*. 2010b, Knafo *et al.* 2016), and survival and population growth (Hyslop *et al*. 2011). Current research efforts address eastern indigo snake thermal ecology, spatial ecology, home range size and habitat use and population viability in south-central Florida (Bauder *et al.* 2016a, b, Bauder *et al*. 2018, entire, Bauder 2018), conservation genetics (both in south Florida and in Georgia) (Spear 2013, Folt *et al*. 2019), and factors influencing occupancy and detection rates in the Altamaha River Drainage of southern Georgia. The goal of the latter study is to determine population trends in the Altamaha drainage, a stronghold for the eastern indigo snake. Orianne continues to take a leading role in supporting eastern indigo snake conservation and recovery. Many more publications will be forthcoming from projects in which they are participating.

The Central Florida Zoo's Orianne Center for Indigo Conservation (OCIC)

The OCIC is located near Eustis, Florida. The OCIC coordinates the species survival plan (SSP), maintains the Association of Zoos and Aquariums (AZA) eastern indigo snake regional studbook and is the premier center for captive propagation of eastern indigo snakes. The OCIC propagates eastern indigo snakes for both the SSP and the species Recovery Plan's repatriation projects. The OCIC is a modern breeding facility with state-of-the-art health care center, herpetarium, outdoor enclosures and quarantine. The OCIC was built and first launched by Orianne, but in 2013 operations were transferred to the Central Florida Zoo. The OCIC continues to work in partnership with Orianne and many other federal, state, and private partners to support the repatriation projects. The OCIC currently co-chairs with Orianne the Eastern Indigo Snake Reintroduction Committee (EISRC), which provides guidance on the captive propagation and repatriation program.

Eastern Indigo Snake Captive Propagation and Repatriation Program

Natural recolonization of eastern indigo snakes into portions of their former range would be difficult despite their ability to move relatively long distances. Exposure to negative influencing factors inherent in fragmented habitats (e.g. road mortality, predation, intentional human persecution etc.) make natural modes of population expansion challenging. Therefore, as part of the species Recovery Plan (USFWS 1982), the development and implementation of a scientifically-designed repatriation program for eastern indigo snakes is underway. Repatriation sites are selected by the EISRC based on specific site criteria.

In 2010, in order to meet the goals of the Eastern Indigo Snake Captive Propagation and Reintroduction Plan, the OCIC, was purchased by Orianne. This facility was expanded upon to become the premier captive propagation center for the eastern indigo snake reintroduction project. In 2014, the Orianne Society partnered with the Central Florida Zoo to operate and manage the OCIC. The Central Florida Zoo has financially supported the OCIC from 2014 to current, but is expanding partnerships and seeking additional support to achieve the recovery program objectives. Partners include the States of Florida, Alabama, and Georgia, Federal Agencies, Universities, Non-profits, Zoos and private consultants.

The OCIC currently houses over 200 eastern indigo snakes to assist with the repatriation of the species. There are two active repatriation sites; the Conecuh National Forest in southern Alabama, initiated in 2010 with 157 snakes released since summer 2018, and the Apalachicola Bluffs and Ravines Preserve in the central Florida Panhandle with 32 snakes released since 2017.

The goal is to release approximately 300 snakes at each site over the next 10+ years (about 30 snakes each year at each site for 10 years), with the possibility of adding new sites in Florida. In order to reach this goal, the OCIC continues to grow its captive stock to meet genetic diversity goals and works with other partners, such as Welaka National Fish Hatchery, Zoo Atlanta and Zoo Tampa at Lowry Park, to increase captive stock capacity.

Gopher Tortoise Conservation

In recent years many public and private partners have joined together in an effort to better understand the status of the gopher tortoise in the eastern portion of its range (in AL, FL, GA and SC) where it is considered a candidate for federal protection under the ESA. In 2008, a Candidate Conservation Agreement (CCA 2012) for the gopher tortoise was developed as a cooperative effort among state, federal, non-governmental and private organizations to proactively implement conservation measures for the species. Partners are implementing critical conservation to protect the species from declining to a level where federal protection under the ESA is warranted. This public-private partnership is focused on land protection and management strategies that will permanently protect gopher tortoise populations across the eastern portion of its range. Gopher tortoise populations are also being restored and augmented (e.g. Eglin Air Force Base in the Panhandle of Florida) through translocation and captive propagation programs. Land protection, via a multi-partnership effort (The Nature Conservancy, Orianne, the Conservation Fund, the state of Georgia and others) to protect the tortoise in Georgia, has been accelerated as part of Georgia's gopher tortoise conservation initiative which has a goal to permanently protect 65 gopher tortoise populations. Many of the newly protected lands have significant conservation value for the eastern indigo snake. On-going efforts to conserve the gopher tortoise will help conserve the longleaf pine ecosystem and have lasting conservation benefits to hundreds of species, including the eastern indigo snake across much of its range.

America's Longleaf Restoration Initiative

This collaborative effort among many public and private sector partners actively supports range-wide efforts to restore and conserve longleaf pine ecosystems, with a goal to increase longleaf from 3.4 to 8.0 million ac (ALRI 2018). These efforts are focused within 16 "significant landscapes." Within these significant landscapes Local Implementation Teams (LITs) are leading conservation efforts by coordinating partners, developing priorities, and fundraising to implement on-the-ground conservation. Five LITs are working within the range of the eastern indigo snake, the Gulf Coastal Plain Ecosystem Partnership, Apalachicola Regional Stewardship Alliance, Fort Stewart/Altamaha Longleaf Pine Restoration Partnership, Okefenokee-Osceola Partnership and the Ocala Local Implementation Team. Each of these LITs has components of their conservation plans that support eastern indigo snake recovery. For example, both the Gulf Coastal Plain Ecosystem Partnership and Apalachicola Regional Stewardship Alliance help restore longleaf habitat and support the ongoing eastern indigo snake repatriation efforts at Conecuh National Forest and the Apalachicola Bluffs and Ravines Preserve, respectively. The other LITs play important roles in habitat restoration, management and monitoring.

<u>Outreach and Education</u>
Improving the public attitude and behavior towards the eastern indigo snake is a priority recovery action. Direct mortality by humans, especially by vehicular strikes, is a significant factor affecting to eastern indigo snakes. Many partners across the species' range are working to educate the public and improve public attitude by hosting events, giving presentations and inviting the public to learn about the species and its habitat *in situ*. The state wildlife agencies, federal agencies, non-profits (e.g. Orianne and OCIC), zoos and other partnerships (e.g. Gopher Tortoise Council Upland Snake Conservation Initiative) play important roles in public education and outreach.

4.9 Summary of Factors Influencing the Eastern Indigo Snake

The best available information suggests that of the past, current and future influences on what the eastern indigo snake needs for long term viability the largest negative factors affecting viability of the species currently and into the future are habitat modification and destruction due to land use changes, especially urbanization, and sea level rise. Urbanization includes a variety of impacts which remove or fragment available habitat or impact snakes directly including: residential and commercial development, road construction and expansion, direct mortality, invasive species, predation and inadequate fire management. Habitat loss for coastal populations due to sea level rise from climate change is also an increasing risk.

The cooperation of many partners to implement conservation efforts can help mitigate the negative factors and positively influence long-term viability of the species. To accelerate recovery, repatriation of eastern indigo snake populations in areas of extirpation is underway. Since listing under the ESA, wild collection of eastern indigo snakes for the pet trade is no longer believed to be a significant threat. Land conservation has increased in some areas, especially where there are on-going efforts to conserve gopher tortoise populations. These conservation efforts have diminished the threat of gassing gopher tortoise burrows, and will have lasting conservation benefits for the eastern indigo snake across much of its range.

CHAPTER 5 – CURRENT CONDITIONS

5.1 Methodology - Analytical Units

To assess the biological status of the eastern indigo snake across the species' range, we used the best available information, including peer reviewed scientific literature, academic reports, professional judgement from eastern indigo snake and other experts, and occurrence data provided by State agencies, the Service, and conservation organizations to inform our analyses.

Methodology differs among surveys and studies, but ultimately provides information that allows for assessment of population factors.

It is difficult to delineate biological populations of the eastern indigo snake across its range due to the snake's large home ranges, secretive behavior, low densities, and other challenges associated with identifying population boundaries. However, over the past decade, progress has been made via research and monitoring efforts to better understand the needs of eastern indigo snakes. We have element occurrence (EOs) data collected over time (a few very early 1800's records, but mostly between the years 1936-2017). These EOs, hereafter called records, are documented as geographic coordinates (latitude, longitude) that can be displayed in a GIS and represent unique observations of eastern indigo snakes at specific locations on specific dates in time. Range-wide species occurrence data used in this analysis is from Enge *et al.* (2013, entire), which includes records up to the year 2012. These records were composed of Type I and Type II records. Type I records were supported by voucher specimens or photographs, published in the literature, or had been verified by one of the authors. Type II records were not substantiated with a specimens or photograph but were reported by biologists or other qualified individuals deemed credible by the authors (Enge *et al.* 2013, p. 290). Occurrence records from 2013 to 2017 were obtained directly from State Natural Heritage Programs, State Biologists and conservation organizations in Florida and Georgia. It is important to note that records are not evenly distributed across the range. The number of records varies across the range with some areas having many records from research and monitoring efforts to other areas having no, or few, records which could represent lower densities of snakes or the area is under-surveyed. In addition, records may represent the same individual snake documented at multiple points in time. Numerous records are from observations on roads (dead or alive).

In addition to the eastern indigo snake records, there is an expanding body of research describing eastern indigo snake home range size (Appendix A), movements and relationships to landscape condition (see section 2.5). Based on this available information we define populations for the eastern indigo snake as described below.

Populations are the basic analytical unit on which resiliency is assessed. For this assessment we delineated populations for the eastern indigo snake by using the location of a record buffered by the snake's estimated maximum home range width (i.e. maximum annual linear distance movement). Home range shape and width are irregular and respond to landscape condition and presence of other eastern indigo snakes (Bauder *et al.* 2016a,b, Bauder *et al*. 2018). Home range area and movement distances are also known to vary latitudinally across the eastern indigo snake's range due to climatic differences (Appendix A). In the northern portion of the range (Southeast Georgia, North Florida and the Panhandle) home ranges and movement distances (Table 1) are larger due to the species' migration-like movements between summer and winter habitats where eastern indigo snakes depend on gopher tortoise burrows for overwintering shelter compared to populations in the southern portion of the range (Peninsular Florida) where dependence is less.

For this SSA we defined the extent of the eastern indigo snake populations across the entire range by buffering all records by 5 mi (8 km). Five miles was found to be the approximate maximum annual linear movement distance for eastern indigo snakes in Georgia (Table 1), where the species is believed to move the longest distances. Five miles is twice the approximate maximum annual linear movement distance documented in Peninsular Florida (Table 1). A population has the *potential* to occur where at least two eastern indigo snake records occur within 5 mi of each other. A similar approach was used to define "populations" for the black pine snake (USFWS 2015). Overlapping buffer areas were merged and assumed to represent the potential maximum extent of populations used in this assessment. Using maximum extent aims to capture the majority of the area potentially used by an individual but also over-estimates the actual area used, or occupied, by that individual. An example of how populations were delineated is provided in Figure 20. Figure 21 depicts delineation of all the eastern indigo snake populations assessed in this report.

Table 1. Linear movement distances for eastern indigo snakes.

Maximum annual linear movements within home ranges (i.e. maximum home range widths)	Linear Distance
Represents "northern" eastern indigo snake populations: Hyslop *et al*. (2014, p.105) (excludes long-range (extreme) movements) Bryan and Liberty Counties Georgia, Fort Stewart area).	5.0 mi (8 km)
Represents "southern" eastern indigo snake populations: Bauder *et al*. (2018, p. 747) 95^{th} quartile of movement data in peninsular Florida (Highlands, Brevard, Polk Counties).	2.4 mi (3.86 km)

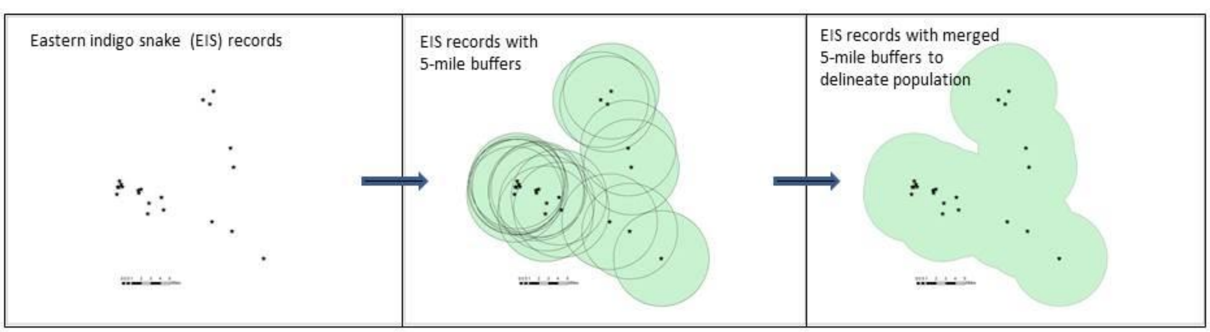


Figure 20: Example of delineation of an eastern indigo snake population

The following rationale and assumptions were made when defining populations (see Appendix B for additional explanation.

1. Home range size vs linear movement: Although we have good estimates of home range size for eastern indigo snakes, application of the home range area as a circle could exclude significant areas used by eastern indigo snakes due to variation in home range widths and shapes. Alternatively, we buffered records by maximum annual linear movement distance to estimate the potential maximum extent of the home range for a given record (see Appendix B, Figure B1 for illustration). This approach is inclusive and captures all the area possibly used by the eastern indigo snake responsible for a given record and therefore represents its biological potential to move in a given area.

2. Five-mile buffer distance: While northern populations generally have larger home ranges and move longer distances it is assumed that southern populations (Peninsular Florida) could also move 5 miles (one male in central Florida was documented to travel about 4.3 mi (7 km) (Breininger and Bolt unpublished data). In addition, snakes may move longer distances than documented because long-distance movements are harder to detect. Missing snakes have been reported from radio-telemetry studies (e.g. Hyslop 2007, Godwin and Steen 2011, Breininger *et al.* 2011) which may be due to snakes moving outside study areas.

3. Demographic connectivity: We assume that eastern indigo snakes that are within 5 mi of each other have increased probability of population persistence (re-colonization of sites after a stochastic event or local extirpation) resulting from periodic addition of immigrants from sources to sinks (Carlson *et al*. 2014, p. 521) within the populations defined in this assessment (e.g. immigrants from an area with good quality habitat into an area adjacent to (sub)urban development). Dispersal of individuals over longer (greater than 5 mi) distances is rare but is important for population connectivity (i.e. genetic connectivity at a wider scale than within-population demographic connectivity).

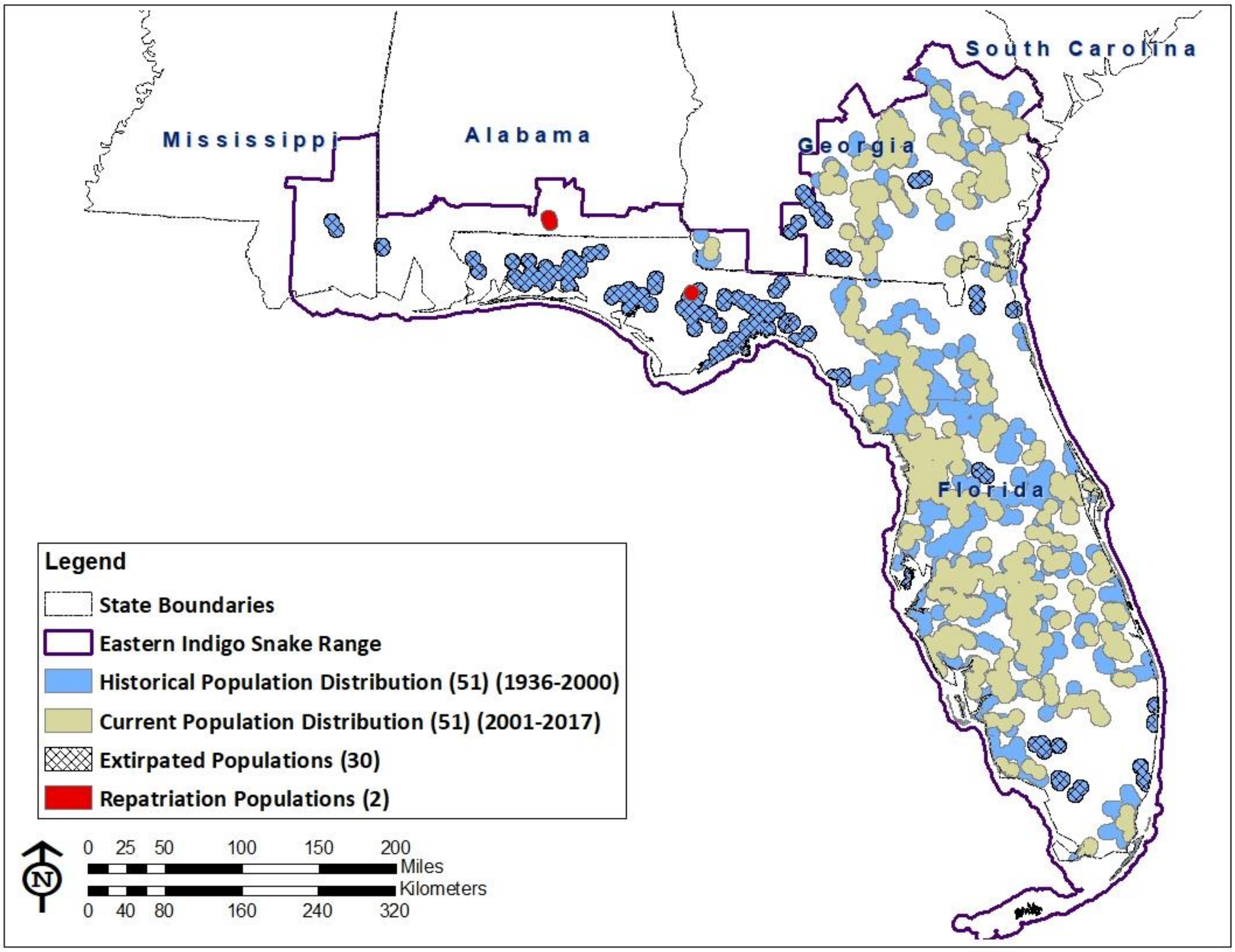


Figure 21: Historical and current distribution and extent of eastern indigo snake populations.

To examine the persistence over time in extent and number of populations, we buffered all records (years 1936-2017) to estimate the historical population distribution. Next, we buffered only those records from 2001-2017 to estimate the distribution of current populations, similar to Enge *et al*. (entire, 2013). Due to poor species detectability and uneven survey and monitoring data, the number of records varies across the range with some areas having more records from research and monitoring efforts to other areas having no or few records which could represent lower numbers of snakes or that the area is under-surveyed. For both historical and current populations we only included populations that had two or more records within 5 mi of each other. Forty-one (41) and 15 single record populations were excluded from the analysis for historical and current populations, respectively. This delineation resulted in 51 historical populations and 53 current populations, including 2 repatriated populations (Figure 21). However, the current populations represent a decrease in the overall distribution of historical populations due to fragmentation of the larger historical populations into multiple smaller populations (now 53 current populations within 21 of the historical populations), and the extirpation of 30 of the historical populations. The average extent (or area) of the historical population distribution was 471,778 ac (190,921 ha) while the average extent of the current population distribution is 237,836 ac (92,248 ha). The 53 current and the 30 extirpated populations represent the total number of populations (83) considered in the population resiliency analysis. See the Representation section 5.3 below for more discussion regarding historical and current populations.

5.2 Resiliency

We use potential populations (hereafter populations) as described above as our analytical unit and describe population and habitat factors that influence the resiliency of each population. While there are multiple population and habitat factors that can affect resiliency, we focused on the most significant factors that influence eastern indigo snake populations and for which we have sufficient data. To summarize the overall current conditions of eastern indigo snake populations, we sorted them into five categories (high, medium, low, very low and extirpated) based on the population factors and habitat elements described below and summarized in Table 2. Populations presumed to be extirpated are included to portray the difference between the historical and current condition of the species. The current condition category is an estimate based on the analysis of two population factors (population extent and population connectivity) and six habitat factors reflecting habitat quantity and quality (habitat amount, habitat type, habitat fragmentation, shelter site availability, tertiary road density and percent urbanized). Population and habitat factors assessed in this report are summarized below. Additional detail and methodology for estimating each population and habitat factor are provided in Appendix B, and results for each population are summarized in Table B3 (in Appendix B).

5.2.1 Population Factors that Influence Resiliency

Demographic data provide a basis for understanding the ecology of a species. We have gained important information on the species' demography from multiple radiotelemetry studies (Speake *et al.* 1978, Moler 1985b, Smith 1987, Breininger *et al.* 2004, Dodd and Barichivich 2007, Hyslop 2007, Hyslop *et al*. 2009a, Jackson 2013, Metcalf 2017, Bauder *et al.* 2018), mark-recapture efforts (Layne and Steiner 1996; Stevenson *et al.* 2003, Stevenson *et al.* 2009, Hyslop *et al.* 2012, Jenkins 2017) and visual encounter surveys and road-cruising (Godley and Moler 2013), however little is known regarding demographic parameters and population trends. This is primarily because of the difficulties in obtaining adequate sample sizes (Hyslop *et al.* 2012, p.146). Occupancy surveys are being implemented in portions of the snake's range (Bauder *et al.* 2017, entire); however, data are still very limited for estimating population attributes, such as density, abundance and recruitment. Therefore, we limited our assessment of population factors affecting resiliency to total population extent using the population definition above and connectivity among those populations.

Population Extent estimates the maximum extent of an area potentially used by a population. Population extent was calculated using the 5-mi buffer rule described in section 5.1. Using maximum extent aims to capture the majority of the area potentially used by population but also over-estimates the actual area used because it includes both eastern indigo snake habitat and non-habitat areas. Although some species may expand their home range when habitat quality declines (Van Horne 1983, entire), studies on eastern indigo snakes found that home ranges in urban and fragmented landscapes were significantly smaller than those snakes in more natural landscapes (Breininger *et al.* 2011, entire, Bauder *et al.* 2018, p. 755). Although home ranges of eastern indigo snakes tracked in Georgia showed some degree of overlap (Hyslop *et al*. 2014, p.106), same-sex home range overlap was reported to be generally very low in Peninsular Florida (Bauder *et al*. 2016a). Therefore, we assume there is increased potential for more individuals to interact within larger population extents and therefore resiliency increases.

Population Connectivity- For the eastern indigo snake to persist as isolated populations within a previously more extensive and connected range, the degree of genetic exchange between populations is critical to reduce the risk of extinction from inbreeding and reduced capacity for evolutionary adaptation (Carlson *et al.* 2014, p. 523). A lack of periodic gene flow between populations can exacerbate impacts of various stressors and reduce the frequency of adaptive alleles. Dispersal of individual eastern indigo snakes over long distances (greater than 5 mi) is not well-known and considered rare; however, an adult male in Georgia was recaptured over 13.5 mi (22 km) linear distance from its original capture location (Stevenson and Hyslop 2010, entire).

Population connectivity (or genetic connectivity) is defined here as the ability for an individual snake from one population to periodically disperse to another population. Populations, as described above, are represented by two or more eastern indigo snake records that are within 5 mi of each other and are potentially demographically connected. Connectivity between populations requires suitable habitat, unfragmented by roads and, shorter and wider corridors than those needed for more vagile animals (Breininger *et al.* 2012, p. 366) to allow for long distance dispersal, resulting in the maintenance of gene flow across the range and long-term persistence. The population connectivity distance for this assessment is represented by a 10-mile (16 km) buffer around eastern indigo snake records (5-mile buffer from record to delineate the population plus an additional 5-mile buffer to assess connectivity among populations). When 10-mile buffers overlapped, populations were considered connected if habitat was present and was not bisected by primary or secondary roads. See Appendix B, Figure B2 for illustration.

5.2.2 Habitat Factors that Influence Resiliency

Due to the difficulties of observing and capturing eastern indigo snakes, even where they are known to occur, the viability of populations is difficult to directly measure. However, research on eastern indigo snake populations has provided important information regarding the species' response to habitat conditions. Therefore, we consider six habitat factors reflecting both habitat quantity and quality that influence the resilience of eastern indigo snake populations. These habitat factors are summarized below and additional detail is provided in Appendix B.

Habitat Quantity- A GIS model was generated for the eastern indigo snake (Appendix C) to assess the current range-wide status of habitat availability and quality. The model identified 39.6 million acres (16.0 million ha) of potential habitat within the known range of the species;

however only 16% of this area is within the known extent of eastern indigo snake populations (Figure 22). The potential habitat within the current population extent of eastern indigo snakes (identified by buffering records by 5 mi as described in section 5.1) is estimated at 6.4 million ac (2.7 million ha). Habitat patches were categorized as primary, secondary and tertiary habitat. Primary habitat identifies the characteristic natural upland habitats preferred by eastern indigo snakes across most of its range. Secondary habitats include other natural habitats, including lowlands, often important for foraging. Tertiary habitats include human-altered landscapes (e.g. pasture, citrus orchards) that may also support critical resource needs. For a complete description of the model methodology refer to Appendix C. Because we know eastern indigo snakes have relatively large home ranges and conspecific overlap of eastern indigo snakes is generally low, it is assumed that habitat quantity requirements are relatively large. Therefore we assessed the total amount of habitat (primary + secondary + tertiary) for each population.

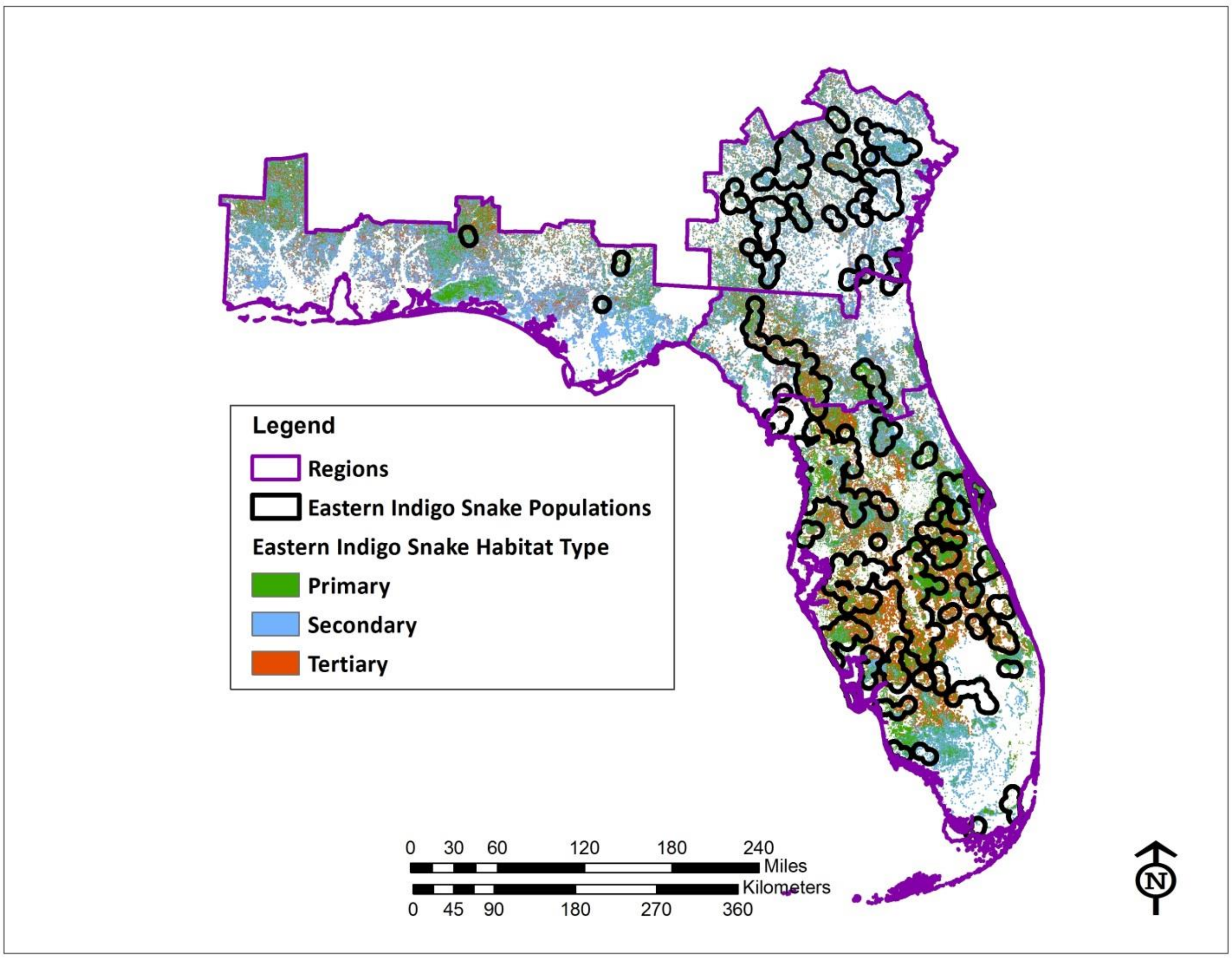


Figure 22: Distribution of eastern indigo snake habitat types generated by the Eastern Indigo Snake Habitat Model (Appendix C). Only 16% (6.4 million ac of 39.6 million ac) of the potential habitat identified by the model is within the current extent of eastern indigo snake populations.

Habitat Quality describes the level of fragmentation, density of tertiary roads, percent of the population extent that is urbanized, presence of shelter (*i.e*. gopher tortoise presence) and percent of total habitat that is considered primary and secondary (habitat type).

Habitat Fragmentation (within population): Using the Eastern Indigo Snake Habitat Model (Appendix C), fragmentation was assessed by calculating the area of habitat patches of different sizes for each population. Habitat patches for this assessment could contain all three types of habitat (primary, secondary and tertiary). Breaks in habitat patches reflect significant breaks in habitat connectivity or non-habitat between patches and often were due to primary or secondary roads, major water bodies and other areas of non-habitat. It has been suggested that eastern indigo snake populations that occur on lands with multiple habitat patches of at least 2,500 ac (1,000 ha) (i.e. >5,000 ac) may have the best chance of long-term viability (Moler 1992). However, high urban edge to habitat area (e.g. habitat edges created by roads or human-altered habitats) has greater extinction risk (Breininger *et al*. 2004, 2011, and 2012, entire). A recent study suggested 2,500 ac is too small to support even a single pair of eastern indigo snakes and suggested about 12,000 – 22,000 ac (5,000 – 9,000 ha) of unfragmented habitat is needed to sustain eastern indigo populations in central Florida (Bauder 2018, p. 160). A modeling study by Sytsma *et al.* (2012, pp. 39–40) estimated a reserve size of 10,000 ac (4,047 ha) to be sufficiently large to support a small population of eastern indigo snakes. However, Hyslop *et al.* (2014, p.109) reported that the collective extent of eastern indigo snakes studied around Fort Stewart in Southeast Georgia, where the snakes are believed to travel the farthest distance, was about 20,000 to 35,000 ac (8,000 to 14,000 ha). We used these suggestions from the literature to develop rules to classify the degree of habitat fragmentation for populations as shown in Table 2.

Tertiary Road Density: Primary and secondary roads are prominent features of urbanized areas and can contribute to isolation and fragmentation of eastern indigo snake populations because they often avoid these type of roads (Bauder *et al.* 2018, p.751), but they may eventually cross these road types when habitat patch sizes decrease and urban edge to habitat area ratio increases (Breininger *et al*. 2004, 2011, and 2012, entire). However, eastern indigo snakes have been found to readily cross tertiary roads subjecting individual snakes to road mortality which can contribute to population declines (Rothermel 2017, p. 22, Godley and Moler 2013, entire) and therefore large tracts of undeveloped land with low densities of tertiary roads is needed (Bauder *et al.* 2018, p. 759). Tertiary roads are paved roads, often characteristic of more rural areas, and generally did not contribute to breaks in habitat patches in the habitat model. Therefore, the density of tertiary roads (miles per 50,265 ac) (USGS 2017) for each population was assessed separately from fragmentation and urbanized area as a measure of habitat quality for each population.

Urbanized Area: Urbanization destroys and fragments habitat and increases direct mortality due to increased human contact. While eastern indigo snakes have been observed entering urban and suburban areas (Breininger *et al*. 2004, p.15), eastern indigo snakes generally avoid urbanized areas (Bauder *et al.* 2018, p.754). Urbanized area is assumed to be correlated with the habitat factors above. For instance, habitat quantity and shelter site availability is assumed to decrease with increasing urban area, and habitat fragmentation and tertiary road density is assumed to increase with increased urban area. However, factors such as direct mortality from increased human and predator interaction would also increase with increasing urban area. Therefore as an additional measure of habitat quality, we assessed percent urbanized area for each population using the base model (2010) of the SLEUTH (Slope, Land use, Excluded area, Urban area, Transportation, Hillside area) model (Terando *et al*. 2014, p. 2).

Shelter Sites (gopher tortoise): Eastern indigo snakes require shelter for protection from cold and hot temperatures throughout their range. In the northern part of the range eastern indigo snakes have a strong dependency on gopher tortoises and their burrows for dens during the winter. It is suspected that the decline of eastern indigo snakes in the northern portion of its range, especially in the Panhandle, is related to declines in gopher tortoises (Enge *et al*. 2013, p.289). In the southern part of the range eastern indigo snake may use other forms of shelter in addition to gopher tortoise burrows, although presence of gopher tortoises and their burrows typically represent good quality habitat and are therefore assessed as a component of habitat quality. We used the results of the 2018 Gopher Tortoise Candidate Conservation Agreement (CCA) report (CCA 2018) to assess presence of gopher tortoise populations for each eastern indigo snake population.

Habitat Type: We assessed the percent of total habitat that is considered primary and secondary as a measure of habitat quality. Eastern indigo snakes require diversity in habitat types to support essential life functions of breeding, feeding, sheltering and nesting. They depend on (in northern portion of range) or prefer (southern portion of range) upland habitat types as their primary habitat. In the northern portion of the range they are highly dependent on sandhills with gopher tortoise burrows for shelter during winter months. In central and south Florida the dependence on gopher tortoises is lower and they are known to use a variety of habitats and shelters, however, snakes continue to exhibit a strong preference to upland habitats (Bauder *et al*. 2018 pp. 754-755). Secondary habitat is also natural, but is generally hardwood, lowland and wetland dominated habitat types and is often used for foraging (feeding). It is believed that a combination of both primary and secondary habitat provides the best matrix of habitat types to support viable eastern indigo snake populations. Tertiary habitat represents potential foraging habitat, but include anthropogenic habitat such as citrus orchards and agricultural fields. Eastern indigo snakes are known to use these habitats, but generally prefer natural primary and secondary habitat (Bauder *et al.* 2018, p. 754). Tertiary habitat often has altered ecology and increased vulnerability to stressors (e.g. roads, predators, disease, human interaction, etc.) making these habitats of lower quality.

Table 2. Population and habitat factor definitions used to assess current condition resiliency classes for eastern indigo snake populations listed in Appendix B, Table B3. Each population was scored as High (4), Medium (3), Low (2) or Very Low (1) for each population and habitat factor. Rationale for condition categories for each factor is provided in Appendix B.

Condition Category (Score)	**POPULATION FACTORS**		**HABITAT FACTORS**					
				Habitat Quality				
	Population Extent	**Population Connectivity**	**Habitat Quantity**	**Fragmentation**	**Tertiary Road Density**	**Urban Area**	**Gopher Tortoise (Shelter)**	**Habitat Type**
High (4)	>300,000 acres	Population connected to 2 or more other populations	Total habitat >150K acres	50% of habitat is >20K acres patch size; or 75% is >10K acres patch size; or 90% >5K acres patch size	Density is <150 miles per 50,265 acres	<5% urban	1 or more Gopher Tortoise Populations per 50,265 acres	>90% of total habitat is primary or secondary habitat
Medium (3)	100,000-300,000 acres	Population connected to least 1 other population	Total habitat is 50-150K acres	25% of habitat is >20K acres patch size; or 50% is >10K acres patch size; or 75% >5K acres patch size	Density is between 150-250 miles per 50,265 acres	5-10% Urban	0.9 – 0.5 Gopher Tortoise Populations per 50,265 acres	70-90% of total habitat is primary or secondary habitat
Low (2)	<100,000 acres	Population within distance of at least 1 other population but fragmented by major road.	Total habitat is 20,000-49,999K acres	15% of habitat is >20K acres patch size; or 25% is >10K acres patch size; or 50% >5K acres patch size	Density is between 251-350 miles per 50,265 acres	11-30% urban	0.5 Gopher Tortoise Populations per 50,265 acres or some are within 2 miles	50-70% of total habitat is primary or secondary habitat
Very Low (1)	NA	Population not connected to another population	Total habitat is <20K acres	>50% of habitat is <5K acres patch size	Density is >350 miles per 50,265 acres	>30% urban	No Gopher Tortoise Populations	<50% of total habitat is primary or secondary habitat

5.2.3 Overall Resiliency Calculations

First, eastern indigo snake populations were assigned a score ("high" to "very low" represented by the numerical values of 4 to 1, respectively) for each population and habitat factor as described in Table 2 above. The population factors (population extent and connectivity) were considered equally important when estimating the combined population score, which was simply an arithmetic average of the two factors. To estimate the combined habitat score, habitat factors were given a baseline weight of 1 and then we adjusted the weights depending on their importance to eastern indigo snakes as documented in the literature. For northern populations gopher tortoise presence was given a weight of 2 because of the snake's apparent dependence on gopher tortoise burrows for winter shelter sites compared to southern populations which was given a weight of 1. Because eastern indigo snakes have large home ranges, habitat fragmentation may have significant negative impacts on long-term population viability. Therefore, habitat fragmentation was given a weight of 2 for both northern and southern populations. Additionally due to the impact of direct mortality from tertiary roads, this factor was weighted as 1.5 for both northern and southern populations. Percent urban is highly correlated with tertiary roads (Appendix B, Figure B3), but also represents additional negative factors such as direct mortality from increased human and predator interaction. Therefore percent urban was given a weight of 0.5, giving tertiary roads and percent urban a cumulative weight of 2. The remaining habitat factors, habitat quantity and type, were each given a baseline weight of 1. Table 3 summarizes the assigned weights for the habitat factors. A more detailed explanation for assigning weights to the habitat factors is provided in Appendix B.

Table 3: Summary of importance weights assigned to each population and habitat factor

POPULATION FACTORS		HABITAT FACTORS					
Population Extent	Population Connectivity	Habitat Quantity	Fragmentation	Tertiary Road Density	% Urban Area	Gopher Tortoise (Shelter)	Habitat Type
1	1	1	2	1.5	0.5	2 Northern Populations 1 Southern Populations	1

Next, using the scores and weights described above, we calculated a total population factor score and total habitat factor score for each eastern indigo snake population, which resulted in a continuous numerical value ranging between 1 and 4, and we assigned a condition class of High, Medium, Low or Very Low as described in Table 4.

Table 4. Resiliency condition classes assigned to total population factor score and total habitat factor score for each population.

Condition Class	High	Medium	Low	Very Low
Score Range (equal intervals)	3.26-4	2.56-3.25	1.76-2.55	1-1.75

Finally, we summarized overall current resiliency condition classes for each eastern indigo snake population by combining the total population and habitat condition classes (e.g. Population Condition Class = Medium and Habitat Condition Class = High, Overall Current Condition Class = Medium-High; or Population Condition Class = Medium and Habitat Condition Class = Low, Overall Current Condition Class = Medium-Low; or Population Condition Class = High and Habitat Condition Class = Low, Overall Current Condition Class = Medium). The intermediate condition classes (medium-high and medium-low) provide some insight to populations that are near the thresholds of the high condition class (medium-high) or medium condition class (medium-low), but are considered medium and low in overall condition, respectively. See Table B3 (in Appendix B) for calculations for each eastern indigo snake population. Figure 23 depicts each population and its estimated overall current resiliency condition class (see Appendix B, Table B3 for naming conventions for each population).

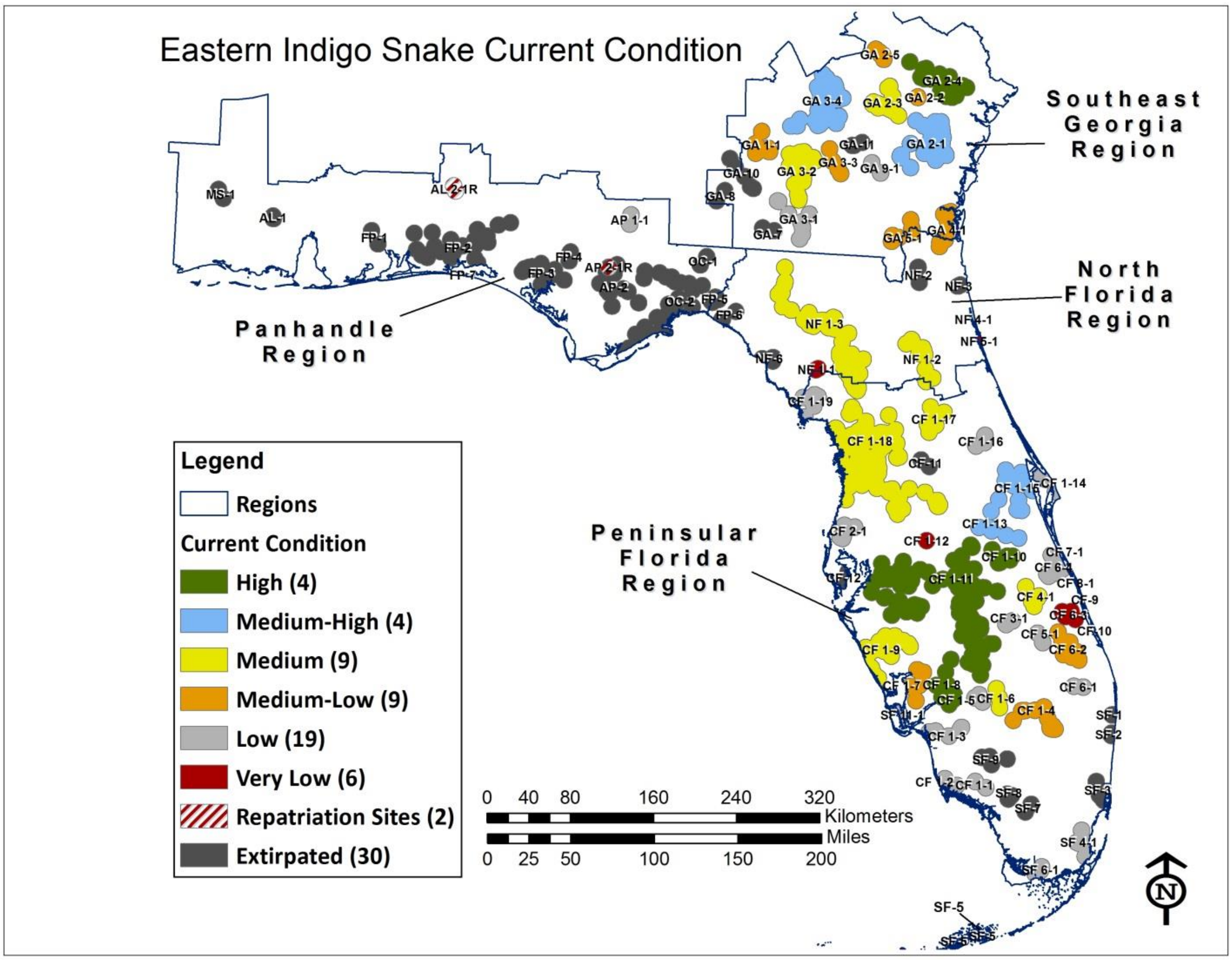


Figure 23: Distribution of eastern indigo snake populations and current resiliency condition classes

Current Condition Resiliency Summary:

Of the 83 populations assessed for current conditions, 36% are extirpated and 9% are in very low condition. Thirty-four percent (34%) are in low to medium-low condition, 16% are in medium to medium-high condition, and 5% are in high condition (Table 5).

The highly resilient populations are found in the central portion of the Peninsular Florida region (CF 1-11, CF 1-10 and CF 1-8) and the northern region of the Southeast Georgia region (GA 2-4) (Figure 23). Populations considered in medium condition are largely found in the North Florida region, the northern portion of the Peninsular Florida region and scattered smaller populations in Southeast Georgia and southern Peninsular Florida. The majority of the extirpated populations are in the western portion of the range in the Panhandle region and the western area of the Southeast Georgia region. Other extirpated populations occur along the eastern side of the North Florida region and in the southern extreme of Peninsular Florida. Low and Very Low resilience populations are found along the coasts and near extirpated populations.

Table 5: Summary of resiliency condition classes for 83 eastern indigo snake populations

Resiliency Condition Class	**Number**	**Percent**
High	**4**	5%
Medium to Medium-High	**13**	16%
Medium-Low to Low	**28**	34%
Very Low (includes 2 repatriation sites)	**8**	9%
Extirpated	**30**	36%

5.3 Representation

Identifying and evaluating representative units that contribute to a species' adaptive potential are important components of assessing overall species' viability (Shaffer and Stein 2000, entire). This is because populations that are distributed throughout multiple representative units may increase a species' ability to respond to environmental changes over time. Representation of the eastern indigo snake can be described in terms of ecological (latitudinal or regional) variability, which incorporates the genetic variability, for the species across its range. Below we examine these aspects of the historical and current distribution.

Ecological Variability- Ecological variability for the eastern indigo snake has decreased because tortoise-dependent populations in the Panhandle region have been lost (97% decline in population extent) and have declined by more than 50% and 30% in the North Florida Region and Southeast Georgia regions, respectively (Table 6). Therefore, only 2 out of 3 northern (gopher-tortoise dependent) regions are currently represented. It is believed that this decline is most likely the result of low densities of gopher tortoises whose populations have been impacted by human harvest for food and by habitat degradation (e.g. fire exclusion, incompatible forestry) (Enge *et al*. 2013, p. 289). Conservation of gopher tortoise populations is on-going throughout the range of the eastern indigo snake and efforts to restore eastern indigo snakes to the Panhandle region are on-going (See section 4.8). Eastern indigo snake populations have also declined (by 42%) in the southern (non-gopher tortoise-dependent) population region (Table 6). Populations remain throughout the region; however considerable declines are most evident in the extreme southern region, including the Florida Keys.

Genetic Variability- Genetic variability has been documented within a north-south gradient (Folt *et al*. 2019) as well as an east-west (Atlantic-Gulf) gradient (Krysko *et al.* 2016b, entire). The north-south genetic gradient is the same as the representation described by the ecological variability (above) and therefore has experienced similar declines. Generally, the Southeast Georgia and North Florida regions represent the Atlantic clade and Peninsular Florida and the Panhandle regions represent the Gulf clade described by Krysko *et al.* (2016b, entire). While representation of the Gulf clade in the Panhandle region has been lost (97% decline), populations remain throughout Peninsular Florida but at a reduced level (42% decline).

Summary

From an ecological and genetic variably perspective, the contemporary distribution of the eastern indigo snake provides species' representation but has considerably decreased from its historical representation. Most notably are the loss of populations in the Panhandle region and a contraction of the distribution in the southern extent of the Peninsular Florida region, including the Florida Keys. In addition losses from the North Florida region may be particularly important for maintaining species diversity because of its geographic location where both the ecological and genetic gradients come together.

5.4 Redundancy

Redundancy is characterized by having multiple, resilient populations distributed within the species' ecological setting and across the species range. Redundancy reduces the risk that a large portion of the species range will be negatively affected by a natural or human-caused catastrophic disturbance.

We assessed eastern indigo snake redundancy by evaluating the number of populations and the extent for both the historical and current distribution of populations. The total number of current populations is 53. Although there were 51 historical populations, the current abundance of populations represents fragmentation of the historically larger populations into multiple, smaller populations, especially in Peninsular Florida (Figure 21, see section 5.1). Thirty (30) of the historical 51 populations are extirpated (59%) (Appendix B, Table B3). Population extent has declined in all regions with a 48% decline across the species' historical range. Southeast Georgia has 1, and Peninsular Florida has 3 highly resilient populations as well as multiple medium resilient populations (Table 6). The Panhandle and North Florida regions have zero (0) highly resilient populations, thus limiting overall redundancy. This is important for the species, especially for the North Florida region, because loss of redundancy in these areas limits connectivity to the other regions. Of extant populations across all regions, 17% of the total population extent (area) has high, 34% has medium, 45% has low, and 4% has very low resiliency (Table 7).

Table 6: A comparison of the historical (A) and current (B) number and extent (% occupied) of eastern indigo snake populations within each region. Note: The total extent of current populations is 12.5 million ac, however approximately half of that area (6.4 million ac) is considered potential habitat.

(A) Historical: all records 1936-2017				
Region	**Region Area (ac)**	**Historical Population Extent (ac)**	**Number of Populations**	**% of Region Occupied**
Southeast Georgia	16,395,372	4,963,121	10	30
North Florida	9,556,835	2,824,993	6	30
Panhandle	20,330,428	2,889,894	13	14
Peninsular Florida	27,805,400	13,382,652	22	48
Total	74,088,035	24,060,660	51	32

(B) Current: 2001-2017					
Region	**Current Population Extent (ac)**	**Number of Extant Populations**	**Number of Populations in High (H) to Medium (M) Resiliency**	**% of Region Occupied**	**% Population Extent Decline**
Southeast Georgia	3,384,099	13	1 H; 4 M	21	32
North Florida	1,251,686	5	0 H; 2 M	13	56
Panhandle	84,042	1 (2R)*	0 H; 0 M	0	97
Peninsular Florida	7,780,784	32	3 H; 7 M	28	42
Total	12,500,611	53	4 H; 13 M	17	**48**

***** There are two repatriation populations (2R) in the Panhandle, one at Conecuh National Forest in Alabama and one in Liberty County, Florida. The repatriation populations are on-going and these populations are not considered viable at this time therefore their population extents are not included in the current population area calculation.

Table 7: Population extent (acres) by region and resiliency condition class

Region	Resiliency Condition Class - Population Extent (acres)				
	High	Medium	Low	Very Low	Total
Southeast Georgia	376,907	1,782,237	1,224,955	0	3,384,099
North Florida	0	1,171,768	9,763	70,155	1,251,686
Panhandle	0	0	84,042	0	84,042
Peninsular Florida	1,744,142	1,262,745	4,365,873	408,024	7,780,784
Total	2,121,049	4,216,750	4,365,873	638	12,500,611
Area %	**17**	**34**	**45**	**4**	**100**

5.5 Conservation Status

Conservation efforts, including land protection and management (see section 4.8 for a summary of on-going conservation efforts) have the potential to maintain or improve current conditions for eastern indigo snake populations. Long-term conservation success for the eastern indigo snake is highest on conserved lands, where various restrictions are assumed to be in place to prevent or limit development. Protection from development alone may not be enough to adequately conserve eastern indigo snake populations because the primary habitat most desired (and required in the northern range) by eastern indigo snakes requires habitat management, specifically fire management. However, those lands in conservation are the mostly likely lands to receive appropriate habitat management.

In Florida, almost 30% of the total land area is considered conservation land (11.7% federally-managed, 13.9% state-managed and 1.4% locally-managed) (FNAI 2018, entire). All of the state of Florida is included in the eastern indigo snake range. In Georgia 12% of total land area within the eastern indigo snake range (section 2.4.4) is considered conservation land (7.8% federally-managed, 2.2% state-managed, 1.9% private conservation-managed and 0.06% locally-managed) (USGS 2016). However, not all conserved lands are relevant to eastern indigo snake conservation. We used the U.S. Geological Survey Protected Areas Database of the United States (PAD-US) (USGS 2016) to assess the status of conserved eastern indigo snake habitat across the species' range. The state of Georgia has increased protected lands in recent years as part of the Gopher Tortoise Initiative and other efforts. These more recently acquired lands were not represented in the PAD-US dataset and were acquired from the Georgia GIS Clearinghouse (Georgia GIS 2018). Figure 24 shows the land conservation status for each eastern indigo snake population. Of the estimated 6.4 million ac of habitat within the extent of eastern indigo snake populations across the range, approximately 2.2 million ac (0.86 million ha) or 34% of the habitat is on some type of conserved land (federal, state and private). Broken down by region, 42% of the habitat in Peninsular Florida is protected, 38% in the Panhandle, 20% in Southeast Georgia and 19% in North Florida (Figure 25). See Appendix B for additional detail regarding methods for calculating eastern indigo snake conserved habitat.

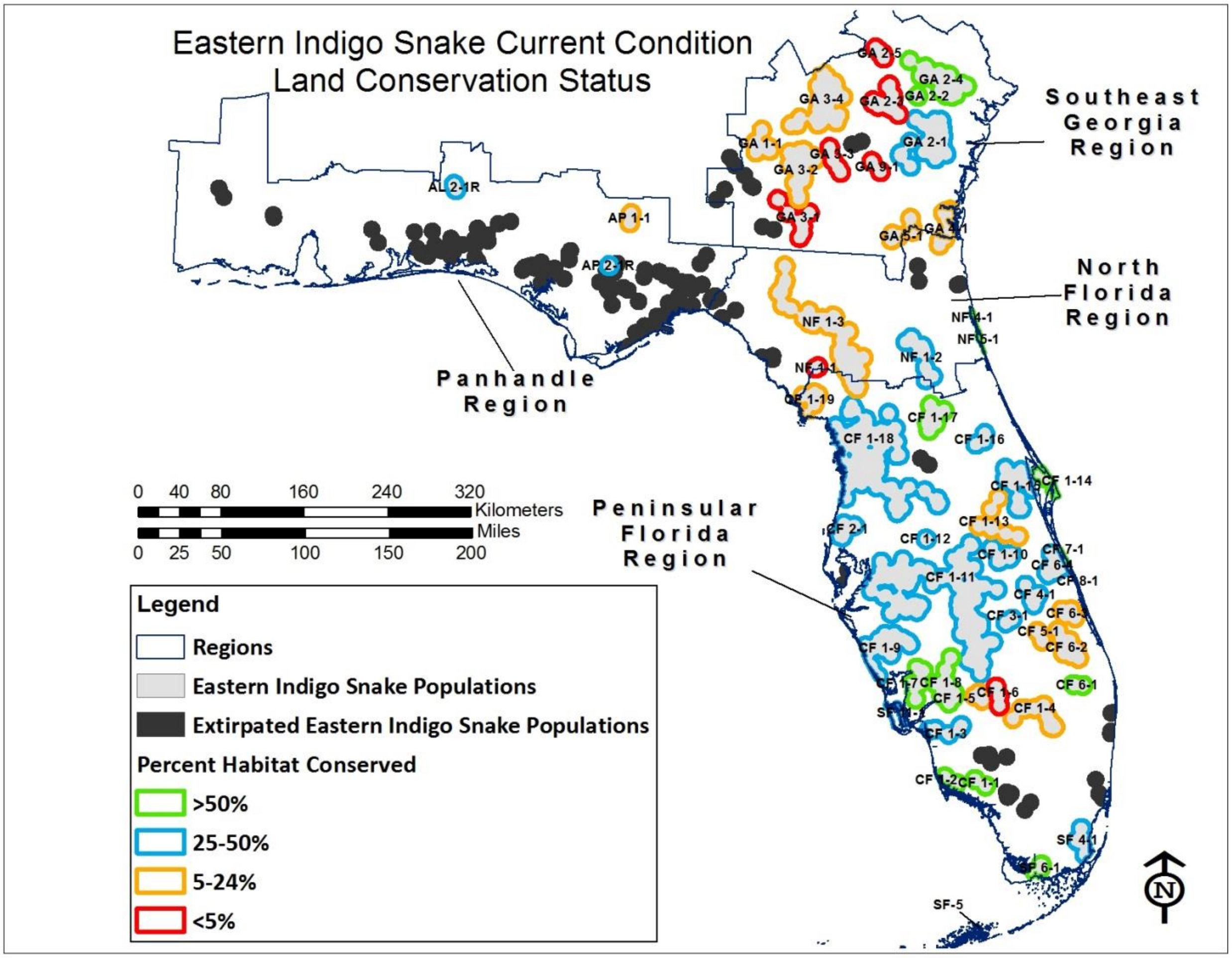


Figure 24: Eastern indigo snake populations and the percent of habitat on conservation lands for each population. Conserved lands include any federal, state or privately owned or managed land identified as conservation land by the U.S. Geological Survey Protected Areas Database of the United States (PAD-US) (USGS 2016).

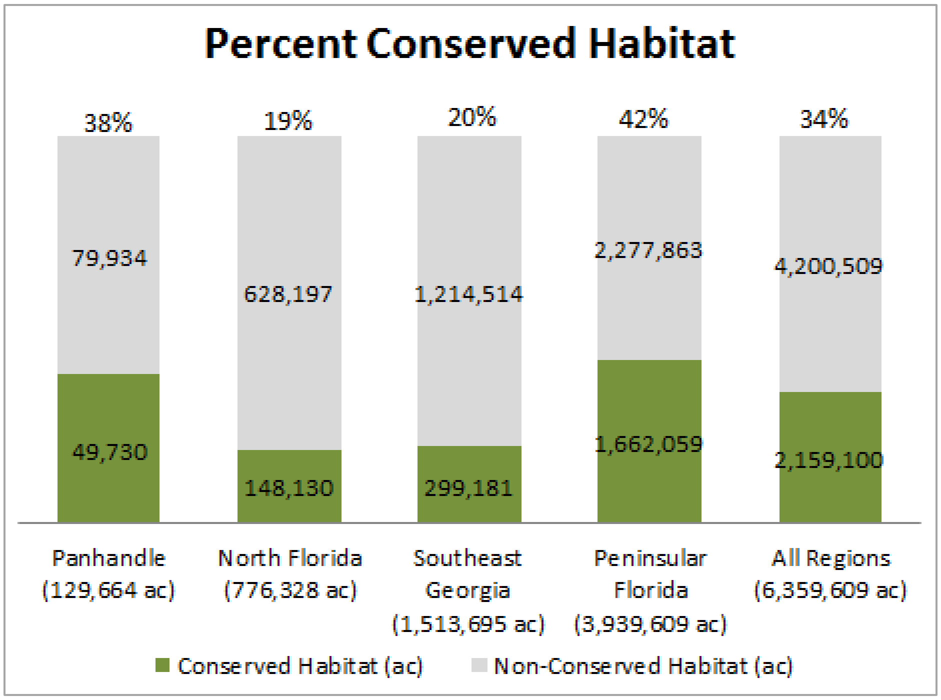


Figure 25: Percent conserved habitat by region. Numbers on bar graph are acres of conserved and non-conserved habitat. Numbers in parentheses are total acres.

5.6 Current Condition Summary

The overall distribution of the species has considerably contracted from the historical distribution. Enge *et al.* (2013, p. 296) suggest that recent non-detection of the species in areas where it was once found might indicate substantial population declines or even extirpation. It is important to note that our assessment is based on species presence, potential extent of populations and a snapshot of habitat conditions as a surrogate for the status of populations. Delineation of biological populations for the eastern indigo snake across its range are problematic due to the snake's large home ranges, secretive behavior, low densities, and other challenges associated with identifying population boundaries.

Based on our assessment, overall current eastern indigo snake population resiliency is medium to low. The majority of the extant populations (34 of 53 or 68%) are in low (53%) to very low (15%) condition and 36% are likely extirpated. Only 8% of the extant populations (4 of 53) are considered to have high resiliency and 25% (13 of 53) are considered to have medium resiliency. Medium to low resiliency populations occupy about 34% and 45%, respectively, of the total current population extent (Table 7). The highly resilient eastern indigo snake populations occupy about 17% of the total current population extent and occur in the northeastern area of the Southeastern Georgia region and the central portion of the Peninsular Florida region. These two strongholds provide species representation (although less than historical conditions) for both the ecological and genetic gradients known for the species but with limited redundancy. The North Florida region and most of Southeast Georgia region populations are in medium condition and those in the Panhandle and extreme southern Peninsular Florida region are largely extirpated which represents a considerable range contraction with losses in representation and redundancy for the species.

The current land conservation status varies across the populations. Most of the highly resilient populations have >25% of habitat on conserved lands (includes federal, state or privately-owned (i.e. easements and conservation organizations) land). The habitat for the 2 repatriation populations in the Panhandle is well-protected. The habitat for populations in Peninsular Florida is also relatively well-protected, however patch size and connectivity among protected habitat patches also influences overall resiliency. The North Florida region populations may be vulnerable because the distribution is limited and the largest population has a low level (<25%) of habitat on conserved lands. Maintaining populations in this region will likely be essential for maintaining genetic connectivity among all the other regions (Southeast Georgia, the Panhandle and Peninsular Florida). This region potentially contains the most ecological and genetic diversity due to its geographic location. In the Southeast Georgia region, while many of the populations currently show medium to high resiliency, the majority of these populations have low to very low conservation of eastern indigo snake habitat posing some risk to maintaining their current resiliency status into the future. Adequate management of protected habitat will be needed to maintain population resiliency.

CHAPTER 6 – FUTURE CONDITIONS

6.1 Future Considerations

The SSA considers not just the factors that influence viability (Chapter 4), but assesses to what degree they influence risk (Smith *et al.* 2018, p. 6). Our analysis of the past, current, and future influences on what the eastern indigo snake needs for long-term viability revealed that there are several influences that pose risks to future viability of the species. These risks are related to habitat changes from urbanization and climate change. Urbanization affects habitat from residential & commercial development, road construction and expansion, energy development such as solar arrays and introduction of invasive species. Increased urbanization can also increase occurrence of direct mortality. While there will likely be indirect effects on eastern indigo snakes due to shifting changes in temperature and precipitation, rising sea levels are expected to directly impact coastal populations of eastern indigo snakes. Other important influencing factors are related to non-urban land use and land management such as fire management, forestry, mining, and agriculture. Therefore to assess potential future condition for the eastern indigo snake, we use projections of urban development and sea level rise to assess potential habitat loss and fragmentation and consider a targeted conservation scenario in which land use and management are included.

In constructing our scenarios, we considered two main influences by which species viability projections could be affected: conservation actions (positive influence) and habitat loss, fragmentation and direct mortality due to urban development and sea level rise (negative influence). Habitat quantity can be negatively impacted by sea rise inundation and development or land use change (particularly on private lands), or positively impacted by land acquisition, restoration, and/or repatriation into unoccupied sites that have suitable habitat.

Our scenarios reflect a range of levels of future urbanization based on the Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade (SLEUTH) model (described further in the next section), and sea level rise based on National Oceanic Atmospheric Administration (NOAA) local projections, at 2 different time steps (years 2050 and 2070). Because there is uncertainty as to the level and extent of future urbanization, we use 3 scenarios to capture low, moderate, and high possible rates of urbanization. We also explore a conservation scenario in which impacts from sea level rise and the moderate urbanization rates are used as a baseline and in combination with conservation actions such as, repatriation of populations into areas of extirpation, surveying and monitoring (which may indicate higher current resiliency conditions than estimated), and increased conservation action (e.g. improved land management, restoration, and land protections) in focal areas to accelerate recovery. These four scenarios provide a range of viability predictions for the species from worst case to optimistic.

Urban Development

We use the SLEUTH models to determine areas predicted to be urbanized in the future. 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, pp.1-3) and has been successfully applied worldwide over the last 15 years to simulate land use change.

The SLEUTH model predictions for each 60m square cell are given as a probability of urbanization, ranging from 0-100%, and are modeled for each decade from 2010 (baseline) to 2100. For each of our time points (years 2050 and 2070), in the low development scenario we considered as developed only those cells with a probability of 90% or higher of being developed. In the moderate development scenario, we considered as developed all cells with a probability of 50% or higher of being developed (more likely to be developed than not). In the high development scenario, we considered as developed all cells with a probability of 20% or higher of being developed. To forecast viability using urban development projections, we assessed resiliency in the context of loss and fragmentation of eastern indigo snake habitat. See appendix D for additional information on the urbanization models used in this report.

Sea Level Rise

To estimate loss of habitat due to inundation from sea level rise for coastal populations of eastern indigo snakes, we used NOAA's shapefiles available at their online sea level rise viewer (NOAA 2017). Projected sea level rise scenarios from NOAA provide a range of inundation levels from low to extreme. We chose the most likely scenario based on the Sea-Level Rise Working Group

(SLRWG 2015), which corresponds to NOAA's intermediate-high scenario. Local scenarios are available at 29 locations along the coast of Florida, with each scenario providing estimates of sea level rise at decadal time steps out to the year 2100. We determined the average sea rise level estimate for the intermediate high NOAA scenario across all 29 stations and used this estimate to project habitat loss at 2050 (2 feet sea level rise) and 2070 (3 feet sea level rise). Sea level rise impacted future resilience of eastern indigo snakes by influencing the population extent, habitat quantity, and fragmentation. See Appendix D for additional information on sea level rise projections used in this assessment.

Conservation Efforts

Eastern indigo snakes require large, relatively unfragmented habitat patches with a diversity of primary and secondary habitat types to maintain resilient populations. They are dependent on conservation to maintain and improve habitat mainly through adequate prescribed fire (for primary habitat) but also by managing invasive species. Long-term monitoring of eastern indigo snakes and range-wide population viability models will be critical to better understand population status. Long-term monitoring is on-going in a few locations (Orianne Indigo Snake Preserve, Archbold Biological Station, Pine Island Sound), however, methodology has varied greatly. Implementing more consistent monitoring in strategic locations could help better elucidate population conditions (including identifying additional populations) and inform land protection and management. Protecting additional habitat with corridors among populations will support resilient and genetically diverse populations. Finally, repatriation of populations into areas where the species has been extirpated may prove valuable for increasing species representation and redundancy.

This targeted conservation scenario attempts to maintain, improve or restore eastern indigo snake populations in potential strategic areas (Conservation Focus Areas) across the historic range with the goal of conserving multiple highly resilient populations with sufficient ecological and genetic diversity. Redundancy will be achieved by maintaining multiple connected populations to allow genetic exchange. For larger populations this would maintain genetic diversity and would reduce risk of extirpation of smaller populations (i.e. genetic rescue and recolonization after extirpation). Repatriation of populations in key areas of extirpation where there is suitable and conserved habitat could contribute to achieving higher levels of representation and redundancy. Other potential focused conservation efforts include additional land protection for populations with less than 25% of habitat protected (see Figure 24) and protection of dispersal corridors among and within populations to facilitate gene flow across the species' range. Conservation action also would include adequate land management (e.g. prescribed fire) and long-term monitoring programs to better measure population trends over time.

The Conservation Focus Areas (Figure 26) were chosen because they contain potentially viable populations or because they will contribute to the connectivity of occupied eastern indigo snake habitat and thus increase dispersal between populations and improve opportunities for new population establishment. The primary factors used in delineating boundaries of Conservation Focus Areas were presence of: (1) intact, unfragmented (by major roads or river systems), naturally-functioning habitat representative of that area's physiographic province that meet the medium or higher threshold for habitat fragmentation (25% of habitat is >20K acres patch size; or 50% is >10K acres patch size; or 75% >5K acres patch size); (2) areas that in their totality, support genetic and ecological integrity of the species by including areas throughout the historical and current range of the eastern indigo snake and in both the Gulf Coastal Plain and Atlantic Coastal Plain; (3) areas that contain multiple, large acreages (greater than 2,500 ac (1,000 ha)) of conservation land such as public lands or property with conservation easements capable of adequate management (e.g., prescribed fire, wildlife corridors); and (4) diverse habitat types (e.g., scrub, sandhills, riverine sand ridges, etc.) as identified by our Eastern Indigo Snake Habitat Model (Appendix C). See Appendix E for additional detail on Conservation Focus Areas (CFAs).

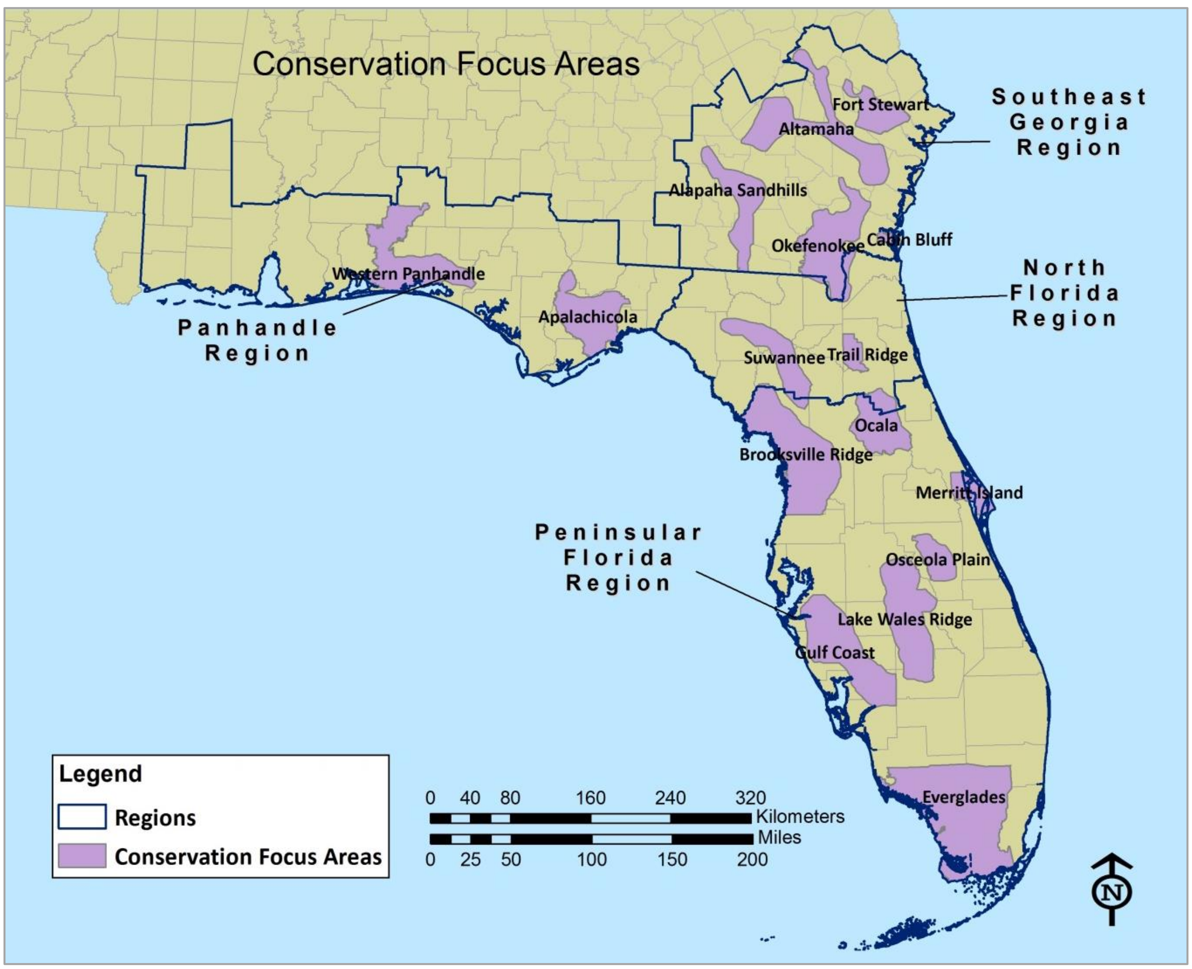


Figure 26: Sixteen (16) eastern indigo snake Conservation Focus Areas (CFAs)

6.2 Future Scenarios

Predictions of eastern indigo snake resiliency, representation, and redundancy were forecasted using approximately a 30 and 50-year time horizon (years 2050 and 2070, respectively). These time horizons were chosen to correspond to the range of available urbanization and sea level rise (SLR) model forecasts. The 2050 year time frame provides a near-term projection with relatively reliable urbanization and sea level rise forecasts, while the 2070 year time frame represents a potential longer-term trajectory for the species, but with lower confidence in the outcome than the 2050 projection. Furthermore, approximately 30 and 50-years represent time frames during which the effects of management actions can be implemented and realized on the landscape, and it is a reasonable time frame (including approximately 3-5 generations) for the species to respond to potential changes on the landscape. The following is a summary of the four (4) scenarios.

1. ***Scenario A* (Low Development)**
Under this scenario, we assume 90% probability SLEUTH + sea level rise at 2050 and 2070

2. ***Scenario B* (Moderate Development)**
Under this scenario, we assume 50% probability SLEUTH + sea level rise at 2050 and 2070

3. ***Scenario C* (High Development)**
Under this scenario, we assume 20% probability SLEUTH + sea level rise at 2050 and 2070

4. ***Scenario D* (Targeted Conservation)**
Under this scenario we assume Scenario B (moderate) development + sea level rise at year 2070. We also assume increased habitat management and land protection within potential "Focus Areas" that can support highly resilient populations with sufficient representation and redundancy.

<u>Resiliency</u>

In order to make comparisons between current and future conditions, we assessed future resiliency conditions for the eastern indigo snake populations using a similar method as the current condition resiliency assessment. First for each scenario, population and habitat factors were recalculated for each eastern indigo snake population, assigned a score ("high" to "very low" represented by the numerical values of 4 to 1, respectively) for each population and habitat factor as described in Table 2 (see section 5.2.3), and given the same weights (Appendix D, Table D2) as the current condition analysis with the following exceptions and modifications:

- <u>Population extent:</u> This population factor was recalculated for the populations that were impacted by SLR assuming inundated land is no longer considered part of the population extent. For all other populations, population extent was held constant (unchanged) in order to facilitate comparison between current and future conditions. For this assessment, we were not able to predict how the population boundaries would shift (e.g. contract or fragment into smaller populations) as a result of habitat loss from urbanization. However, we provide a discussion of how populations may become fragmented into smaller, less resilient populations.

- Habitat Type and Shelter Sites (gopher tortoise): These habitat factors were held constant (unchanged) between current condition and future condition assessments because it is difficult to predict how these factors will change based on the models used in this assessment. In general, urbanization mostly impacts tertiary habitat (unpublished data), but it is difficult to know how primary and secondary habitats will change as a result of declining tertiary habitat (e.g. primary habitat converted to agricultural land). For gopher tortoises, we assume the tortoise populations described in the 2018 Gopher Tortoise CCA Annual Report (CCA 2018) are tracked by the States and will retain some level of site affinity (See section 4.5 & 4.8). In holding these factors constant, we are not asserting that the conditions will in fact remain constant into the future, but are rather holding them constant to enable us to assess how the other changing factors will alter resilience compared to the current condition.

- Tertiary Road Density and Urban Area: Tertiary road density was combined with percent urban area in the future scenario analysis. It is difficult to predict how tertiary roads will change in the future (e.g. tertiary roads becoming primary or secondary roads and where new tertiary roads will occur). Tertiary road density and percent urban area are highly correlated (see Appendix B, Figure B3) therefore we absorbed tertiary road density into the urban area factor and combined their weights, giving percent urban a weight of 2 for both northern and southern populations.

Next, using the scores and weights described above, we calculated a total population factor score and total habitat factor score for each eastern indigo snake population, which resulted in a continuous numerical value ranging between 1 and 4, and we assigned a resiliency condition class of High, Medium, Low or Very Low as described in Table 4 (see section 5.2.3).

Finally, we summarized overall future condition resiliency classes for each eastern indigo snake population, for each scenario, by combining the total population and habitat condition classes as described for current condition (see section 5.2.3).

For these projections, high condition populations were defined as those with high resiliency at the end of the predicted time horizon (at years 2050 and 2070). Populations in high condition are expected to persist into the future, beyond either year 2050 or 2070, and have the ability to withstand stochastic events. Populations in medium condition (includes medium-high and medium) were defined as having lower resiliency than those in high condition but are still expected to persist beyond either year 2050 or 2070. Populations in medium condition typically have smaller population extents and/or have lower habitat conditions than those in high condition. Finally, those populations in medium-low to very low condition were defined as having low resiliency and may not be able to withstand stochastic events. As a result, medium-low to very low condition populations were predicted to be much less likely to persist beyond either 30 or 50 years.

6.3 Resiliency

The overall current distribution of the species has considerably contracted from the historical distribution (see section 5.6). In some areas the current land conservation status may protect against further declines associated with urbanization, however effects from sea level rise may not be ameliorated.

Urbanization and sea level rise both will cause considerable losses of eastern indigo snake habitat within the current population extent across the range, from a 15% loss in the low development scenario at year 2050 to as much as 34% loss in the high development scenario by year 2070 (Table 8). Urbanization has the greatest impact on overall percent habitat loss in the North Florida region (33% by 2050, and 47% by 2070 with moderate development (Scenario B)), followed by the Peninsular Florida, Southeast Georgia, and Panhandle regions (Table 8).

Table 8: Estimated habitat loss from eastern indigo snake populations by regions from urbanization (urban) and SLR for each Scenario (Scenarios A, B & C = Low, Moderate & High Development, respectively). Difference between the sum of urban and SLR losses and the total percent loss column are due to rounding.

Scenario	Region	Total Habitat Acres	% Urban loss	% SLR Loss	% Total Loss
Current	Southeast Georgia	1,513,695	na	na	na
Current	Panhandle	129,664	na	na	na
Current	North Florida	776,328	na	na	na
Current	Peninsular Florida	3,939,923	na	na	na
Current	**All Regions**	**6,359,609**	**na**	**na**	**na**
Scenario A 2050	Southeast Georgia	1,385,624	8	1	8
Scenario A 2050	Panhandle	125,870	3	0	3
Scenario A 2050	North Florida	545,547	29	1	30
Scenario A 2050	Peninsular Florida	3,318,974	13	2	16
Scenario A 2050	**All Regions**	**5,376,015**	**14**	**2**	**15**

Scenario	Region	Total Habitat Acres	% Urban loss	% SLR Loss	% Total Loss
Scenario B 2050	Southeast Georgia	1,367,064	9	1	10
Scenario B 2050	Panhandle	124,954	4	0	4
Scenario B 2050	North Florida	515,275	33	1	34
Scenario B 2050	Peninsular Florida	3,108,979	19	2	21
Scenario B 2050	**All Regions**	**5,116,272**	**18**	**2**	**20**
Scenario C 2050	Southeast Georgia	1,358,997	10	1	10
Scenario C 2050	Panhandle	123,875	4	0	4
Scenario C 2050	North Florida	495,237	36	1	36
Scenario C 2050	Peninsular Florida	2,905,013	24	2	26
Scenario C 2050	**All Regions**	**4,883,122**	**22**	**2**	**23**
Scenario A 2070	Southeast Georgia	1,333,886	11	1	12
Scenario A 2070	Panhandle	123,509	5	0	5
Scenario A 2070	North Florida	423,508	43	2	45
Scenario A 2070	Peninsular Florida	3,034,923	20	3	23
Scenario A 2070	**All Regions**	**4,915,826**	**21**	**2**	**23**
Scenario B 2070	Southeast Georgia	1,306,374	13	1	14
Scenario B 2070	Panhandle	122,146	6	0	6
Scenario B 2070	North Florida	391,410	47	2	50
Scenario B 2070	Peninsular Florida	2,445,323	35	3	38
Scenario B 2070	**All Regions**	**4,265,253**	**31**	**2**	**33**
Scenario C 2070	Southeast Georgia	1,270,081	15	1	16
Scenario C 2070	Panhandle	120,599	7	0	7
Scenario C 2070	North Florida	361,878	51	2	53
Scenario C 2070	Peninsular Florida	2,445,323	35	3	38
Scenario C 2070	**All Regions**	**4,197,882**	**32**	**2**	**34**

Habitat loss from seal level rise is greatest in Peninsular Florida (2-3%) and is relatively low compared to urbanization throughout the range of the eastern indigo snake. Sea level rise contributes to measurable habitat losses for 22 of the 53 current populations (Figure 27), with significant losses for the island populations (Table 9). Population extirpation due to loss of habitat from sea level rise occurs by 2050 (2ft sea level rise) and no additional populations are lost by 2070 (3ft sea level rise). Seven populations listed (in **bold**) in Table 9 are considered extirpated in all future scenarios due to loss of habitat from sea level rise.

Table 9: Eastern indigo snake populations most affected (>10% habitat loss) by sea level rise by 2050 (2ft rise) and 2070 (3ft rise). Those in **bold** are considered extirpated in the future and those with (i) are island populations.

Population	% Habitat Loss Year 2050 2Ft	% Habitat Loss Year 2070 3Ft
Central Florida 1-14	25	48
Central Florida 1-2	38	49
Central Florida 7-1 (i)	58	78
Central Florida 8-1* (i)	100	100
North Florida 4-1 (i)	8	18
North Florida 5-1 (i)	26	44
South Florida 11-1 (i)	46	58
South Florida 4-1	76	85
South Florida 6-1*	15	15

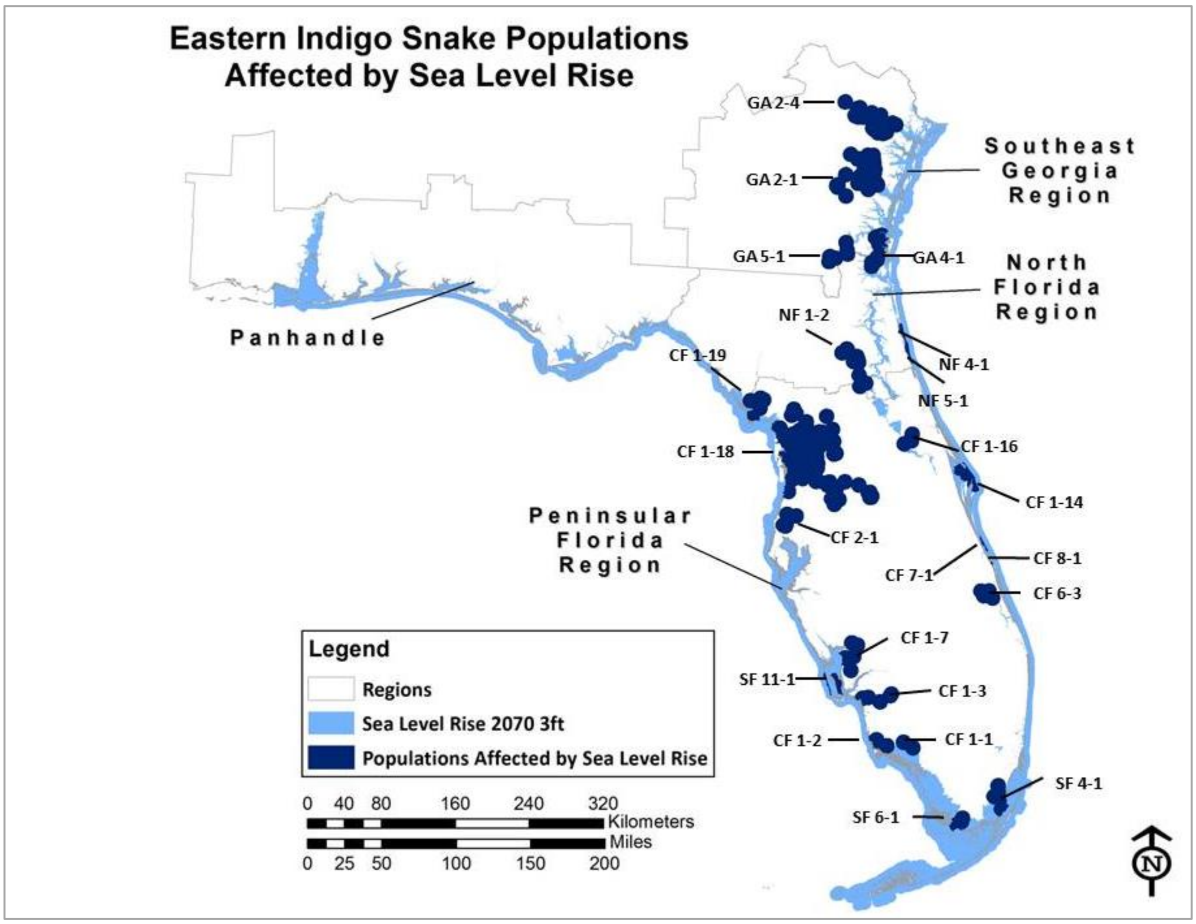
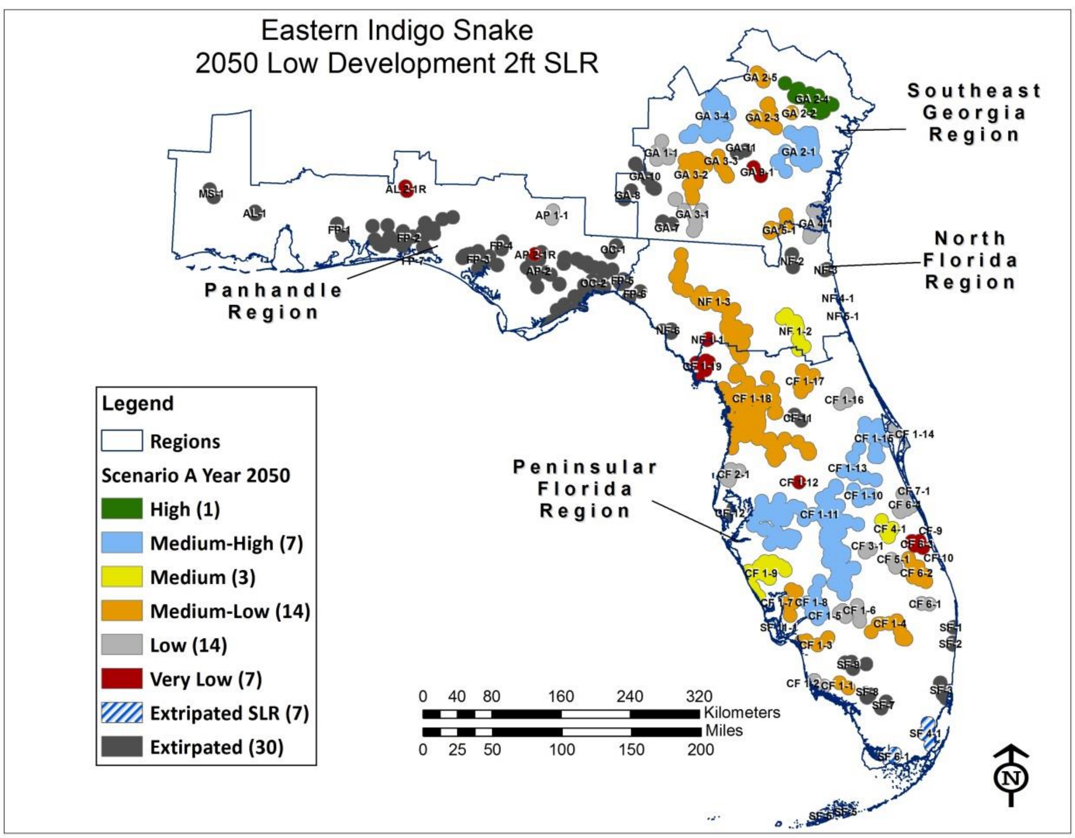


Figure 27: Eastern indigo snake populations (22) impacted by sea level rise.

6.3.1 Scenario A (Low Development)

In the Scenario A, population resiliency declines from current condition having only one highly resilient population remaining throughout the range in Southeast Georgia (GA 2-4) (Figure 28). Several medium-high and medium resilient populations remain in Southeast Georgia and Peninsular Florida. In Southeast Georgia, populations GA 2-3 and 3-2, decline from a medium current condition to medium-low future condition which may be reduce connectivity among the Georgia populations. Given their central location within the eastern indigo snake range, the decline of populations NF 1-3 and NF 1-2 (by 2070) in North Florida and CF 1-18 and CF 1-17 in Peninsular Florida from medium to medium-low resiliency may reduce connectivity among populations necessary to maintain gene flow across the species' ecological and genetic gradients. Also notable is the resiliency of population CF 1-11 in Peninsular Florida declines from highly resilient in its current condition to medium-high. By 2070 the decline of additional Peninsular Florida populations CF 1-10 and CF 1-13 from medium-high to medium-low resiliency further reduce connectivity among populations in this region. Seven populations are lost to sea level rise, NF 1-4 and 1-5 in North Florida and CF 7-1, CF 8-1, SF 4-1, SF 6-1 and SF 11-1 in Peninsular Florida. Resiliency condition classes for each population are listed in Table D3 (Appendix D).



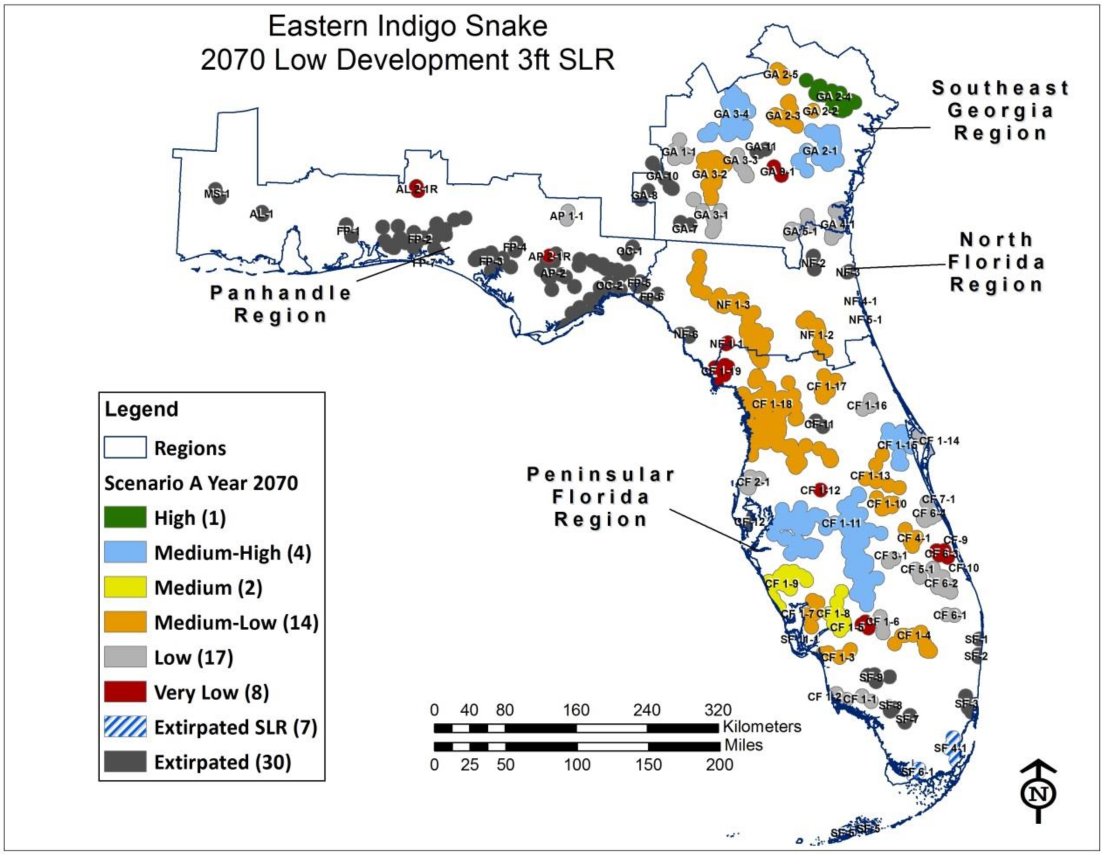
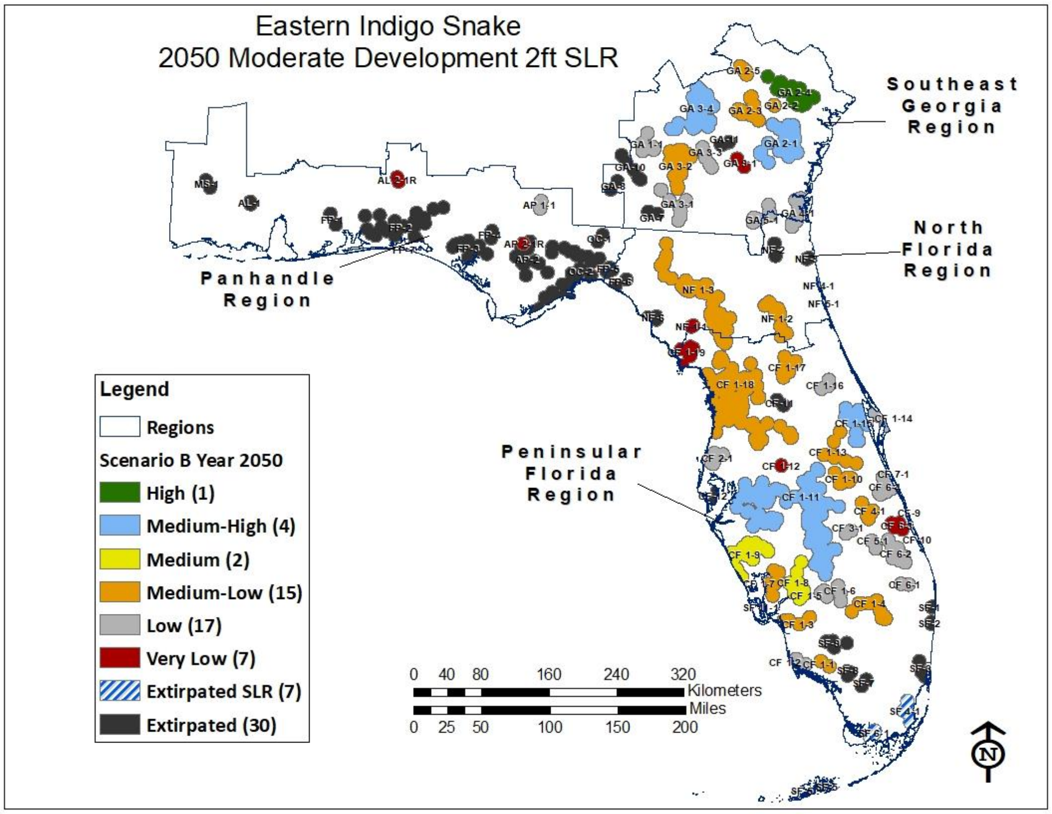


Figure 28: Eastern indigo snake population resiliency condition classes for Scenario A (low development) at year 2050 (2 ft sea level rise) and year 2070 (3 ft sea level rise).

6.3.2 Scenario B (Moderate Development)

In Scenario B, population resiliency at 2050 remains about the same as Scenario A at 2070 condition having only one highly resilient population remaining throughout the range in Southeast Georgia (GA 2-4) (Figure 29). By year 2070, populations in Southeast Georgia and North Florida remain the same as 2050, however in Peninsular Florida populations CF 1-11 and CF 1-15 decline from medium-high to medium condition and CF 1-8 declines from medium to low. Resiliency condition classes for each population are listed in Table D3 (Appendix D).



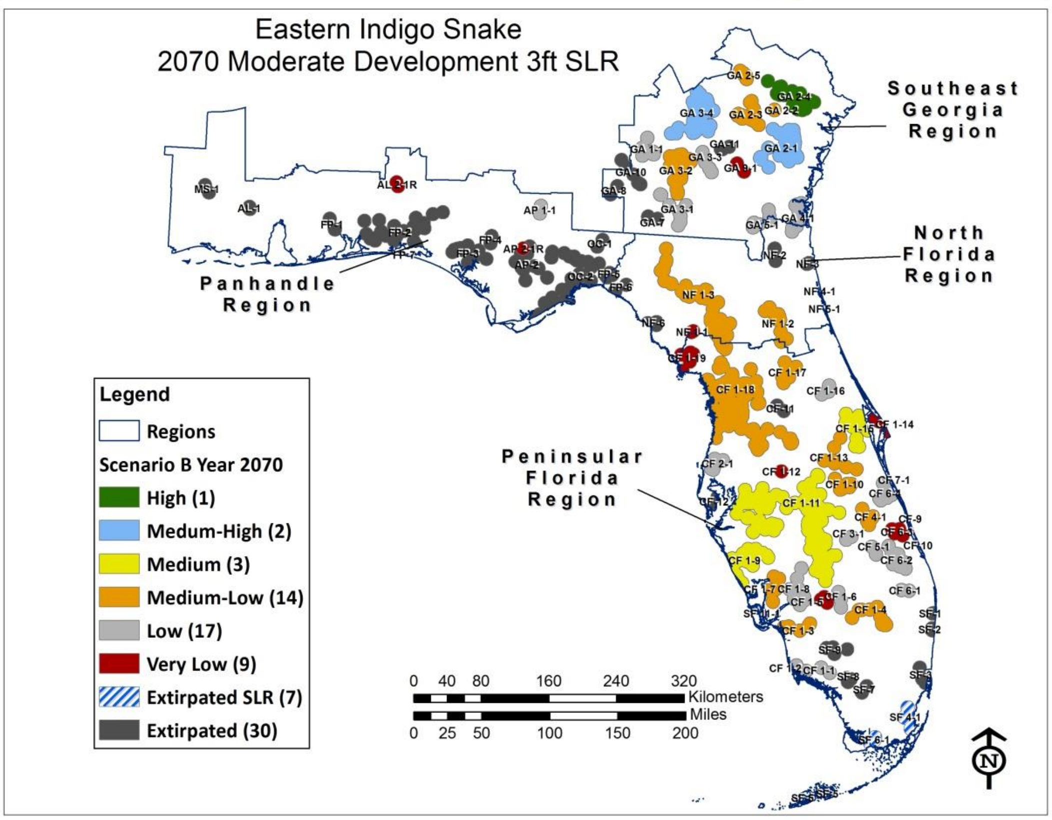
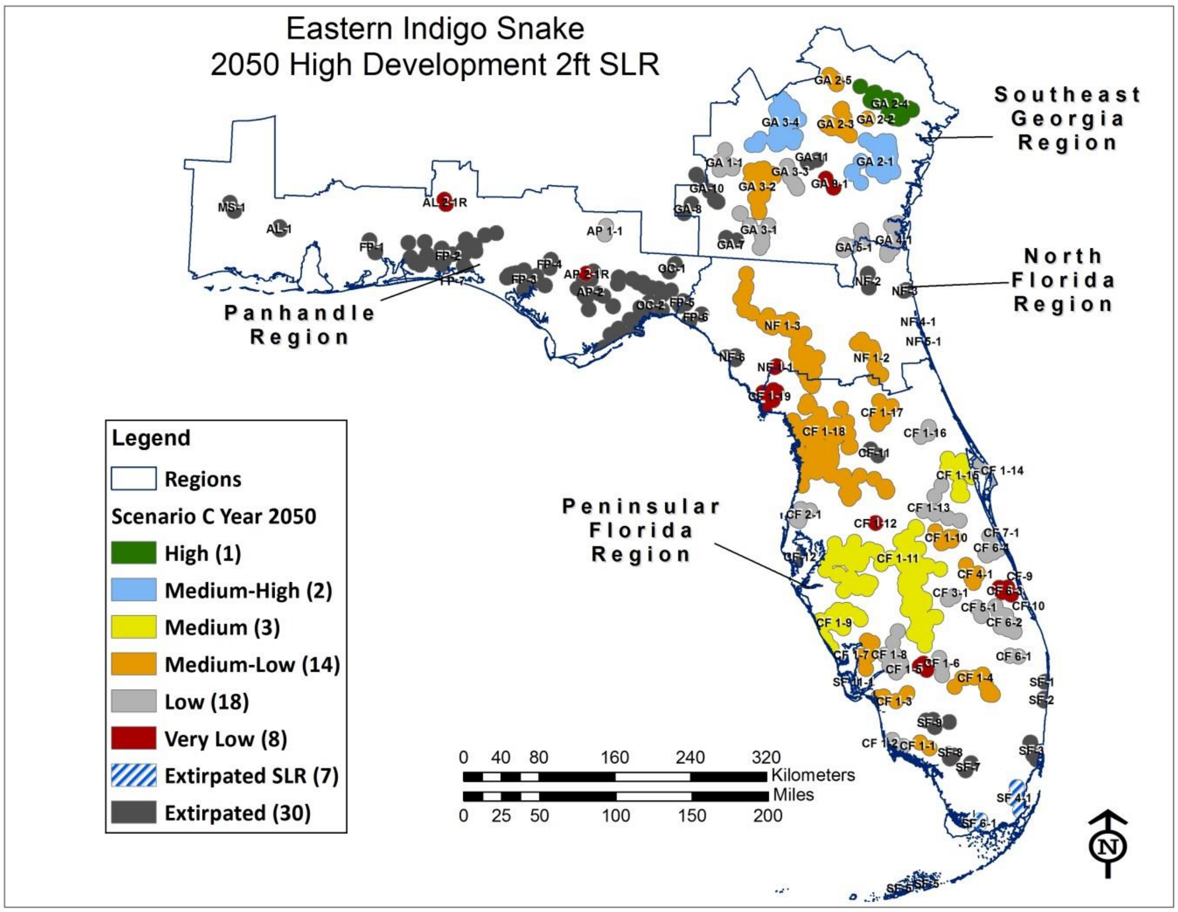


Figure 29: Eastern indigo snake population resiliency condition classes for Scenario B (moderate development) at year 2050 (2 ft sea level rise) and year 2070 (3 ft sea level rise).

6.3.3 Scenario C (High Development)

In Scenario C, population resiliency at 2050 is very similar to the population resiliency in Scenario B at 2070 (Figure 30). Population resiliency remains the same in Southeast Georgia and North Florida with one highly resilient and two medium-high resilient populations remaining in Southeast Georgia, and no high to medium resilient populations in North Florida. Three medium resilient populations remain in Peninsular Florida. Between 2050 and 2070, the east-central area of Peninsular Florida experiences additional declines due to urbanization where CF 1-14 becomes very low, CF 1-13 becomes low, and CF 1-15 becomes medium-low. Population GA 3-4 in Southeast Georgia also declines from medium-high to medium condition. Resiliency condition classes for each population are listed in Table D3 (Appendix D).



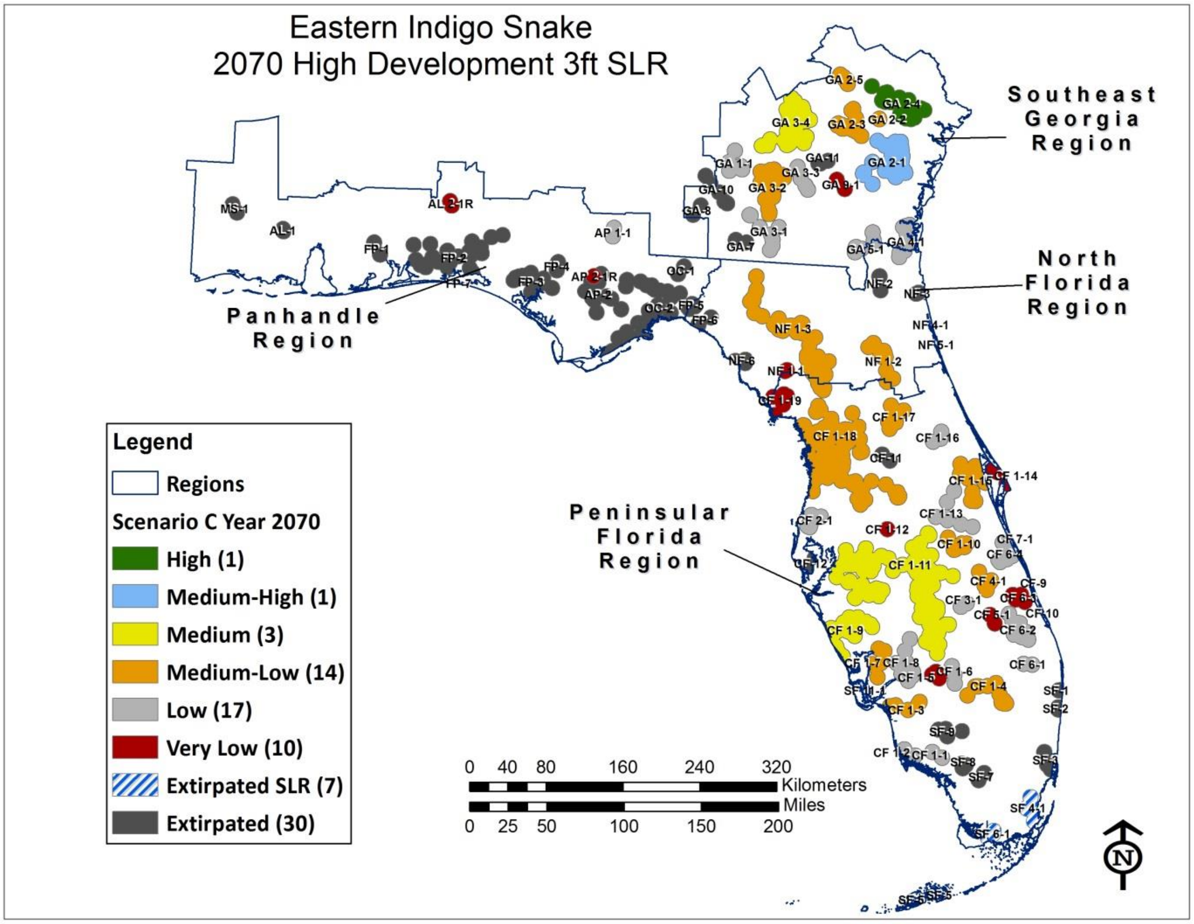


Figure 30: Eastern indigo snake population resiliency condition classes for Scenario C (high development) at year 2050 (2 ft sea level rise) and year 2070 (3 ft sea level rise).

6.3.4 Scenario D (Targeted Conservation)

In Scenario D, moderate urbanization at year 2070 (Scenario B) is assumed with focused conservation efforts in Conservation Focus Areas (CFAs). Current population resiliency is maintained or improved within 16 proposed CFAs, with about 6 highly resilient populations across Southeast Georgia (3) and Peninsular Florida (3), 2 medium resilient populations are maintained in North Florida and at least 2 restored populations in the Panhandle (Figure 31). In all previous scenarios the 2 on-going repatriation sites remain in very low condition assuming conservation efforts are minimal at these sites, however with conservation focus these populations are assumed to be successful and in medium condition by year 2070. Medium resiliency for the repatriated sites is a conservative estimate. It may be possible for these populations to improve to medium resiliency before 2050 or a higher resiliency by 2070. In the conservation targeted scenario conservation efforts (i.e. funding) are expanded and up to 2 additional repatriated (or restored) populations in the Panhandle region are considered depending on the success of the on-going repatriation projects (AL 2-1R and AP 2-1R). Resiliency condition classes for each population are listed in Table D3 (Appendix D).

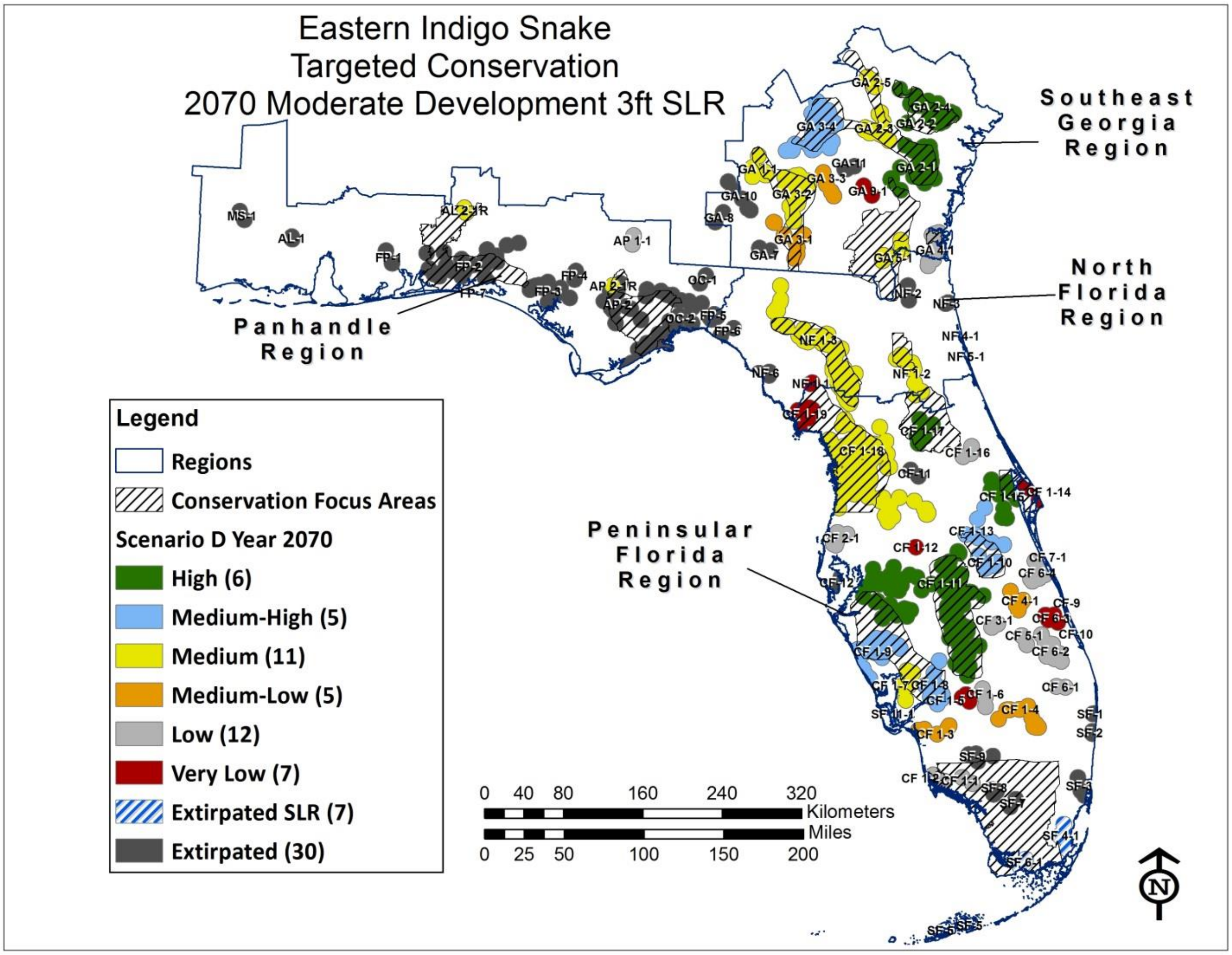


Figure 31: Eastern indigo snake population resiliency condition classes for Scenario D (conservation targeted) at year 2070 with moderate projected development and 3 ft sea level rise.

Future Condition Resiliency Summary

The resiliency of the eastern indigo snake declines across all scenarios and time steps, except the Targeted Conservation scenario where focused conservation maintains and potentially increases the number of highly resilient populations to 6 with numerous medium resilient (16) populations (Figure 32, Table D3 in Appendix D). Habitat losses due to urbanization, with some impact from sea level rise, contribute to the overall decline in the resiliency of eastern indigo snake populations. As expected the worst case scenario is the high development scenario (Scenario C) where 48 (out of 53) populations are projected to be low to very low or are extirpated and only one highly resilient population persists (GA 2-4, Fort Stewart) (Figure 32). Projected population resiliency declines across scenarios (A-C) and timesteps where high and medium resilient populations decline to low and very low with increased development over time and only one highly resilient population is expected to persist.

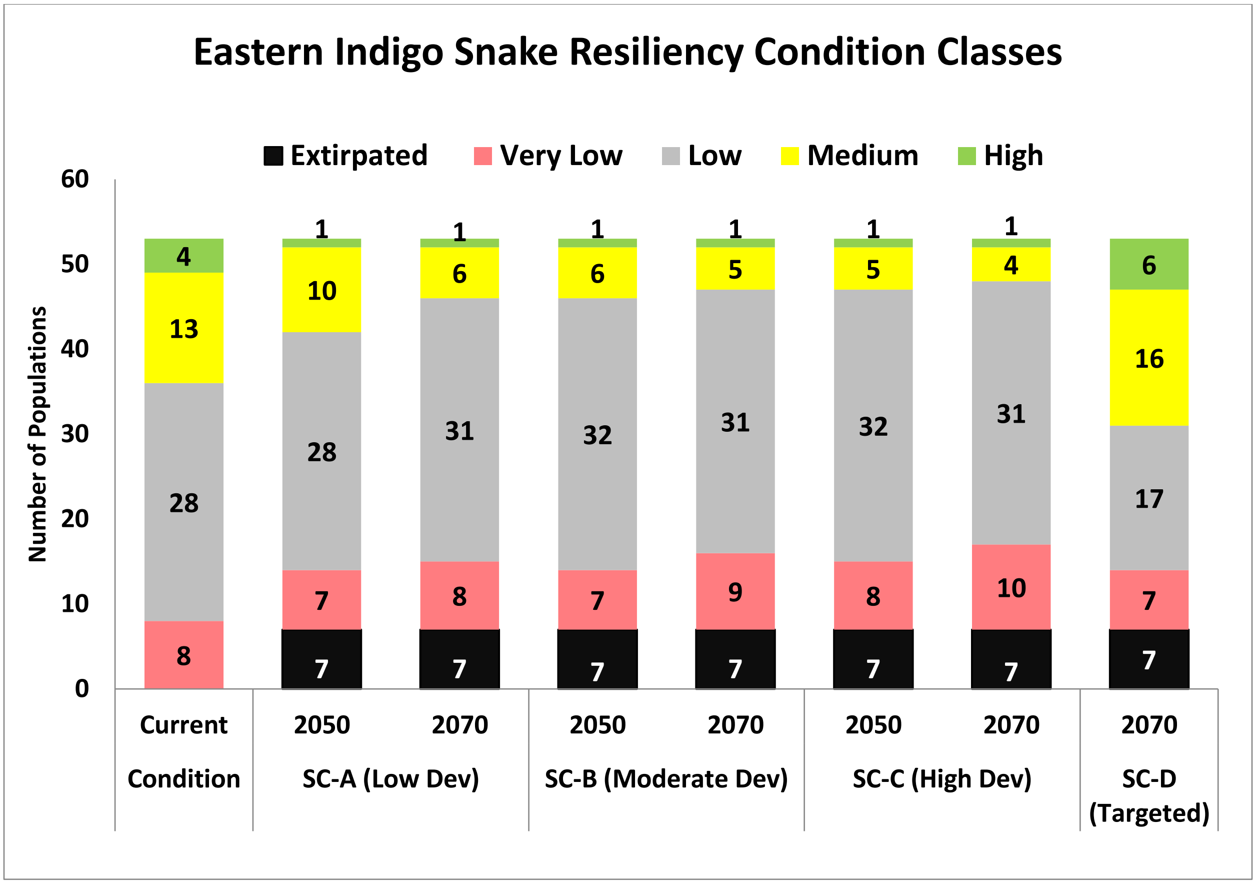


Figure 32: Comparison of the number of eastern indigo snake populations in each resiliency condition class across all scenarios and time steps. There are 30 extirpated historical populations not shown on graph.

6.4 Representation and Redundancy

In the current condition, representation and redundancy are limited because there are no high to medium resilient populations in the Panhandle region, however the other the regions have one high to ten medium resilient populations. In the future, ecological and genetic representation (north-south and east-west gradients) decrease in Scenarios B and C (high or medium resilient populations are absent from the Panhandle and North Florida regions), and the redundancy of high to medium resilient populations is considerably decreased from the current condition (Figure 33). Most notably for Scenarios A, B and C no highly resilient populations remain in Peninsular Florida, medium resilient populations are lost by 2070 (Scenario A) in the North Florida region, and high to medium resilient populations remain absent from the Panhandle (Figure 33). Redundancy of resilient (high to medium) populations is lost in the North Florida region. Furthermore, all island populations of eastern indigo snakes are likely lost (with the possible exception of CF 1-14, see Martin *et al.* 2018) by 2050 due to both sea level rise and urbanization. Although the ecological and genetic uniqueness of island populations of eastern indigo snakes has not been studied, these population losses exemplify further declines in representation and redundancy for the species.

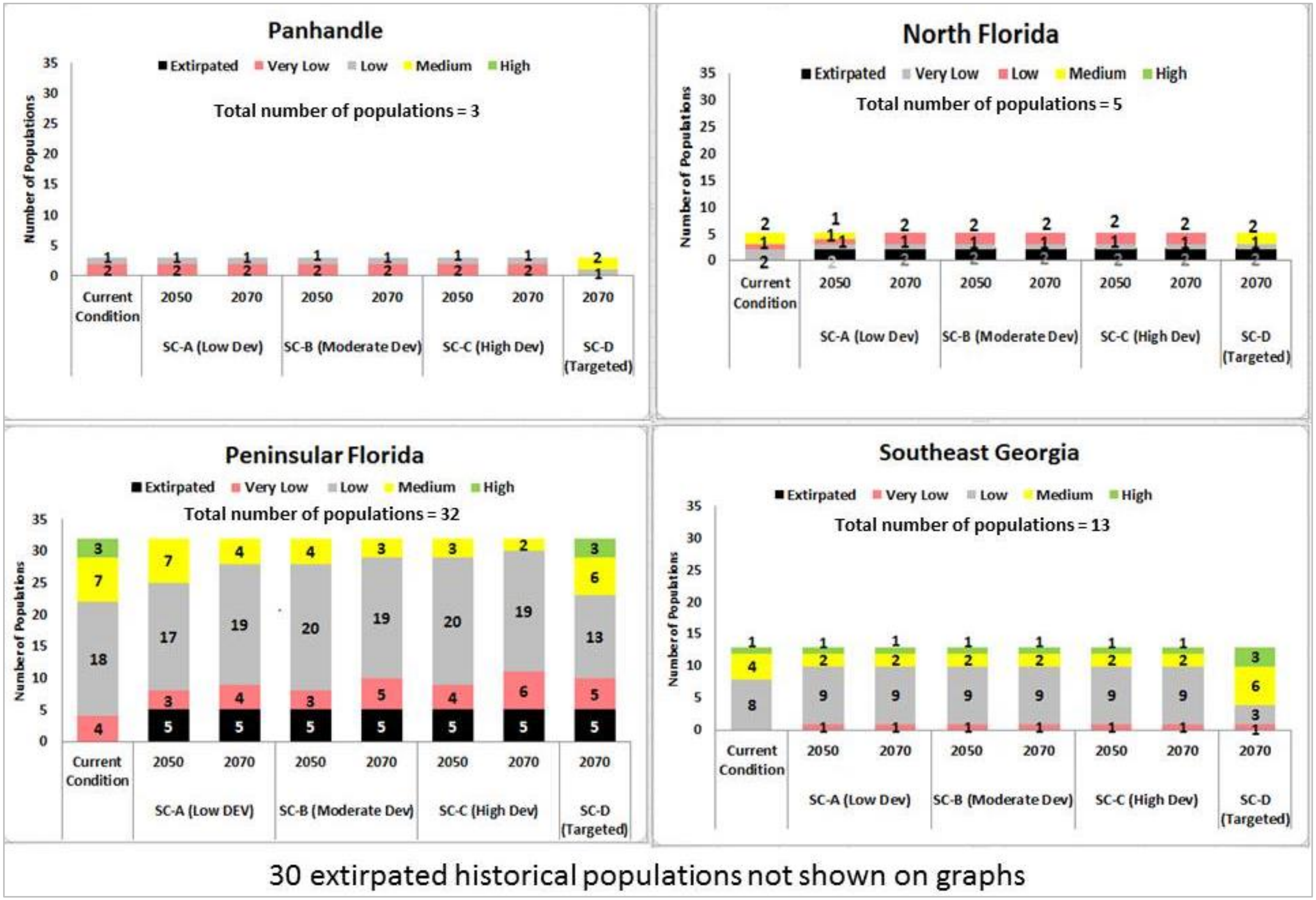


Figure 33: Future eastern indigo snake populations and their resiliency condition classes by Regions.

6.5 Future Condition Summary

Based on our assessment, future overall eastern indigo snake population resiliency is low to very low. In the future Scenarios A-C, the majority (66 to 77%) of the currently extant populations (53) are expected to be in low to very low resiliency condition and 13% (7) are likely to be extirpated. High to medium resiliency are predicted for 9-22% of the extant populations. In contrast, for the conservation focused scenario, low to very low condition populations make up 45% of the extant population and high and medium resilient populations make up 11 and 30% of the total, respectively. Medium to low and very low resiliency populations occupy about 12-30% and 65-85%, respectively, of the total current population extent (Table 10). The highly resilient eastern indigo snake population in the Southeast Georgia region occupies about 3% of the total current population extent. The Southeast Georgia population (GA 2-4, Fort Stewart) is the only population that remains highly resilient in all future scenarios without targeted conservation. The most significant shifts in resiliency occur first between current condition and year 2050 (any scenario) where number of extant populations that are highly resilient (Figure 32) and their population extent (Table 10) declines considerably. Also while the number of populations that have low to very low resiliency is about the same across scenarios and time (Figure 32), the extent of those populations increases (Table 10). The next considerable drop in resiliency is apparent in Scenario B by year 2070 when the number of populations in medium resiliency (Figure 32) and their population extent (Table 10) declines by about half from the current condition. The decline of populations in North Florida and the northern portion of Peninsular Florida are important losses in representation and redundancy and may have significant implications for long-term genetic connectivity across the range.

Table 10: Percent of current population extent (area) within each resiliency condition class by scenario.

	Resiliency Class			
Scenario	**High (%)**	**Medium (%)**	**Low (%)**	**Very Low (%)**
Current	17	34	45	4
Scenario A 2050 (Low Dev)	3	30	45	22
Scenario A 2070 (Low Dev)	3	25	48	24
Scenario B 2050 (Moderate Dev)	3	25	50	22
Scenario B 2070 (Moderate Dev)	3	13	59	25
Scenario C 2050 (High Dev)	3	13	60	24
Scenario C 2070 (High Dev)	3	12	59	26
Scenario D 2070 (Targeted)	14	42	20	25

Our analysis did not predict how the population extents might fragment into smaller, potentially less resilient, populations as a result of urbanization. For example in North Florida, population NF 1-3 declines from medium to medium-low. This population is heavily impacted by urbanization (habitat loss and fragmentation), but is assumed to retain viable gopher tortoise populations and overall habitat quantity is high (> 150,000 acres, see Table 2 in section 5.2). However, resiliency may be lower than predicted for this population due to the extensive habitat fragmentation caused by the projected level of urbanization (about 50% habitat loss predicted, Figure 34). This level of fragmentation would likely cause this population to fragment into smaller and less connected populations; especially because of the amount of conservation land is minimal in this region (<25% of habitat is on conservation land). Population NF 1-3 is of particular interest because this population may be an important link among the all the other regions and may provide critical gene flow that supports the ecological and genetic diversity for the species. Other populations, particularly in northern portion of Peninsular Florida (e.g. CF 1-11 and CF 1-18), may also experience similar fragmentation effects due to urbanization and larger populations may fragment into smaller populations.

Other influencing factors not directly assessed in the future condition estimates include habitat loss and degradation from other land uses such as agriculture, forestry and mining. These land uses are likely to have some effect on populations that are projected to be less impacted by urbanization, such as populations in Southeast Georgia. Development and implementation of conservation actions within the Conservation Focus Areas may provide opportunities to reduce overall impacts to the species. However, eastern indigo snake population declines may still occur from cumulative, unsustainable mortality from vehicular traffic even if there are no appreciable declines in habitat quantity and quality (Godely and Moler 2013).

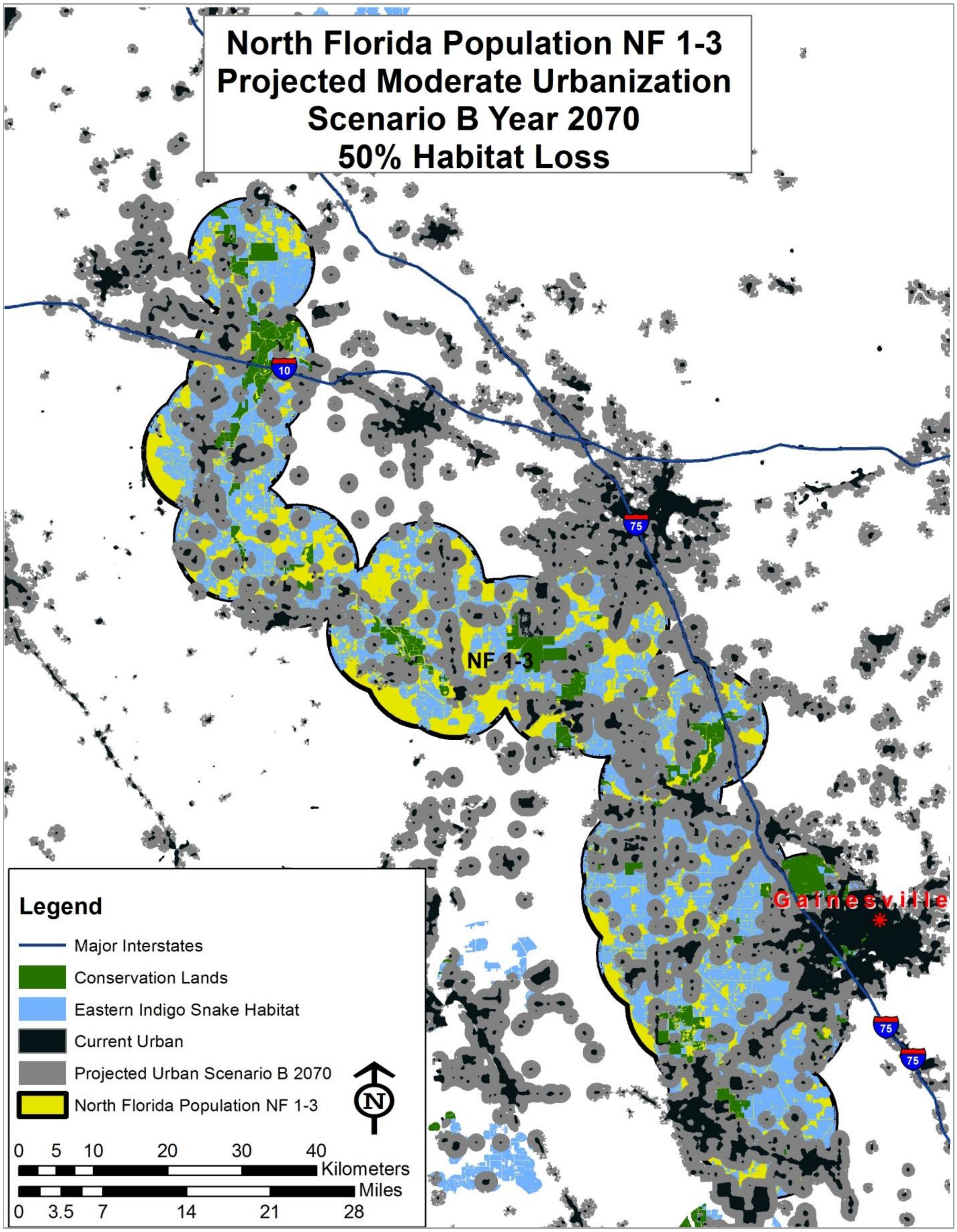


Figure 34: Projected urbanization in Scenario B (moderate development) at year 2070 of Population NF 1-3 in the North Florida Region.

6.6 Status Assessment Summary

The current distribution for the eastern indigo snake has contracted from its historical distribution. Some of the range contraction has occurred since listing under the ESA, particularly in the Florida Panhandle (currently no resilient populations) due to the decline of gopher tortoise populations (Enge *et al.* 2013); however conservation efforts are underway to repatriate gopher tortoise and eastern indigo snake populations in this region. The overall current population resiliency is medium to low and is predicted to be low to very low in the future without targeted conservation efforts. The eastern indigo snake faces a variety of negative influencing factors from habitat fragmentation and loss, and direct mortality that are predicted to be exacerbated by urbanization and sea level rise. At least seven island populations are predicted to be extirpated due to sea level rise and many decline in resiliency as a result of urbanization. Future ecological and genetic representation decreases due to loss of resilient populations in the North Florida region, lowering the species' potential to adapt to changing environmental conditions. Low (in Southeast Georgia and Peninsular Florida) to no (in Panhandle and North Florida) redundancy in representative areas increases the species' risk to catastrophic events. One population is predicted to remain highly resilient without targeted conservation efforts aimed to protect and repatriate populations. On-going conservation efforts (e.g. gopher tortoise conservation, habitat conservation and repatriation) are positively influencing the eastern indigo snake and are key to mitigating negative factors and ensuring long-term viability of the species. Table 11 provides a summary of the current and future conditions of the eastern indigo snake organized by the 3Rs.

Table 11: Summary of the current and future conditions of the eastern indigo snake "3Rs."

The 3Rs Population and Species Needs	**Current Condition**	**Future Condition (Viability):** Projections based on future urbanization and sea level rise scenarios at years 2050 and 2070:
Resiliency (population level): • Large populations able to withstand stochastic events **Needs** • High habitat quantity • Habitat diversity • Low habitat fragmentation • Adequate shelter • Population connectivity	• 53 (of 83) extant populations • Population resiliency: 4 High 13 Medium 28 Low 8 Very Low 30 Extirpated	• 46 (of 83) extant populations. Seven lost to sea level rise, and 44 to 47 very low or extirpated. • Low urbanization rates: One highly resilient population and 6 to 10 medium resilient populations at 2050 and 2070, respectively. • Moderate urbanization rates: One highly resilient population and 5 to 6 medium resilient populations at 2050 and 2070, respectively. • High urbanization rates: One highly resilient population and 4 to 5 medium resilient populations at 2050 and 2070, respectively. • Targeted Conservation: Moderate urbanization rates are mitigated via habitat conservation & repatriation. By 2070, 6 highly resilient populations, 16 medium resilient and 2-4 populations repatriated.

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<table>
<tr><th>The 3Rs
Population and Species Needs</th><th>Current Condition</th><th>Future Condition (Viability): Projections based on future urbanization and sea level rise scenarios at years 2050 and 2070:</th></tr>
<tr><td>Representation (species level):
• Genetic and ecological diversity to maintain species adaptive potential

Needs
• Genetic variation exists between populations
• Ecological variation exists across geographic gradient</td><td>Compared to historical distribution:
• 3 of 4 regions represented, but considerable declines in occupancy across the regions (Panhandle* 97% loss, North Florida 56% loss, Southeast Georgia 32% loss and Peninsular Florida 42% loss)
• Genetic and ecological variation retained but with losses in key areas needed for connectivity</td><td>• 3 of 4 regions continue to be represented but with declines across all scenarios.
• All scenarios exhibit declines in representation due to population declines across genetic and ecological gradients.
• Low, Moderate and High Urbanization scenarios: No highly resilient and 2-7 medium resilient populations remain in Peninsular Florida; no high or medium resilient populations remain in the North Florida (by 2070) or occur in the Panhandle and one highly resilient and 2 medium resilient populations in Southeast Georgia.
• Island populations are mostly lost across all scenarios due to seal level rise.
• Targeted Conservation: Number of highly resilient populations increase in Southeast Georgia (3), and are maintained in Peninsular Florida (3). North Florida populations are maintained at medium levels and 2-4 Panhandle populations are repatriated.</td></tr>
<tr><td>Redundancy (species level):
• Number and distribution of populations to withstand catastrophic events

Needs
• Multiple resilient populations in each area of representation</td><td>• 30 of 83 historical populations extirpated
• Overall 48% decline in population extent
• 4 highly resilient populations:
Panhandle*: 0
North Florida: 0
Southeast Georgia: 1
Peninsular Florida: 3</td><td>• Low, Moderate and High Urbanization: Low (Southeast Georgia 2, Peninsular Florida 2-7) to no redundancy (North Florida, Panhandle) of medium resilient populations. No redundancy of highly resilient populations, only one remains in Southeast Georgia.
• Targeted Conservation: 6 highly resilient populations, 16 medium resilient populations retained in key areas and some populations restored (but at medium to low levels)
Panhandle: 0 High, 2-4 repatriated
North Florida: 0 High, 2 Medium
Southeast Georgia: 3 High, 6 Medium
Peninsular Florida: 3 High, 6 Medium</td></tr>
</table>

* Panhandle Region includes portions of Alabama, Florida, Mississippi and Georgia. See report for detail.

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APPENDIX A – Home Range Comparison Data and Habitat

Annual home range comparison data for eastern indigo snakes collected in specific locations from various studies using radio telemetry to track snake movements. All annual home range sizes were calculated using 100% minimum convex polygons or minimum bounding geometry.

State	Region	County	Study Authors	Sex	# of snakes	Mean in acres (ha)	Min in acres (ha)	Max in acres (ha)
FL	North FL	Levy	Moler 1985	M	5	348.4 (141.0)	79.1 (32.0)	694.4 (281.0)
FL	North FL	Putnam	Dodd and Barichivich 2007	M	1	457.9 (185.3)	457.9 (185.3)	457.9 (185.3)
FL	Peninsular FL (Central)	Highlands, Polk	Layne and Steiner 1996	M	12	183.6 (74.3)	na	492.2 (199.2)
FL	Peninsular FL (Central)	Highlands, Polk	Layne and Steiner 1996	F	7	46.0 (18.6)	na	120.1 (48.6)
FL	Peninsular FL (Central)	Highlands	Bauder *et al.* 2018, Bauder *et al.* 2016, Bauder 2018, Breininger *et al.* 2011	M	9	606.9 (245.6)	68.4 (27.7)	1127.3 (456.2)
FL	Peninsular FL (Central)	Highlands	Bauder *et al.* 2018, Bauder *et al.* 2016, Bauder 2018, Breininger *et al.* 2011	F	3	150.0 (60.7)	67.2 (27.2)	290.8 (117.7)
FL	Peninsular FL (SE)	Brevard, Indian River, Polk	Bauder *et al.* 2018, Bauder *et al.* 2016, Bauder 2018, Breininger *et al.* 2011	M	31	299.2 (121.1)	15.3 (6.2)	373.4 (151.1)
FL	Peninsular FL (SE)	Brevard, Indian River, Polk	Bauder *et al.* 2018, Bauder *et al.* 2016, Bauder 2018, Breininger *et al.* 2011	F	28	117.9 (47.7)	25.5 (10.3)	373.4 (151.1)

State	Region	County	Study Authors	Sex	# of snakes	Mean in acres (ha)	Min in acres (ha)	Max in acres (ha)
FL	Peninsular FL (SE and Central from above)	Combined Brevard, Highlands, Indian River, Polk	Bauder *et al.* 2018, Bauder *et al.* 2016, Bauder 2018, Breininger *et al.* 2011	M	40	368.4 (149.1)	15.3 (6.2)	1127.3 (456.2)
FL	Peninsular FL (SE and Central from above)	Combined Brevard, Highlands, Indian River, Polk	Bauder *et al.* 2018, Bauder *et al.* 2016, Bauder 2018, Breininger *et al.* 2011	F	31	121.1 (49.0)	25.5 (10.3)	373.4 (151.1)
FL	Peninsular FL (SE)	Martin	Jackson 2013	M	4	105.8 (42.8)	58.1 (23.5)	162.6 (65.8)
FL	Peninsular FL (SE)	Martin	Jackson 2013	F	1	24.0 (9.7)	24.0 (9.7)	24.0 (9.7)
FL	Peninsular FL (SW)	Collier	Metcalf 2018	M	4	546.1 (221.0)	511.5 (207.0)	575.8 (233.0)
FL	Peninsular FL (SW)	Collier	Metcalf 2018	F	1	279.2 (113.0)	279.2 (113.0)	279.2 (113.0)
GA	Southeast GA	Bryan, Liberty	Hyslop *et al*. 2014, Hyslop 2007	M	19	1260.2 (510.0)	345.9 (140.0)	3775.8 (1528)
GA	Southeast GA	Bryan, Liberty	Hyslop *et al*. 2014, Hyslop 2007	F	13	252.0 (102.0)	81.5 (33.0)	874.8 (354.0)

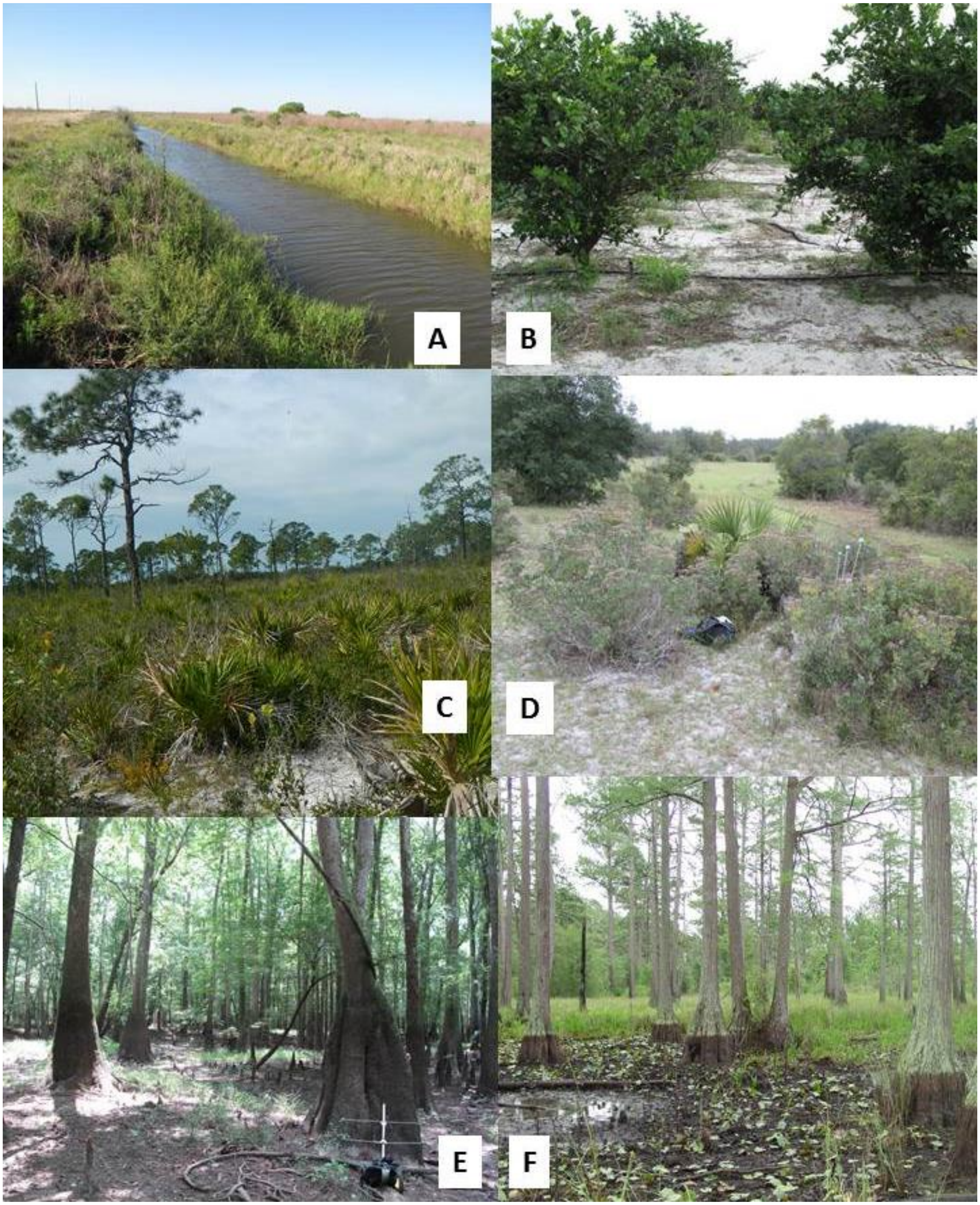

Figure A1: Eastern indigo snake habitat photos. (A) Canal System, FL; (B) Citrus Orchard, FL; (C) Coastal Dune, FL; (D) Scrubby Pasture, FL; (E) Bottomland Forest, GA; and (F) Cypress Pond, GA. Photos A & E by Javan Bauder/Orianne Society; Photo B by Lance Paden/Orianne Society; Photo C by Matt Metcalf; and Photo F by Dirk Stevenson.

APPENDIX B – Current Conditions Methods

Defining populations

The following rationale and assumptions were made when defining populations.
(1) Home range size versus linear movement data: Although we have good estimates of home range sizes for eastern indigo snakes in portions of the range (Appendix A), applying a home range area drawn as a circle around records could exclude a significant portion of the actual home range due to a wide variation in documented home range widths and shapes. Alternatively, we buffered records by maximum annual linear movement distance to estimate the potential maximum extent of the home range for a given record (Figure B1 below for illustration). This approach is inclusive and captures all the area possibly used by the eastern indigo snake responsible for a given record and therefore represents its biological potential to move in a given area. A similar approach was applied by Bauder *et al*. (2018, p.747) to define study areas (using 2.4 mi/3.86km as the buffer distance) for assessing influence of habitat variables on eastern indigo snakes in central Florida.

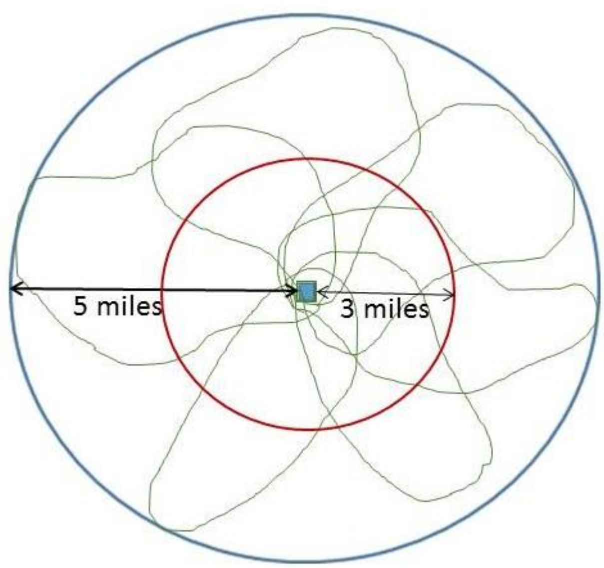

Figure B1: Illustration comparing estimation of home range extent, using maximum annual linear distance traveled versus using radius of a circle calculated based on maximum home range area. Green areas represent theoretical home ranges based on one record (blue square). Maximum distance moved within each home range is about five miles and maximum home range area is 1,528 ha (3,776 ac). The area of the red circle is 1,528 ha and its radius is about 3 miles. If actual home range areas are unknown, buffering an eastern indigo snake record by the maximum distance moved would overestimate actual area used by the snake but be less likely to exclude areas within the true home range.

(2) Five-mile buffer distance: Eastern indigo snake movements are known to vary between northern and southern populations (Appendix A) with northern populations generally having larger home ranges and moving longer distances. It is assumed that southern populations (Peninsular Florida) could also move 5 miles (one male was documented to travel about 4.3 mi (7 km) (Breininger and Bolt unpublished data), but may not need to move as far due to less of a dependency on winter habitats containing viable gopher tortoise populations (shelter), and/or incompatible land use restricts their ability to move. Also it is possible additional eastern indigo snakes, and their home ranges, may occur between records used in this assessment.

(3) Demographic connectivity: Eastern indigo snake genetic structure has been shown to have high levels of contemporary gene flow across its range and has been described as continuously distributed, isolated by distance, rather than discrete evolutionary lineages (Folt *et al*. 2019). The 5-mile distance, applied here, is assumed to represent this potential for demographic connectivity and source-sink population dynamics. We assume that eastern indigo snakes that are within 5 miles of each other have increased probability of population persistence (re-colonization of sites after a stochastic event or local extirpation) resulting from periodic addition of immigrants from sources to sinks (Carlson *et al.* 2014, p. 521) within the populations defined in this assessment (e.g. immigrants from an area with good quality habitat into an area adjacent to (sub)urban development). Dispersal of individuals over longer (greater than 5 miles) distances is rare but is important for population connectivity (i.e. genetic connectivity), which is important for reducing inbreeding (genetic rescue) and may contribute to evolution necessary for adapting to environmental changes (Carlson *et al*., p. 532).

Resiliency

Population Factors

1. **Population Extent**- Measured as the cumulative area of each population created by overlapping 5-mile (8-km) buffers of the eastern indigo snake records. The area of one 5-mile radius circle is 50,265 acres (20,342 ha). At least two records must be present within 5 miles of each other to be considered a potential population and included in the analysis. Therefore, the resilience categories were defined as: Low: <100,000 acres (<40,469 ha) represents records occurring very close to each other that may represent the same snake and would have a small population extent. Two or more records within 5 miles of each other but spaced relatively further apart would have population extent closer to 100,000 acres. Medium: 100,000 to 300,000 acres (40,469 to 121,405 ha); 150,000 acres (60,703 ha) represents 3 times the area of a 5-mile radius circle and would include at least 3 eastern indigo records. High: >300,000 (>121,405 ha) acres and represents numerous records distributed across a broad area.

Although some species may expand their home range when habitat quality declines (Van Horne 1983, entire), studies on eastern indigo snakes found that home ranges in urban and fragmented landscapes were significantly smaller than those of snakes in more natural landscapes (Breininger *et al.* 2011, Bauder *et al*. 2018, p. 13). Although home ranges of eastern indigo snakes tracked in Georgia showed some degree of overlap (Hyslop *et al.* 2014, p.106), same-sex home range overlap was reported to be generally very low in Peninsular Florida (Bauder *et al*. 2016, p. entire). Therefore, we assume there is increased potential for more individuals to interact within larger population extents and therefore resiliency increases.

2. **<u>Population Connectivity</u>**- Measured as the overlap and presence of connected suitable habitat among populations within a 5-mile buffer around populations. This "population connectivity buffer" is represented by a 10-mile buffer around eastern indigo snake records (or a 5-mile buffer from record = population plus an additional 5-mile buffer to assess overlap (i.e. connectivity) among populations).

   Connectivity to other populations is critical in maintaining gene flow and ability to adjust to changing conditions. Primary and secondary roads represent significant barriers to connectivity. Bauder *et al.* (2018, p. 751) found that eastern indigo snakes had a "near zero" probability of crossing primary and secondary roads (defined below under 5. Tertiary Road Density). Furthermore, snakes need suitable habitat to successfully move across the landscape. Therefore, we counted the number of overlapping "population connectivity buffers" for each population. Then we examined the habitat (using the Eastern Indigo Snake Habitat Model, Appendix C) within the overlapping area. Populations were considered "connected" if habitat patches were present between populations and were not bisected by one or more primary or secondary roads. Resilience categories were defined as: High: population connected to 2 or more populations, Medium: population connected to at least 1 other population, Low: population connectivity buffer overlaps with at least one other population connectivity buffer but is fragmented by a major road (primary or secondary). Very Low: population is not connected to another population. See Figure B2 for illustration.

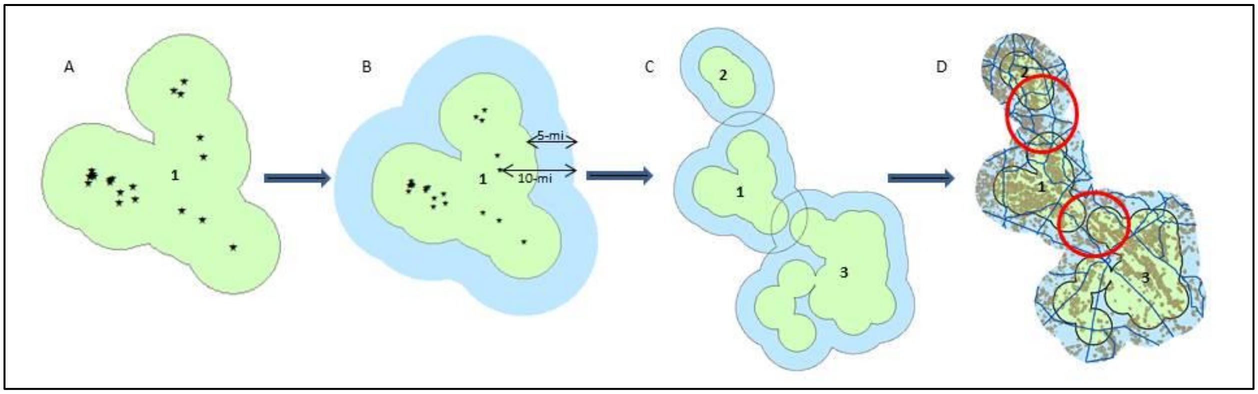

Figure B2: Example of eastern indigo snake population connectivity. (A) Represents eastern indigo snake records with merged 5-mile buffers to delineate population 1 (see Figure 20). (B) Population 1 with additional 5-mile buffer (in blue) around records to delineate population connectivity buffer. Total 10-mile buffer around records. (C) Three delineated populations with overlapping population connectivity buffers. (D) Assessment of habitat and roads between populations with overlapping buffers (within red circles). In this example, populations 1 and 3 would be considered connected because there is habitat between populations and no primary or secondary roads bisect the habitat. Populations 1 and 2 are not connected due to roads bisecting habitat.

Habitat Factors

1. **Habitat Quantity and Type**: A Geographic Information Systems (GIS) model was generated for the eastern indigo snake (Appendix C) to assess the current range-wide status of habitat availability and quality (Figure 22). Habitat patches were categorized as primary, secondary and tertiary habitat. Primary habitat identifies the characteristic natural upland habitats preferred by eastern indigo snakes across most of its range. Secondary habitats include other natural habitats, including lowlands, often important for foraging. Tertiary habitats include human-altered landscapes (e.g. pasture, citrus orchards) that may also support critical resource needs. For a complete description of the model methodology, refer to Appendix C. Because we know eastern indigo snakes have relatively large home ranges and conspecific overlap of eastern indigo snakes is generally low, it is assumed that habitat quantity requirements are relatively large. Therefore we assessed the total amount of habitat (primary + secondary + tertiary) for each population

   Resiliency categories were defined for habitat quantity (regardless of patch sizes) as high, medium, low and very low categories by assessing the total amount of habitat per population. High condition are those populations that have more than (>) 150,000 acres of habitat (more than half of the 300,000 acres population extent required for a High condition population extent score and Medium are those with 50,000-150,000 acres of habitat (half of the 100,000 – 300,000 acres population extent required for a Medium condition population extent score, and so on for Low and Very low conditions. Very Low are populations with less than 20,000 acres of total habitat. Habitat quantity measures total habitat regardless of patch size. The degree of fragmentation (size and number of habitat patches) is an important habitat factor and is considered as a separate measure of habitat quality (described below).

2. **Primary and Secondary Habitat:** Eastern indigo snakes require diversity in habitat types to support essential life functions of breeding, feeding, sheltering and nesting. They depend on (in northern portion of range) or prefer (southern portion of range) upland habitat types as their primary habitat. In the northern portion of the range they are highly dependent on sandhills with gopher tortoise burrows for shelter during winter months. In central and south Florida the dependence on gopher tortoises is less and they are known to use a variety of habitats and shelters, however, snakes continue to exhibit a strong preference to upland habitats (Bauder *et al*. 2018 pp. 754-755). Secondary habitat is also natural, but is generally hardwood, lowland and wetland dominated habitat types and is often used for foraging (feeding). It is believed that a combination of both primary and secondary habitat provides the best matrix of habitat types to support viable eastern indigo snake populations. Tertiary habitat represents potential foraging habitat, but are human altered such as citrus orchards and agricultural fields. Eastern indigo snakes are known to use these habitats, but generally will avoid citrus and pastureland (Bauder *et al.* 2018, p. 754). Tertiary habitat often has altered ecology and increased vulnerability to stressors (e.g. roads, predators, disease, human interaction, etc.) making these habitats of lower quality, therefore we assessed the percent of total habitat that is considered primary and secondary versus tertiary as a measure of habitat quality.

   Primary habitat (preferred habitat and important for all essential life functions) and secondary habitat were considered together as a measure of habitat quality because primary habitat varies between northern and southern populations such as upland dry hardwood forest (potentially considered secondary for northern populations and primary for southern populations). Together primary and secondary habitats are generally natural habitats that provide important habitat for eastern indigo snakes.

3. **Shelter (Gopher Tortoise):** We examined gopher tortoise population data gathered from the 2018 Gopher Tortoise CCA Annual report (CCA 2018); and data acquired from the States of Georgia (unpublished data) and Florida (unpublished data). Throughout its range eastern indigo snakes require shelter for protection from temperature extremes and shelter from predators. In the northern parts of the range eastern indigo snakes are highly correlated with gopher tortoises and depend on the burrows for hibernacula during winter. In the central and southern portions of the range burrows remain important

shelter, but eastern indigo snakes may use other types of shelter where gopher tortoise burrows are absent or in low densities.

For each population the presence of Gopher Tortoise Minimal Viable Populations was assessed. Minimum Viable Population (MVP) for the gopher tortoise is 250 adults with a density of no less than 0.4 tortoises/ha and that the minimum reserve size for a MVP to persist is 100 ha of superb habitat. Primary Support Populations are populations with between 50-250 adults which are candidates for population restoration by improving habitat to increase natural recruitment, or through population augmentation to attain MVP status. By definition, Primary Support Populations must occur on sites large enough to sustain a MVP. Secondary Support Populations are populations of <50 adults, some of which are constrained from reaching primary support status because of limited habitat or management options. Secondary Support Populations are important for education, community interest, or can be used for augmentation purposes. If sufficient potential habitat is present and managed, Secondary Support Populations are candidates for habitat restoration and/or population augmentation to attain Primary Support Population or MVP status (Gopher Tortoise Council 2014).

We counted the number of all MVPs, primary, and secondary support gopher tortoise populations for each eastern indigo snake population. A comparative Gopher Tortoise score was calculated for each population by dividing the number of gopher tortoise populations by 50,265 ac. The area of a circle with a radius of 5 miles is 50,265 ac. This area represents the possible maximum extent of an eastern indigo snake occurrence and is the minimum size of an eastern indigo snake population as defined in this assessment.

4. **Habitat Fragmentation:** Using the Eastern Indigo Snake Habitat Model (Appendix C), fragmentation was assessed by calculating the area of habitat patches of different sizes for each population. Habitat patches for this assessment could contain all three types of habitat (primary, secondary and tertiary). Breaks in habitat patches reflect significant breaks in habitat connectivity or non-habitat between patches and often were due to primary or secondary roads, major water bodies and other areas of non-habitat. It has been suggested that eastern indigo snake populations that occur on lands with multiple habitat patches of at least 2,500 ac (1,000 ha) (i.e. >5,000 ac), with few roads or human-altered habitats which increase habitat fragmentation and mortality, may have the best chance of long-term viability (Moler 1992, Breininger *et al*. 2004). A recent study suggested 2,500 ac is too small to support even a single pair of eastern indigo snakes and suggested about 12,000 – 22,000 ac (5,000 – 9,000 ha) of unfragmented habitat is needed to sustain eastern indigo populations in central Florida (Bauder 2018, p. 160). A modeling study by Sytsma *et al.* (2012, pp. 39–40) estimated a reserve size of 10,000 ac (4,047 ha) to be sufficiently large to support a small population of eastern indigo snakes.

However, Hyslop *et al.* (2014, p.109) reported that the collective extent of eastern indigo snakes studied around Fort Stewart in Southeast Georgia, where the snakes are believed to travel the farthest distance, was about 20,000 to 35,000 ac (8,000 to 14,000 ha). We used these suggestions from the literature to develop rules to classify the fragmentation of populations as shown in Table 2 (Section 5.2 in report). Therefore, populations with more than 75% of habitat patches that are >10,000 acres (or 50% are >20,000 acres) are considered High and populations where more than 50% of the patches are less than 5,000 acres are considered Very Low resiliency. Medium and Low resiliency condition classes are intermediate to High and Very Low. Resiliency increases as the proportion of patches size increases.

5. **Tertiary Road Density**: Primary and secondary roads can contribute to isolation and fragmentation of eastern indigo snake populations because they often avoid these types of roads. However, eastern indigo snakes have been found to readily cross tertiary roads subjecting individuals to road mortality which can contribute to population declines and conservation of large tracts of undeveloped land with low densities of tertiary roads is needed (Bauder *et al.* 2018, p. 759). Therefore, the density of tertiary roads was assessed as a measure of habitat quality for each population segment.

   Tertiary road density is calculated as miles of road per population divided by 50,265 acres. The area of a circle with a radius of 5 miles is 50,265 ac. This area represents the possible maximum extent of an eastern indigo snake occurrence and is the minimum size of an eastern indigo snake population as defined in this assessment. Thresholds for High to Very Low were determined based on the distribution of road density across all populations. Transportation data (or road data) were acquired for each state (AL, FL, and GA) from the USGS National Map: National Transportation Dataset (USGS 2017). Primary, secondary and tertiary roads were grouped similar to Bauder *et al.* (2018) using the feature class code definitions as follows:

   PRIMARY ROADS = S1100 Primary Road Road/Path Features: Primary roads are generally divided, limited-access highways within the interstate highway system or under state management, and are distinguished by the presence of interchanges. These highways are accessible by ramps and may include some toll highways.
   SECONDARY ROADS= S1200 Secondary Road Road/Path Features: Secondary roads are main arteries, usually in the U.S. Highway, State Highway or County Highway system. These roads have one or more lanes of traffic in each direction, may or may not be divided, and usually have at-grade intersections with many other roads and driveways. They often have both a local name and a route number.
   TERTIARY ROADS= S1400 Local Neighborhood Road, Rural Road, City Street Road/Path Features: Generally a paved non-arterial street, road, or byway that usually

has a single lane of traffic in each direction. Roads in this feature class may be privately or publicly maintained. Scenic park roads would be included in this feature class, as would (depending on the region of the country) some unpaved roads.
NOT ASSESSED= S1500 Vehicular Trail (4WD) Road/Path Features: An unpaved dirt trail where a four-wheel drive vehicle is required. These vehicular trails are found almost exclusively in very rural areas. Minor, unpaved roads usable by ordinary cars and trucks belong in the S1400 category.

DEFINITIONS can be found at (https://www.census.gov/geo/reference/mtfcc.html)

6. **Percent (%) Urbanized:** Urbanization destroys and fragments habitat and increases direct mortality due to increased human contact. While eastern indigo snakes have been observed entering urban and suburban areas (Breininger *et al*. 2004, p.15), in general eastern indigo snakes avoid urbanized areas (Bauder *et al.* 2018, p.754). Urbanized area is assumed to be correlated with the habitat factors above especially tertiary roads (Figure B3). For instance, habitat quantity and shelter site availability are assumed to decrease with increasing urban area, and habitat fragmentation and tertiary road density is assumed to increase with increased urban area. However, factors such as direct mortality from increased human and predator interaction would also increase with increasing urban area. Therefore as an additional measure of habitat quality, we assessed percent urbanized area for each population using the base model (2010) of the SLEUTH (Slope, Land use, Excluded area, Urban area, Transportation, Hillside area) model (Terando *et al.* 2014, p. 2). Percent of urbanized area was calculated for each population segment using the base model (2010) of the SLEUTH (Slope, Land use, Excluded area, Urban area, Transportation, Hillside area) model (Terando *et al.* 2014, p. 2). Eastern indigo snake response to specific thresholds of urban area are not known, however research on the impact of urban land cover and percent impervious surfaces provide a reasonable scale. Most watershed indicators decline when impervious surface exceeds 10% with severe degradation beyond 30% (CWP 2003, p1). Therefore thresholds for urban cover (i.e. impervious surface) were High <5%; Medium 5-10%; Low 11-30% and very low >30%.

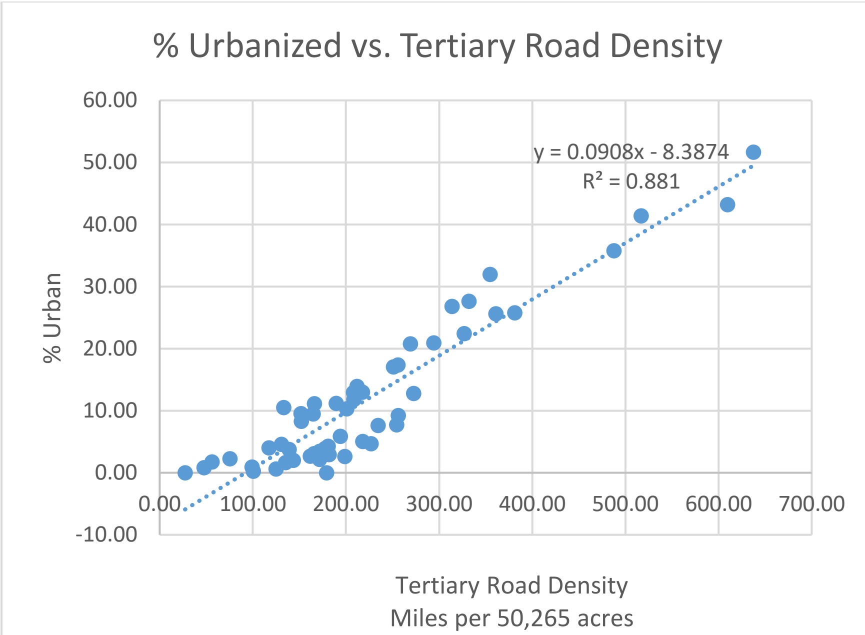

Figure B3. Correlation between tertiary road density and percent urban area used in this report.

Rational for weighting habitat factors in Table 2 (Section 5.2 in Report)

First, eastern indigo snake populations were assigned a score ("high" to "very low" represented by the numerical values of 4 to 1, respectively) for each population and habitat factor as described in Table 2 above. The population factors (population extent and connectivity) were considered equally important when estimating the combined population score, which was simply an arithmetic average of the two factors. To estimate the combined habitat score, habitat factors were given a baseline weight of 1 and then we adjusted the weights depending on their importance to eastern indigo snakes as documented in the literature. For northern populations gopher tortoise presence was given a weight of 2 because of the snake's apparent dependence on gopher tortoise burrows for winter shelter sites compared to southern populations which was given a weight of 1. Because eastern indigo snakes have large home ranges, habitat fragmentation may have significant negative impacts on long-term population viability. Therefore, habitat fragmentation was given a weight of 2 for both northern and southern populations. Additionally due to the impact of direct mortality from tertiary roads, this factor was weighted as 1.5 for both northern and southern populations. Percent urban is highly correlated with tertiary roads (Figure B3), but also represents additional negative factors such as direct mortality from increased human and predator interaction. Therefore percent urban was given a weight of 0.5, giving tertiary roads and percent urban a cumulative weight of 2. The remaining habitat factors, habitat quantity and type, were each given a baseline weight of 1. Table B1 summarizes the assigned weights for the habitat factors.

Table B1: Summary of importance weights assigned to each population and habitat factor

POPULATION FACTORS		HABITAT FACTORS					
Population Extent	Population Connectivity	Habitat Quantity	Fragmentation	Tertiary Road Density	% Urban Area	Gopher Tortoise (Shelter)	Habitat Type
1	1	1	2	1.5	0.5	2 Northern Populations 1 Southern Populations	1

Next, using the scores and weights described above, we calculated a total population factor score and total habitat factor score for each eastern indigo snake population, which resulted in a continuous numerical value ranging between 1 and 4, and we assigned a condition class of High, Medium, Low or Very Low as described in Table B2.

Table B2. Resiliency condition classes assigned to total population factor score and total habitat factor score for each population.

Condition Class	High	Medium	Low	Very Low
Score Range (equal intervals)	3.26-4	2.56-3.25	1.76-2.55	1-1.75

Finally, we summarized overall current condition resiliency classes for each eastern indigo snake population by combining the total population and habitat condition classes (e.g. Population Condition Class = Medium (M) and Habitat Condition Class = High (H), Overall Current Condition Class = Medium-High (M-H); or Population Condition Class = Medium (M) and Habitat Condition Class = Low (L), Overall Current Condition Class = Medium-Low (L-M); or Population Condition Class = High (H) and Habitat Condition Class = Low (L), Overall Current Condition Class = Medium (M)). The intermediate condition classes (medium-high and medium-low) provide some insight to populations that are near the thresholds of the high condition class (medium-high) or medium condition class (medium-low), but are considered medium and low in overall condition, respectively. See Table B3 for calculations for each eastern indigo snake population. Figure 23 (in report) depicts each population and its estimated overall current resiliency condition class (Table B3 for naming conventions for each population).

It is fairly well-understood that eastern indigo snakes need large amounts of unfragmented natural, undeveloped habitat (with an emphasis on upland habitat types) because eastern indigo snakes have large home ranges and move considerable distances. Fragmentation is the result of primary and secondary roads, areas of non-indigo snake habitat (such as urban landcover), or large bodies of water that create patches of habitat in the habitat model. Habitat fragmentation can create too many "edges" that result in increased snake mortality (Breininger *et al.* 2012, p. 366) due to the snake's large home range and increased exposure to various threats (roads, predators, invasive species, etc.). Additionally, habitat management can be negatively impacted by fragmentation, such as the ability to conduct prescribed fires. Therefore habitat fragmentation was given a weight of 2. Gopher tortoises (burrows) are critically important to northern populations of eastern indigo snakes and used opportunistically in southern populations, therefore presence of gopher tortoise populations was given a weight of 2 for northern populations, and a weight of 1 for southern populations. Tertiary roads do not generally create fragmentation within the habitat model (Appendix C) but these types of roads are believed to increased direct snake mortality from vehicular strikes because eastern indigo snakes will readily cross these roads compared to primary and secondary roads (Bauder *et al*. 2018, p. 757), therefore tertiary roads was given a weight of 1.5. Percent urban is highly correlated with tertiary roads (Appendix B, Figure B3), but also represents increased influencing factors such as direct mortality from increased human and predator interaction. Therefore percent urban was given a weight of 0.5, giving tertiary roads and percent urban a cumulative weight of 2. The remaining habitat factors, habitat quantity and type, were each given a baseline weight of 1.

Table B3: Current condition resiliency scores for 83 eastern indigo snake populations. See Table 2 in report for condition category definitions.

Region	Population Name	Population Factors				Habitat Factors								Overall Population Resiliency Score
		Population Extent	Population Connectivity	Combined Population Score		Habitat Quantity	Fragmentation	Tertiary Road Density	% Urbanized	Gopher Tortoise (shelter)	Habitat Type	Combined Habitat Score		
North Florida	NF 1-1	2	2	2.0	L	1	1	2	2	1	2	1.43	VL	VL
North Florida	NF 1-2	3	1	2.0	L	4	3	3	2	4	3	3.31	H	M
North Florida	NF 1-3	4	2	3.0	M	4	2	2	3	4	2	2.81	M	M
North Florida	NF 4-1	2	1	1.5	VL	1	1	4	2	4	4	2.75	M	L
North Florida	NF 5-1	2	1	1.5	VL	1	1	1	1	1	4	1.43	VL	VL
Panhandle	AL 2-1R	2	1	1.5	VL	3	4	4	4	4	3	3.75	H	VLX
Panhandle	AP 1-1	2	1	1.5	VL	2	1	4	4	4	3	2.88	M	L
Panhandle	AP 2-1R	2	1	1.5	VL	2	3	4	4	4	3	3.38	H	VLX

Region	Population Name	Population Factors				Habitat Factors								Overall Population Resiliency Score
		Population Extent	Population Connectivity	Combined Population Score		Habitat Quantity	Fragmentation	Tertiary Road Density	% Urbanized	Gopher Tortoise (shelter)	Habitat Type	Combined Habitat Score		
Southeast Georgia	GA 1-1	3	2	2.5	L	3	2	3	3	4	3	3.00	M	L-M
Southeast Georgia	GA 2-1	4	3	3.5	H	4	2	3	4	3	3	2.94	M	M-H
Southeast Georgia	GA 2-2	2	3	2.5	L	2	3	2	3	4	4	3.06	M	L-M
Southeast Georgia	GA 2-3	3	3	3.0	M	3	2	3	4	2	3	2.56	M	M
Southeast Georgia	GA 2-4	4	3	3.5	H	4	3	3	3	4	4	3.50	H	H
Southeast Georgia	GA 2-5	3	1	2.0	L	2	2	3	4	4	3	2.94	M	L-M
Southeast Georgia	GA 3-1	3	1	2.0	L	3	1	3	4	2	3	2.31	L	L
Southeast Georgia	GA 3-2	4	2	3.0	M	3	2	4	4	3	3	3.00	M	M
Southeast Georgia	GA 3-3	3	2	2.5	L	3	2	3	4	4	3	3.06	M	L-M
Southeast Georgia	GA 3-4	4	2	3.0	M	4	3	4	4	4	3	3.63	H	M-H
Southeast Georgia	GA 4-1	3	1	2.0	L	3	3	3	2	3	3	2.94	M	L-M
Southeast Georgia	GA 5-1	3	1	2.0	L	3	2	3	4	3	3	2.81	M	L-M
Southeast Georgia	GA 9-1	2	2	2.0	L	2	1	3	4	2	2	2.06	L	L
Peninsular Florida	CF 1-1	2	3	2.5	L	2	1	4	4	1	4	2.43	L	L
Peninsular Florida	CF 1-2	2	3	2.5	L	2	2	3	2	1	4	2.36	L	L
Peninsular Florida	CF 1-3	3	1	2.0	L	3	3	2	2	2	3	2.50	L	L

Region	Population Name	Population Factors				Habitat Factors								Overall Population Resiliency Score
		Population Extent	Population Connectivity	Combined Population Score		Habitat Quantity	Fragmentation	Tertiary Road Density	% Urbanized	Gopher Tortoise (shelter)	Habitat Type	Combined Habitat Score		
Peninsular Florida	CF 1-4	3	3	3.0	M	2	3	3	4	1	1	2.36	L	L-M
Peninsular Florida	CF 1-5	2	3	2.5	L	2	2	2	2	1	1	1.71	VL	L
Peninsular Florida	CF 1-6	3	4	3.5	H	2	2	4	3	1	1	2.21	L	M
Peninsular Florida	CF 1-7	3	3	3.0	M	3	3	2	2	1	3	2.43	L	L-M
Peninsular Florida	CF 1-8	3	4	3.5	H	4	4	4	3	2	2	3.36	H	H
Peninsular Florida	CF 1-9	4	2	3.0	M	4	4	2	2	2	2	2.75	M	M
Peninsular Florida	CF 1-10	3	4	3.5	H	3	4	4	4	3	2	3.43	H	H
Peninsular Florida	CF 1-11	4	4	4.0	H	4	4	3	2	4	2	3.36	H	H
Peninsular Florida	CF 1-12	2	1	1.5	VL	1	1	2	2	1	2	1.43	VL	VL
Peninsular Florida	CF 1-13	3	4	3.5	H	4	4	3	2	1	2	2.69	M	M-H
Peninsular Florida	CF 1-14	2	1	1.5	VL	2	1	3	3	1	4	2.14	L	L
Peninsular Florida	CF 1-15	4	3	3.5	H	4	3	3	2	2	3	2.81	M	M-H
Peninsular Florida	CF 1-16	3	1	2.0	L	2	1	1	1	1	4	1.57	VL	L
Peninsular Florida	CF 1-17	3	1	2.0	L	4	4	4	4	1	3	3.43	H	M
Peninsular Florida	CF 1-18	4	2	3.0	M	4	2	2	2	4	3	2.88	M	M
Peninsular Florida	CF 1-19	3	1	2.0	L	2	1	3	4	1	2	1.93	L	L

Region	Population Name	Population Factors				Habitat Factors								Overall Population Resiliency Score
		Population Extent	Population Connectivity	Combined Population Score		Habitat Quantity	Fragmentation	Tertiary Road Density	% Urbanized	Gopher Tortoise (shelter)	Habitat Type	Combined Habitat Score		
Peninsular Florida	CF 2-1	3	1	2.0	L	3	3	1	1	1	3	2.14	L	L
Peninsular Florida	CF 3-1	2	2	2.0	L	2	2	4	4	1	1	2.29	L	L
Peninsular Florida	CF 4-1	3	2	2.5	L	3	4	4	4	3	2	3.43	H	M
Peninsular Florida	CF 5-1	2	3	2.5	L	2	2	3	3	1	1	2.00	L	L
Peninsular Florida	CF 6-1	2	1	1.5	VL	2	4	3	2	1	4	2.69	M	L
Peninsular Florida	CF 6-2	3	3	3.0	M	3	2	4	4	1	1	2.43	L	L-M
Peninsular Florida	CF 6-3	3	1	2.0	L	2	1	1	2	1	1	1.21	VL	VL
Peninsular Florida	CF 6-4	3	1	2.0	L	3	2	1	2	1	3	1.93	L	L
Peninsular Florida	CF 7-1	2	1	1.5	VL	1	1	1	1	1	4	1.43	VL	VL
Peninsular Florida	CF 8-1	2	1	1.5	VL	1	1	3	4	1	1	1.64	VL	VL
Peninsular Florida	SF 4-1	3	1	2.0	L	2	1	1	1	1	4	1.57	VL	L
Peninsular Florida	SF 6-1	2	1	1.5	VL	1	1	4	4	1	4	2.29	L	L
Peninsular Florida	SF 11-1	2	1	1.5	VL	1	1	2	2	4	4	2.14	L	L

H= High; M-H= Medium-High; M= Medium; L-M= Medium-Low; L= Low; VL= Very Low. AL2-1R* and AP2-1R* are repatriation sites. Both have good habitat conditions, but population numbers are low, reintroductions are on-going and these populations are not considered viable at this time. Therefore, overall condition for these two sites is considered Very Low or Extirpated (VLX). There are 30 extirpated populations shown in Figure 21 in section 5.1 of the report that are not included in this table.

Representation and Redundancy

Population Extent (%) Decline- Using the approach described in section 5.1 in the report to define populations; we assessed changes in population extent by comparing historical and current distribution data to assess overall changes in distribution and range for the eastern indigo snake. Declines in population extent may reflect overall declines in abundance of individuals. Enge *et al.* (2013, p. 296) suggest that recent non-detection of the species in a particular area where it was historically detected might indicate substantial population declines or even extirpation. Population extent was calculated as the sum of the area created by two or more records within the 5 mile buffer. Population extent percent decline was measured as the change in extent (area) over time. “Over time” is described as the population extent of “recent” buffered records divided by the population extent of all buffered records (1936-2017). “Recent” records are those recorded post year 2000 as described by Enge *et al.* (2013).

Conservation Status

To estimate the amount of eastern indigo snake habitat that is on protected land we used the Protected Areas Database of the United States (PAD-US) produced by the USGS Gap Analysis Program. PAD-US is the official inventory of public parks and other protected open space held in trust by thousands of federal, state, and regional/local governments, as well as non-profit conservation organizations (Gergely and McKerrow 2016). The spatial data are available for download online and for the purposes of this report are current through 2016 (USGS 2016). We clipped the eastern indigo snake habitat produced by the habitat model (see Appendix C) by the eastern indigo snake populations. Then we clipped the eastern indigo snake habitat by the protected areas boundaries. Finally, we summarized the area of habitat within the protected areas (Table B6).

Table B6: Total habitat area, total protected habitat area and percent of total habitat protected within each region.

Region	Protected habitat (acres)	Total Habitat (acres)	Percent protected
Panhandle	49,729.80	129,664.22	38.3
North Florida	148,130.19	776,327.60	19.1
Peninsular Florida	1,662,059.42	3,939,922.73	42.2
Southeast Georgia	287,131.02	1,513,694.81	19.0
Total	2,147,050.43	6,359,609.36	33.8

APPENDIX C – Eastern Indigo Snake Rangewide Potential Habitat Model

A GIS model was generated for the eastern indigo snake to assess the current range-wide status of habitat availability and quality. The model identified 39.6 million acres (16.0 million ha) of potential habitat within the known range of the species; however only 16% of this area is within the known extent of eastern indigo snake populations (Figure 22, see section 5.2.2). The potential habitat within the current population extent of eastern indigo snakes (identified by buffering records by 5 mi as described in section 5.1) is estimated at 6.4 million ac (2.7 million ha). Habitat patches were categorized as primary, secondary and tertiary habitat. Primary habitat identifies the characteristic natural upland habitats preferred by eastern indigo snakes across most of its range. Secondary habitats include other natural habitats, including lowlands, often important for foraging. Tertiary habitats include human-altered landscapes (e.g. pasture, citrus orchards) that may also support critical resource needs.

Source Datasets Used

USGS National GAP Landcover - The GAP National Terrestrial Ecosystems – Ver 3.0 is a 2011 update of the National Gap Analysis Program Land Cover Data – Version 2.2 for the conterminous U.S. The GAP National Terrestrial Ecosystems – Version 3.0 represents a highly thematically detailed land cover map of the U.S. The map legend includes types described by NatureServe's Ecological Systems Classification (Comer et al. 2002) as well as land use classes described in the National Land Cover Dataset 2011 (Homer *et al.* 2015). These data cover the entire continental U.S. and are a continuous data layer. These raster data have a 30 m x 30 m cell resolution. The land cover map identifies 107 different land cover types within the range of the Eastern Indigo Snake.

GA Gopher Tortoise Model- With federal, state, and other partners, The Georgia Cooperative Fish & Wildlife Research Unit at the University of Georgia (UGA Research Unit), assessed the status of the gopher tortoise to inform listing and conservation management decisions to stabilize and recover gopher tortoise populations.

Using a comprehensive database of 63,354 occurrence records and expert input contributed by partners, the UGA Research Unit developed a range-wide species distribution model to identify and rank suitable habitat and measure the influence of environmental attributes on habitat suitability. Tortoise habitat suitability was positively associated with well-drained, sandy soils, compatible land cover, Topographic Position Index, and fire frequency and was highest for intermediate values of canopy cover. 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. The model output has a data range of 0 – 1, a continuous scale of habitat suitability from unsuitable habitat (0 Value) to suitable habitat (1 value). A suggested cutoff values to create a binary representation of potential habitat are 0.21 and 0.47, with 0.47 being a stricter cutoff value that minimizes the rate of false positives and negatives.

Tele Atlas U.S. Major Highways- Represents the major highways of the United States (Tele Atlas 2010). These include interstates, U.S. highways, state highways, and major roads.

Defining the range

The range of the eastern indigo snake was delineated by including all counties that overlapped an Eastern Indigo Snake range map (Enge *et al*. 2013, entire). We also included a small number of additional counties to shorten and make more linear the county boundary delineation. The county boundary delineation includes all parts of the Indigo's range; present, possible historical, likely extirpated, and extirpated.

Model Steps

The USGS National GAP Landcover dataset was clipped to the range of the indigo snake and reclassified three categories corresponding to eastern indigo snake habitat priorities: primary, secondary and tertiary habitats (Table C1). Primary habitat identifies the characteristic upland habitats used by eastern indigo snakes, secondary habitat identifies the foraging habitats used by eastern indigo snakes, and tertiary habitat identifies foraging habitats that are human altered. Our classification scheme was based upon expert opinion.

Table C1. Eastern Indigo Snake habitat classifications using the USGS National GAP landcover dataset.

Classification Codes: 0 = Non-indigo snake habitat within indigo range extent, 1 = Primary habitat within indigo extent, 2 = secondary habitat within indigo extent, 3 = tertiary habitat within indigo extent, 4 = Areas not classed in the landcover (i.e. classed as 0 in the landcover, such as disturbed/successional - grass/forb regeneration) but was identified as gopher tortoise habitat in the UGA Model (see description), and 99 = landcover classes outside the indigo extent.

Landcover Category Number	Landcover Category Name	Habitat Classification
84	Southern and Central Appalachian Oak Forest	0
290	South Florida Shell Hash Beach	0
291	Southeast Florida Beach	0
292	Southwest Florida Beach	0
388	Atlantic Coastal Plain Southern Beach	0
389	Florida Panhandle Beach Vegetation	0
410	East Gulf Coastal Plain Depression Pondshore	0
447	Atlantic Coastal Plain Central Salt and Brackish Tidal Marsh	0
451	Florida Big Bend Salt-Brackish Tidal Marsh	0
453	Mississippi Sound Salt and Brackish Tidal Marsh	0
552	Unconsolidated Shore	0
553	Undifferentiated Barren Land	0
556	Cultivated Cropland	0
565	Disturbed, Non-specific	0

Landcover Category Number	Landcover Category Name	Habitat Classification
574	Disturbed/Successional - Grass/Forb Regeneration	0
575	Disturbed/Successional - Shrub Regeneration	0
577	Open Water (Aquaculture)	0
578	Open Water (Brackish/Salt)	0
579	Open Water (Fresh)	0
580	Quarries, Mines, Gravel Pits and Oil Wells	0
581	Developed, Open Space	0
582	Developed, Low Intensity	0
583	Developed, Medium Intensity	0
584	Developed, High Intensity	0
5	South Florida Hardwood Hammock	1
6	Southeast Florida Coastal Strand and Maritime Hammock	1
7	Southwest Florida Coastal Strand and Maritime Hammock	1
8	South Florida Pine Rockland	1
11	Atlantic Coastal Plain Upland Longleaf Pine Woodland	1
12	Atlantic Coastal Plain Xeric River Dune	1
13	East Gulf Coastal Plain Interior Upland Longleaf Pine Woodland - Open Understory Modifier	1
15	Florida Longleaf Pine Sandhill - Scrub/Shrub Understory Modifier	1
16	Florida Longleaf Pine Sandhill- Open Understory Modifier	1
17	West Gulf Coastal Plain Upland Longleaf Pine Forest and Woodland	1
36	East Gulf Coastal Plain Interior Upland Longleaf Pine Woodland - Offsite Hardwood Modifier	1
238	Southern Coastal Plain Hydric Hammock	1
258	Central Florida Pine Flatwoods	1
262	South Florida Pine Flatwoods	1
362	Florida Dry Prairie	1
363	Florida Peninsula Inland Scrub	1
1	South Florida Bayhead Swamp	2
2	South Florida Cypress Dome	2
3	South Florida Dwarf Cypress Savanna	2
4	South Florida Mangrove Swamp	2
9	Atlantic Coastal Plain Fall-line Sandhills Longleaf Pine Woodland - Open Understory	2
10	Atlantic Coastal Plain Fall-line Sandhills Longleaf Pine Woodland - Scrub/Shrub Understory	2
14	East Gulf Coastal Plain Interior Upland Longleaf Pine Woodland - Scrub/Shrub Modifier	2
19	Atlantic Coastal Plain Southern Maritime Forest	2
21	East Gulf Coastal Plain Limestone Forest	2

Landcover Category Number	Landcover Category Name	Habitat Classification
22	East Gulf Coastal Plain Maritime Forest	2
24	East Gulf Coastal Plain Southern Mesic Slope Forest	2
26	Southern Coastal Plain Dry Upland Hardwood Forest	2
27	Southern Coastal Plain Oak Dome and Hammock	2
33	Atlantic Coastal Plain Fall-Line Sandhills Longleaf Pine Woodland - Loblolly Modifier	2
37	East Gulf Coastal Plain Near-Coast Pine Flatwoods - Offsite Hardwood Modifier	2
38	Evergreen Plantation or Managed Pine	2
103	Atlantic Coastal Plain Dry and Dry-Mesic Oak Forest	2
104	Atlantic Coastal Plain Fall-line Sandhills Longleaf Pine Woodland - Offsite Hardwood	2
120	Southern Atlantic Coastal Plain Mesic Hardwood Forest	2
213	Atlantic Coastal Plain Blackwater Stream Floodplain Forest - Forest Modifier	2
214	Atlantic Coastal Plain Brownwater Stream Floodplain Forest	2
216	Atlantic Coastal Plain Small Blackwater River Floodplain Forest	2
217	Atlantic Coastal Plain Small Brownwater River Floodplain Forest	2
219	East Gulf Coastal Plain Large River Floodplain Forest - Forest Modifier	2
220	East Gulf Coastal Plain Small Stream and River Floodplain Forest	2
221	East Gulf Coastal Plain Tidal Wooded Swamp	2
228	Mississippi River Riparian Forest	2
230	Southern Coastal Plain Blackwater River Floodplain Forest	2
239	Southern Coastal Plain Seepage Swamp and Baygall	2
241	Atlantic Coastal Plain Nonriverine Swamp and Wet Hardwood Forest - Taxodium/Nyssa Modifier	2
242	Atlantic Coastal Plain Nonriverine Swamp and Wet Hardwood Forest - Oak Dominated Modifier	2
247	Southern Coastal Plain Nonriverine Basin Swamp	2
248	Southern Coastal Plain Nonriverine Basin Swamp - Okefenokee Bay/Gum Modifier	2
249	Southern Coastal Plain Nonriverine Basin Swamp - Okefenokee Pine Modifier	2
250	Southern Coastal Plain Nonriverine Basin Swamp - Okefenokee Taxodium Modifier	2
254	Atlantic Coastal Plain Clay-Based Carolina Bay Forested Wetland	2

Landcover Category Number	Landcover Category Name	Habitat Classification
255	Atlantic Coastal Plain Clay-Based Carolina Bay Herbaceous Wetland	2
256	Atlantic Coastal Plain Southern Wet Pine Savanna and Flatwoods	2
260	East Gulf Coastal Plain Near-Coast Pine Flatwoods - Open Understory Modifier	2
261	East Gulf Coastal Plain Near-Coast Pine Flatwoods - Scrub/Shrub Understory Modifier	2
263	Southern Coastal Plain Nonriverine Cypress Dome	2
293	South Florida Everglades Sawgrass Marsh	2
294	South Florida Freshwater Slough and Gator Hole	2
295	South Florida Wet Marl Prairie	2
353	East Gulf Coastal Plain Black Belt Calcareous Prairie and Woodland - Herbaceous Modifier	2
370	Atlantic and Gulf Coastal Plain Interdunal Wetland	2
371	Atlantic Coastal Plain Southern Dune and Maritime Grassland	2
373	East Gulf Coastal Plain Dune and Coastal Grassland	2
379	Southwest Florida Dune and Coastal Grassland	2
399	Atlantic Coastal Plain Peatland Pocosin	2
401	Atlantic Coastal Plain Central Fresh-Oligohaline Tidal Marsh	2
404	Florida Big Bend Fresh-Oligohaline Tidal Marsh	2
405	Atlantic Coastal Plain Depression Pondshore	2
407	Central Florida Herbaceous Pondshore	2
408	Central Florida Herbaceous Seep	2
409	East Gulf Coastal Plain Savanna and Wet Prairie	2
411	Floridian Highlands Freshwater Marsh	2
412	Southern Coastal Plain Herbaceous Seepage Bog	2
413	Southern Coastal Plain Nonriverine Basin Swamp - Okefenokee Clethra Modifier	2
414	Southern Coastal Plain Nonriverine Basin Swamp - Okefenokee Nupea Modifier	2
449	Atlantic Coastal Plain Indian River Lagoon Tidal Marsh	2
512	East Gulf Coastal Plain Large River Floodplain Forest - Herbaceous Modifier	2
562	Introduced Riparian and Wetland Vegetation	2
34	Deciduous Plantations	3
557	Pasture/Hay	3
567	Harvested Forest - Grass/Forb Regeneration	3
568	Harvested Forest-Shrub Regeneration	3

Landcover Category Number	Landcover Category Name	Habitat Classification
35	East Gulf Coastal Plain Interior Upland Longleaf Pine Woodland - Loblolly Modifier	99
60	Allegheny-Cumberland Dry Oak Forest and Woodland - Hardwood	99
61	Allegheny-Cumberland Dry Oak Forest and Woodland - Pine Modifier	99
66	East Gulf Coastal Plain Black Belt Calcareous Prairie and Woodland - Woodland Modifier	99
75	Northeastern Interior Dry Oak Forest - Mixed Modifier	99
76	Northeastern Interior Dry Oak Forest - Virginia/Pitch Pine Modifier	99
77	Northeastern Interior Dry Oak Forest-Hardwood Modifier	99
87	Southern Ridge and Valley Dry Calcareous Forest	99
88	Southern Ridge and Valley Dry Calcareous Forest - Pine modifier	99
91	Ruderal forest	99
92	Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier	99
105	East Gulf Coastal Plain Interior Shortleaf Pine-Oak Forest - Hardwood Modifier	99
106	East Gulf Coastal Plain Interior Shortleaf Pine-Oak Forest - Mixed Modifier	99
109	Southeastern Interior Longleaf Pine Woodland	99
110	Southern Appalachian Low Mountain Pine Forest	99
112	Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier	99
113	Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier	99
122	East Gulf Coastal Plain Northern Mesic Hardwood Forest	99
126	South-Central Interior Mesophytic Forest	99
129	Southern Piedmont Mesic Forest	99
202	South-Central Interior Large Floodplain - Forest Modifier	99
203	South-Central Interior Small Stream and Riparian	99
218	Atlantic Coastal Plain Southern Tidal Wooded Swamp	99
223	Southeastern Great Plains Riparian Forest	99
226	Mississippi River Floodplain and Riparian Forest	99

Landcover Category Number	Landcover Category Name	Habitat Classification
231	Southern Piedmont Large Floodplain Forest - Forest Modifier	99
232	Southern Piedmont Small Floodplain and Riparian Forest	99
237	Gulf and Atlantic Coastal Plain Swamp Systems	99
243	East Gulf Coastal Plain Southern Loblolly-Hardwood Flatwoods	99
268	Northern Rocky Mountain Conifer Swamp	99
351	Southern Ridge and Valley / Cumberland Dry Calcareous Forest	99
354	East Gulf Coastal Plain Jackson Prairie and Woodland	99
387	Atlantic Coastal Plain Sea Island Beach	99
390	Louisiana Beach	99
428	Cumberland Riverscour	99
452	Gulf and Atlantic Coastal Plain Tidal Marsh Systems	99
519	East Gulf Coastal Plain Dry Chalk Bluff	99
525	Southern Piedmont Cliff	99
528	Southern Piedmont Granite Flatrock	99
558	Introduced Upland Vegetation - Annual Grassland	99
561	Introduced Upland Vegetation - Shrub	99
563	Introduced Upland Vegetation - Treed	99

To augment the primary habitat identification for indigo snakes, we reclassified the UGA Gopher Tortoise potential habitat map to retain all areas that scored greater than 0.47 and merged them with the landcover-derived indigo snake primary habitat data layer. A score of 0.47 or greater in the UGA Gopher Tortoise potential habitat map is a stricter cut-off point that minimizes the rate of false positives and negatives (Crawford and Maerz 2017). The higher scoring UGA Gopher Tortoise potential habitat map areas further identify core habitat areas in the range of the indigo snake which the landcover map alone did not identify. With this merged dataset we selected all primary habitat patches greater than 10 acres in size and removed (clipped) all identified areas within the redhills region of Florida and Georgia where eastern indigo snakes are not believed to have occurred historically (Enge *et al.* 2013).

References:

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APPENDIX D – Future Condition Methods

Source Datasets Used

NOAA Sea Level Rise Data – NOAA has developed sea level rise GIS layers (raster and polygon options) that represent current sea levels, and potential flooding from one to six feet of sea level rise for all coastal US states and territories except Alaska. Sea levels represent the mean higher high water level, which is a long-term average of the highest high tide that occurs in a day (many locations experience two high tides and two low tides each day). The methods used to map sea level rise inundation are described by the NOAA Office for Coastal Management (NOAA 2017, entire).

To estimate loss of habitat due to inundation from sea level rise for coastal populations of Eastern indigo snakes, we used NOAA's shapefiles available at their online sea level rise viewer (NOAA 2018). Projected sea level rise scenarios from NOAA provide a range of inundation levels from low to extreme. We chose the most likely scenario based on the Sea-Level Rise Working Group (SLRWG 2015), which corresponds to NOAA's intermediate-high scenario. Local scenarios are available at 29 locations along the coast of Florida, with each scenario providing estimates of sea level rise at decadal time steps out the year 2100. We found the average sea rise level estimate for the intermediate high NOAA scenario across all 29 stations and used this estimate to project habitat loss at 2050 (2 feet sea level rise) and 2070 (3 feet sea level rise). Loss of habitat due to sea level rise was in addition to loss of habitat due to urban development.

https://coast.noaa.gov/digitalcoast/tools/slr.html

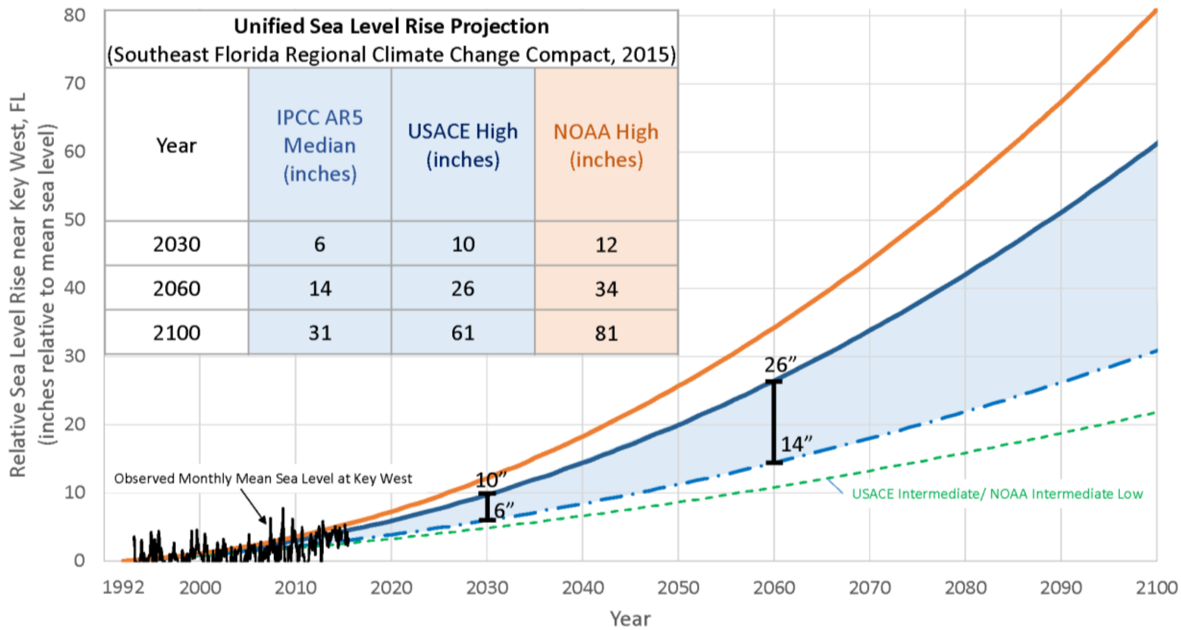

Figure D1: Projected sea-level rise scenarios according to IPCC, U.S. Army Corps of Engineers [USACE] and NOAA estimates. Shaded blue area is the most likely scenario (Figure A-1 from Sea-Level Rise Working Group [SLRWG] 2015).

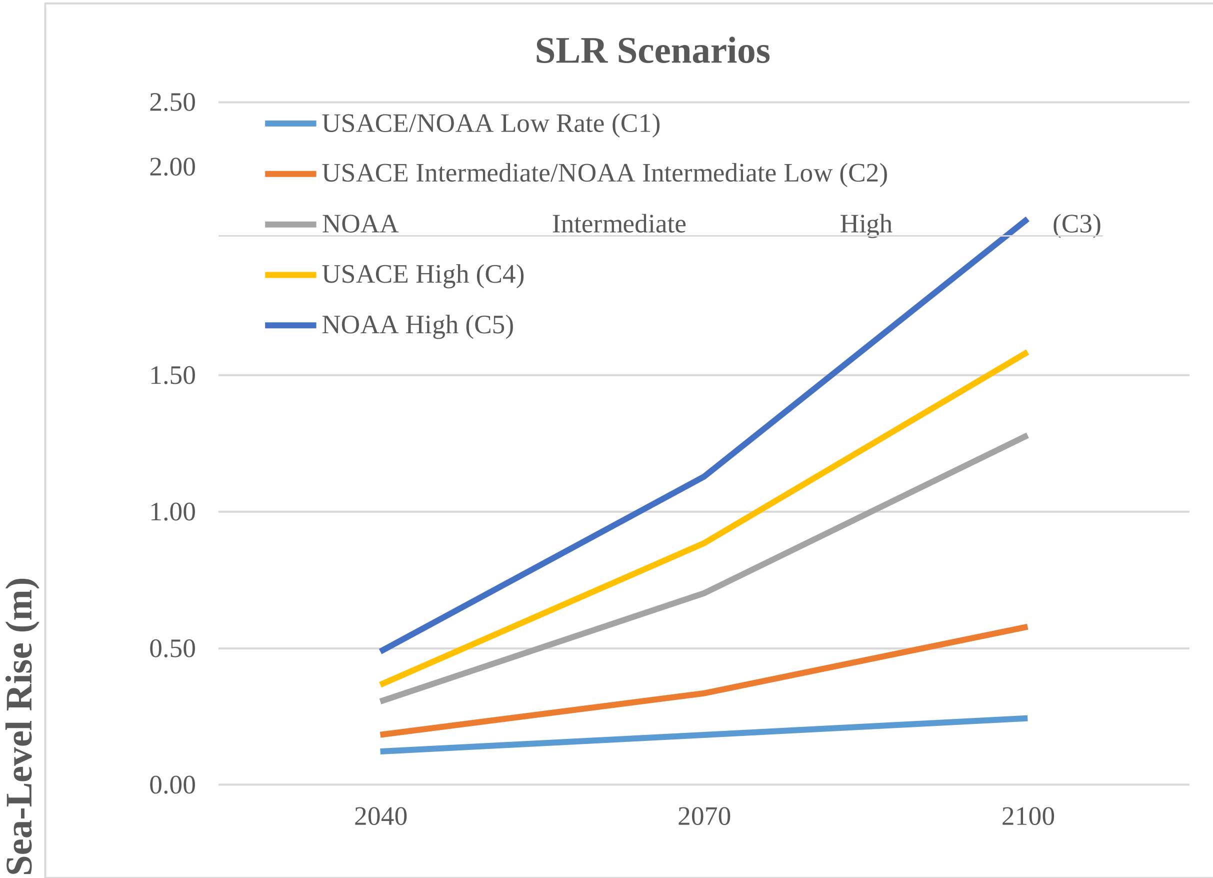

Figure D2: Predicted sea-level rise amounts (m) and data sources for the Lower Florida Keys for years 2040, 2070, and 2100. We used C2, C3, and C5 for this SSA.

SLEUTH Urbanization Data – We used the Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade (SLEUTH; Jantz *et al*. 2010, entire) model to determine areas predicted to be urbanized in the future. The SLEUTH model has previously been used to predict probabilities of urbanization across the southeastern US in 10-year increments, and the resulting GIS data are freely available (Belyea and Terrando 2013, entire). For our future projections, we used the SLEUTH raster data sets from the years 2050 and 2070, and examined the area predicted to be urbanized with 20%, 50%, or 90% probability depending on the scenario.

We considered using the FL2070 (citation) urbanization model that was developed specifically for Florida, but comparisons of the FL2070 and SLEUTH baseline (current) urbanization models revealed that the SLEUTH model was more accurate in identifying current urbanization in moderately to highly developed areas than the FL2070 model (which was more accurate than SLEUTH in low density developed areas).

Eastern Indigo Snake Rangewide Potential Habitat Model – We calculated habitat area using the habitat model described in Appendix C, which identifies and ranks suitable habitat.

Projecting Resilience Factors

We used the above datasets to generate future predictions for population extent, population connectivity, habitat quantity, habitat type, and urbanization under three urbanization scenarios (high, moderate, and low urbanization) at two time points, 2050 and 2070. The 2050 time point was associated with one predicted foot of sea level rise, and the 2070 time point was associated with a prediction of two feet of sea level rise. The following summarizes each population and habitat factor (Table D1)

Table D1. Factors used to assess current resilience and future resilience

Population Factors		Habitat Factors					
Population extent	**Population Connectivity**	**Habitat Quantity**	**Habitat Type**	**Gopher Tortoise (Shelter)**	**Fragmentation**	**Tertiary Road Density**	**% Urban Area**
Updated for future	Updated for future	Updated for future	Held constant at current condition	Held constant at current condition	Updated for future	Combined with % Urban	Updated for future

1. **Population Extent** – Measured as the cumulative of area of each population created by overlapping 5-mile (8 km) buffers of the eastern indigo snake records, as it was measured in the current condition. The only time population extent changed between current to future conditions for any population was when land area within the current population extent was predicted to be inundated by sea level rise in the future. In these instances, the future population extent was equal to the current population extent minus the area of land predicted to be inundated.

2. **Population Connectivity** – Measured as the overlap and presence of connected suitable habitat among populations within a 5-mile buffer around populations. This "population connectivity buffer," is represented by a 10-mile buffer around eastern indigo snake records (or 5-mile buffer from record = population plus an additional 5-mile buffer to assess overlap (i.e. connectivity) among populations.

   We measured this habitat factor the same way as we did for current condition but used the updated potential habitat layer with losses from urbanization and sea level rise for each scenario. We counted the number of overlapping "population connectivity buffers" for each population. Then we examined the habitat (Easter Indigo Snake Habitat Model, Appendix C) within the overlapping area. Populations were considered "connected" if habitat patches were present between populations and were not bisected by one or more primary or secondary roads. Resilience categories were defined as: High: population connected to 2 or more populations, Medium: population connected to at least 1 other population, Low: population connectivity buffer overlaps with at least one other population connectivity buffer but is fragmented by major road (primary or secondary). Very Low: population is not connected to another population. See Figure B2, Appendix B for illustration.

3. **Habitat Quantity and Type** – Habitat quantity (acres) of habitat for each habitat type (primary, secondary and tertiary), and in total, was calculated for each population using the Eastern Indigo Snake Habitat Model (Appendix C), with habitat removed for predicted future sea level rise and urbanization. Habitat was removed by overlaying sea level rise (one foot for 2050, two feet for 2070) and predicted urbanization (20%, 50%, and 90% for high, moderate, and low urbanization scenarios, respectively, in both 2050 and 2070) onto current habitat in GIS. Habitat that overlapped with the increased sea level or predicted urbanization was removed from the calculation of future habitat quantity. We did not predict changes in habitat type (primary, secondary, or tertiary) habitat in the future due to high amounts of uncertainty in how land use will change.

4. **Gopher Tortoise (Shelter)** – Held constant as current condition. Appendix B for more detail.

5. **Habitat Fragmentation** - Using the Eastern Indigo Snake Habitat Model (Appendix C), fragmentation was assessed by re-calculating the area of habitat patches of different sizes for each population for each scenario. Habitat patches for this assessment could contain all three types of habitat (primary, secondary and tertiary). Breaks in habitat patches reflect significant breaks in habitat connectivity or non-habitat between patches and often were due to primary or secondary roads, major water bodies and other areas of non-habitat. Additional information on habitat fragmentation metrics can be found in Appendix C.

6. **Tertiary Roads and % Area Urbanized** – Percent of urbanized area was calculated for each population using the 2050 and 2070 outputs of the SLEUTH model. The SLEUTH model provides a probability that each pixel (60 x 60 m) will be urbanized. We assessed urbanization in 2050 and 2070 at three urbanization probabilities. A 20% or more probability of being developed is very inclusive and represented a high development scenario. A 50% or more probability of being developed included only those pixels that were more likely to be developed than not, and represented a medium development scenario. A 90% or more probability of development is the most restrictive scenario we assessed, where only pixels that are very likely to be developed were considered, representing a low development scenario.

Weights assigned to factors in Table D1.

Table D2. Factors used to assess future resilience and their importance weights

POPULATION FACTORS		HABITAT FACTORS				
Population Extent	Population Connectivity	Habitat Quantity	Fragmentation	% Urban Area	Gopher Tortoise (Shelter)	Habitat Type
1	1	1	2	2	2 Northern Populations 1 Southern Populations	1

Habitat factors were given the same importance weights as applied to the current condition analysis, except tertiary road density was combined into percent urban area in the future scenario analysis (Table D2). It is difficult to predict how tertiary roads will change in the future (e.g. tertiary roads becoming primary or secondary roads and where new tertiary roads will occur). Tertiary road density and percent urban area are highly correlated (Appendix B, Figure B3) therefore we combined these two factors and their weights into one, therefore percent urban was given a weight 2 for both northern and southern populations.

See Appendix B for additional rational for weighting habitat factors.

Table D3: Future condition resiliency scores for 83 eastern indigo snake populations. See Table 2 in report for condition category definitions.

Population		Current Condition	Scenario A (Low Urban)		Scenario B (Moderate Urban)		Scenario C (High Urban)		Scenario D Targeted Conservation 2070	Conservation Focus Area
Region	Name		2050	2070	2050	2070	2050	2070		
Panhandle	AL 2-1R	VLX	VL	VL	VL	VL	VL	VL	M	Western Panhandle
Panhandle	AP 1-1	L	L	L	L	L	L	L	L	
Panhandle	AP 2-1R	VLX	VL	VL	VL	VL	VL	VL	M	Apalachicola
North Florida	NF 1-1	VL	VL	VL	VL	VL	VL	VL	VL	
North Florida	NF 1-2	M	M	L-M	L-M	L-M	L-M	L-M	M	Trail Ridge
North Florida	NF 1-3	M	L-M	L-M	L-M	L-M	L-M	L-M	M	Suwannee

Population		Current Condition	Scenario A (Low Urban)		Scenario B (Moderate Urban)		Scenario C (High Urban)		Scenario D Targeted Conservation 2070	Conservation Focus Area
Region	Name		2050	2070	2050	2070	2050	2070		
North Florida	NF 4-1	L	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	
North Florida	NF 5-1	VL	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	
Southeast Georgia	GA 1-1	L-M	L	L	L	L	L	L	M	Alapaha Sandhills
Southeast Georgia	GA 2-1	M-H	M-H	M-H	M-H	M-H	M-H	M-H	H	Altamaha
Southeast Georgia	GA 2-2	L-M	L-M	L-M	L-M	L-M	L-M	L-M	H	Fort Stewart
Southeast Georgia	GA 2-3	M	L-M	L-M	L-M	L-M	L-M	L-M	M	Altamaha
Southeast Georgia	GA 2-4	H	H	H	H	H	H	H	H	Fort Stewart
Southeast Georgia	GA 2-5	L-M	L-M	L-M	L-M	L-M	L-M	L-M	M	Altamaha
Southeast Georgia	GA 3-1	L	L	L	L	L	L	L	L-M	Alapaha Sandhills
Southeast Georgia	GA 3-2	M	L-M	L-M	L-M	L-M	L-M	L-M	M	Alapaha Sandhills
Southeast Georgia	GA 3-3	L-M	L-M	L	L	L	L	L	L-M	
Southeast Georgia	GA 3-4	M-H	M-H	M-H	M-H	M-H	M-H	M	M-H	Altamaha
Southeast Georgia	GA 4-1	L-M	L	L	L	L	L	L	L	Cabin Bluff
Southeast Georgia	GA 5-1	L-M	L-M	L	L	L	L	L	M	Okefenokee

Population		Current Condition	Scenario A (Low Urban)		Scenario B (Moderate Urban)		Scenario C (High Urban)		Scenario D Targeted Conservation 2070	Conservation Focus Area
Region	Name		2050	2070	2050	2070	2050	2070		
Southeast Georgia	GA 9-1	L	VL	VL	VL	VL	VL	VL	VL	
Peninsular Florida	CF 1-1	L	L-M	L	L-M	L	L-M	L	L	Everglades
Peninsular Florida	CF 1-10	H	M-H	L-M	L-M	L-M	L-M	L-M	M-H	Osceola Plain
Peninsular Florida	CF 1-11	H	M-H	M-H	M-H	M	M	M	H	Lake Wales Ridge
Peninsular Florida	CF 1-12	VL	VL	VL	VL	VL	VL	VL	VL	
Peninsular Florida	CF 1-13	M-H	M-H	L-M	L-M	L-M	L	L	M-H	Osceola Plain
Peninsular Florida	CF 1-14	L	L	L	L	VL	L	VL	VL	Merritt Island
Peninsular Florida	CF 1-15	M-H	M-H	M-H	M-H	M	M	L-M	H	Merritt Island
Peninsular Florida	CF 1-16	L	L	L	L	L	L	L	L	
Peninsular Florida	CF 1-17	M	L-M	L-M	L-M	L-M	L-M	L-M	H	Ocala
Peninsular Florida	CF 1-18	M	L-M	L-M	L-M	L-M	L-M	L-M	M	Brooksville Ridge
Peninsular Florida	CF 1-19	L	VL	VL	VL	VL	VL	VL	VL	
Peninsular Florida	CF 1-2	L	L	L	L	L	L	L	L	Everglades
Peninsular Florida	CF 1-3	L	L-M	L-M	L-M	L-M	L-M	L-M	L-M	

Population		Current Condition	Scenario A (Low Urban)		Scenario B (Moderate Urban)		Scenario C (High Urban)		Scenario D Targeted Conservation 2070	Conservation Focus Area
Region	Name		2050	2070	2050	2070	2050	2070		
Peninsular Florida	CF 1-4	L-M	L-M	L-M	L-M	L-M	L-M	L-M	L-M	
Peninsular Florida	CF 1-5	L	L	VL	L	VL	VL	VL	VL	
Peninsular Florida	CF 1-6	M	L	L	L	L	L	L	L	
Peninsular Florida	CF 1-7	L-M	L-M	L-M	L-M	L-M	L-M	L-M	M	Gulf Coast
Peninsular Florida	CF 1-8	H	M-H	M	M	L	L	L	M-H	Gulf Coast
Peninsular Florida	CF 1-9	M	M	M	M	M	M	M	M-H	Gulf Coast
Peninsular Florida	CF 2-1	L	L	L	L	L	L	L	L	
Peninsular Florida	CF 3-1	L	L	L	L	L	L	L	L	
Peninsular Florida	CF 4-1	M	M	L-M	L-M	L-M	L-M	L-M	L-M	
Peninsular Florida	CF 5-1	L	L	L	L	L	L	VL	L	
Peninsular Florida	CF 6-1	L	L	L	L	L	L	L	L	
Peninsular Florida	CF 6-2	L-M	L-M	L	L	L	L	L	L	
Peninsular Florida	CF 6-3	VL	VL	VL	VL	VL	VL	VL	VL	
Peninsular Florida	CF 6-4	L	L	L	L	L	L	L	L	

Population		Current Condition	Scenario A (Low Urban)		Scenario B (Moderate Urban)		Scenario C (High Urban)		Scenario D Targeted Conservation 2070	Conservation Focus Area
Region	Name		2050	2070	2050	2070	2050	2070		
Peninsular Florida	CF 7-1	VL	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	
Peninsular Florida	CF 8-1	VL	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	
Peninsular Florida	SF 11-1	L	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	
Peninsular Florida	SF 4-1	L	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	
Peninsular Florida	SF 6-1	L	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	XVL-SLR	Everglades

H= High; M-H= Medium-High; M= Medium; L-M= Medium-Low; L= Low; VL= Very Low; XVL-SLR are those populations extirpated due to sea level rise. AL2-1R* and AP2-1R* are repatriation sites. Therefore, overall condition for these two sites is considered Very Low or Extirpated (VLX). There are 30 extirpated populations shown in Figure 21 in section 5.1 of the report that are not included in this table.

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APPENDIX E – Conservation Focus Areas

Sixteen Conservation Focus Areas (Figure E1), distributed throughout portions of the historic and current range of the eastern indigo snake were identified, to provide our partners with a potential conservation scenario to consider to implement recovery efforts. Populations within these areas, if protected and managed for eastern indigo snakes under this scenario, could improve the status of the species. The areas were chosen because they contain potentially viable populations or because they will contribute to the connectivity of occupied eastern indigo snake habitat and thus increase dispersal between populations and improve opportunities for new population establishment. Preservation and enhancement of habitat within each focus area is important to maintain and expand the distribution of eastern indigo snake populations range-wide. Conservation Focus Areas in the historic range represent important elements of the species' historic distribution and were selected to prevent further range collapse. Unoccupied areas may require varying degrees of rehabilitation (e.g., prescribed fire, gopher tortoise translocations) to restore habitat suitability prior to future recolonization or reestablishment efforts. These potential areas would require long-term protection and management so that existing and newly-established populations achieve and maintain viability.

Conservation Focus Areas were selected based on a review of the historical/current distribution and habitat requirements of the species. Data were incorporated from a review of the current literature, primarily Enge *et al*. (2013, entire); comments provided by eastern indigo snake experts; and an eastern indigo snake habitat model (Appendix C). The primary factors used in delineating boundaries of Conservation Focus Areas within specific physiographic provinces were presence of: (1) intact, unfragmented (by major roads or river systems), naturally-functioning habitat representative of that area's physiographic province that meet the medium or higher threshold for habitat fragmentation (25% of habitat is >20K acres patch size; or 50% is >10K acres patch size; or 75% >5K acres patch size); (2) areas that in their totality, support genetic and ecological integrity of the species by including areas throughout the historical and current range of the eastern indigo snake and in both the Gulf Coastal Plain and Atlantic Coastal Plain; (3) areas that contain multiple, large acreages (greater than 2,500 ac (1,000 ha)) of conservation land such as public lands or property with conservation easements capable of adequate management (e.g., prescribed fire, wildlife corridors); and (4) diverse habitat types (e.g., scrub, sandhills, riverine sand ridges, etc.) as identified by our eastern indigo snake habitat model (Appendix C).

Physiographic provinces were used as described by Brooks (1981) for Florida and Wharton (1978) for Georgia. A discussion of the habitat types used by eastern indigo snakes in these physiographic provinces is provided below in the discussion of each individual Conservation Focus Area. Conservation Focus Areas were given names that would be identifiable to the general public by using a geographic area name or, as in the case of Fort Stewart and

Okefenokee, the name of a major Federal landholding. Conservation Focus Areas may include entire watersheds and thus are composed of both public and private lands.

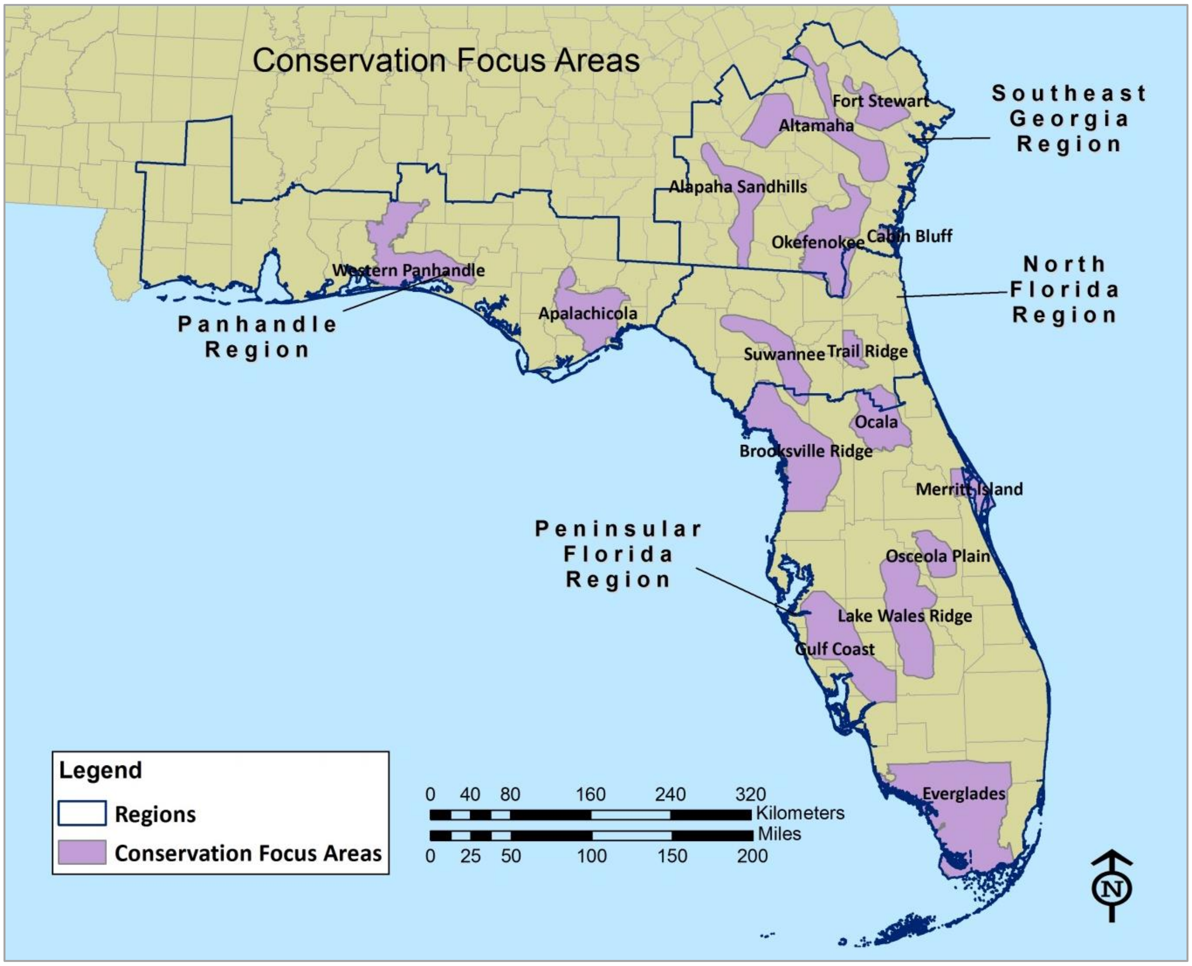

Figure E1: Eastern indigo snake conservation focus areas for potential future targeted conservation scenario.

CONSERVATION FOCUS AREAS

<u>*PANHANDLE*</u>

Western Panhandle

The Western Panhandle Conservation Focus Area includes parts of Covington and Escambia counties in Alabama, and parts of Okaloosa, Santa Rosa, and Walton counties in Florida. Most of this Conservation Focus Area lies within the Western Highlands Physiographic Province, while the more southerly portions closer to the Gulf Coast are within the Coastal Lowlands. This area, close to the western margin of the species' range, includes large and well-managed (e.g. regular prescribed fire) public lands both in Alabama and Florida (Conecuh National Forest, Blackwater River State Forest, Choctawhatchee River Wildlife Management Area (WMA), Eglin

Air Force Base); and a privately-owned nature preserve dedicated to the preservation of native biodiversity (Nokuse Plantation). It contains approximately 845,607 ac (342,205 ha) of potential eastern indigo snake habitat. The most recent verifiable eastern indigo snake record for the region was at Eglin Air Force Base in 1999; a credible (but not verified by photo or specimen) eastern indigo snake sighting was reported from close to the base boundary in 2011 (Enge *et al*. 2013). The decline of eastern indigo snakes in this region may have resulted from a dramatic decline in gopher tortoise populations, going back to the mid 1900's and coinciding with a period of heavy human predation on tortoises. Currently, an eastern indigo snake reintroduction effort is underway on the Conecuh National Forest, Alabama (Stiles *et al.* 2013, entire). In this region, eastern indigo snakes require tortoise burrows for cool-season shelter sites and other aspects of their ecology.

Apalachicola National Forest and Vicinity

The Apalachicola National Forest and Vicinity Conservation Focus Area occupies parts of Franklin, Gadsen, Leon, Liberty, and Wakulla counties in Florida. The Apalachicola National Forest (ANF) is located almost entirely within the Delta Plain and Coastal Strip physiographic regions, however the northeastern section, a large block of xeric sandhill (called the Munson Sandhills), is part of the Paleodelta Relics region (also known as the Woodville Karst Plain). North of the ANF an extensive sand ridge that is a part of the Quincy Hills physiographic region occurs on the east side of, and parallel to, the Apalachicola River in Liberty County. Apalachicola Bluffs and Ravines Preserve (owned by The Nature Conservancy) is located on this sand ridge, is actively managed for longleaf pine-wiregrass, and supports a gopher tortoise population. The Munson Sandhills and Apalachicola Bluffs and Ravines supported eastern indigo snake populations into the late 1980s-to-mid-1990s (Enge *et al*. 2013). Much of the western half of the ANF is too poorly-drained (i.e., mesic savannas and flatwoods, swamps) to support eastern indigo snakes, however this Conservation Focus Area contains 424,274 ac (171,698 ha) of potential eastern indigo snake habitat. In this part of their range, eastern indigo snakes require tortoise burrows excavated in well-drained xeric sands for cool-season shelter sites and other aspects of their ecology. If snake reintroductions are attempted in the Florida panhandle within the historic range of the species, the Munson Sandhills and Apalachicola River sandhills will be likely areas to consider for the effort.

<u>NORTH FLORIDA</u>

Suwannee River

The Suwannee River Conservation Focus Area includes portions of Alachua, Columbia Gilchrist, Lafayette, Levy, and Suwannee counties in Florida. This Conservation Area is located within the Northern Peninsula Plains, Suwannee River Valley and Newberry Sand Hills physiographic provinces and includes a portion of the Brooksville Ridge. The northern part of this area includes significant xeric sandhill habitats along the Suwannee River in Suwannee and Lafayette counties. The southern portion encompasses the northern extent of the Brooksville

Ridge in Levy County. Approximately 406,732 ac (164,599 ha) of potential eastern indigo snake habitat occurs in this Conservation Focus Area. There are recent eastern indigo snake records for the rolling sandhills of Goethe State Forest, Watermelon Pond Wildlife and Environmental Area, and Ashton Biological Preserve in southwestern Alachua County; Troy Springs Conservation Area; Lafayette Blue Springs State Park in Levy County; Ichetucknee Springs State Park and Little River Conservation Area in Suwannee County; and Twin Rivers State Forest in Madison County. Habitat management of longleaf pine–wiregrass communities is ongoing at conservation tracts throughout this Conservation Focus Area. In this region, eastern indigo snakes require gopher tortoise burrows excavated in well-drained xeric sands for cool-season shelter and other aspects of their ecology.

Trail Ridge

The Trail Ridge Conservation Focus Area occurs in portions of Clay and Putnam counties, Florida. Trail Ridge is the largest of several long, low north-trending ridges in central Florida and is among the most distinctive landforms in an area of otherwise low topographic relief. The ridges are complexes of sand dunes formed during the Pleistocene and contain 110,031 ac (44,528 ha) of potential eastern indigo snake habitat. The Trail Ridge Conservation Focus Area is composed of portions of three physiographic regions: Duval Upland, Interlachen Sand Hills and Okefenokee Upland. In this Conservation Focus Area, eastern indigo snakes are thought to require gopher tortoise burrows excavated in well-drained xeric sands for cool-season shelter and other aspects of their ecology. Conservation lands in this region known to support eastern indigo snake populations include Camp Blanding Joint Training Center, Belmore State Forest, Etoniah Creek State Forest, and Gold Head Branch State Park.

PENINSULAR FLORIDA

Brooksville Ridge and Vicinity

The Brooksville Ridge and Vicinity Conservation Focus Area includes all of Citrus County and portions of Gilchrist, Hernando, Levy, Marion, and Sumter counties, Florida. It is situated within 10 different physiographic regions and encompasses 589,489 ac (238,558 ha) of potential eastern indigo snake habitat. The Brooksville Ridge, an ancient, linear dune line that extends from Levy County to southern Hernando County, is characterized by high-quality tracts of longleaf pine sandhills. Elevations along the ridge range from 70 to 300 ft (230 to 984 m) above sea level. This region is a recognized stronghold for the species in Florida (Enge *et al.* 2013). Although at this latitude eastern indigo snakes do not absolutely require gopher tortoise burrows, many indigo populations in this region are associated with xeric sandhills and large tortoise populations, and at these sites it is likely that they exhibit frequent use of tortoise burrows. Other habitats utilized by snakes in this region include scrubby and mesic pine flatwoods, hydric hammocks, and depressional wetlands. Conservations lands within this Conservation Focus Area with recent eastern indigo snake records include Marjorie Carr Cross Florida Greenway, Chassahowitzka National Wildlife Refuge, Chassahowitzka WMA, Ross Prairie State Forest, Goethe State Forest, Crystal River State Park, Weekiwachee Preserve, Lake Panasoffkee WMA, Half Moon WMA, Halpata Tastanaki Preserve, Annutteliga Hammock (a conservation land administered by the Southwest Florida Water Management District), Rainbow Springs State Park, and six different tracts comprising the Withlacoochee State Forest.

Gulf Coast

The Gulf Coast Conservation Focus Area occupies in portions of Charlotte, DeSoto, Hardee, Hillsborough, Lee, Manatee, and Sarasota counties, Florida. It is located primarily within the DeSoto Slope physiographic region, but also occurs within a portion of the Bone Valley Uplands region. The area is composed of a mix of dry prairie, pinelands, freshwater marsh, wet prairie, and hardwood swamp. Eastern indigo snakes do not depend on gopher tortoise burrows in this area and snake populations occur in various habitats. However, it's likely that tortoise burrows are used where the species overlap. A significant portion of the natural habitat has been converted to pasture and cropland, however approximately 773,207 ac (312,906 ha) of this Conservation Focus Area represent potential eastern indigo snake habitat. Conservation lands in the region with potential habitat and recent records for eastern indigo snakes include Babcock Ranch Preserve, Myakka River State Park, and Duette Preserve. Babcock-Webb WMA also has potential habitat for the species.

Everglades

The Everglades Conservation Focus Area occurs in portions of Broward, Collier, Monroe, and Miami-Dade counties, Florida. This Conservation Focus Area is within the Big Cypress Swamp, Everglades, Southern Atlantic Coastal Strip, and Ten Thousand Islands physiographic regions. It is located in southernmost peninsular Florida and contains 657,004 ac (265,880 ha) of potential eastern indigo snake habitat. In this area, eastern indigo snakes are locally distributed and uncommon, inhabiting pine rocklands, hardwood hammocks, wetland margins, mangroves, and disturbed habitats. Eastern indigo snakes do not depend on gopher tortoise burrows in this area (in fact, natural tortoise populations are absent from most of this predominantly wetland region). Conservation lands in this region known to support eastern indigo snake populations include Everglades National Park, Big Cypress National Preserve, Rookery Bay National Estuarine Research Preserve, and Fakahatchee Strand Preserve State Park.

Ocala

The Ocala Conservation Focus Area occurs in portions of Lake, Marion, Putnam, and Volusia counties, Florida. It is situated within portions of Crescent City-Deland Ridge, Lynne Karst, Ocala Scrub, and St. John's Offset Physiographic regions, lies between the Ocklawaha and St. Johns Rivers in central Florida and includes the Ocala National Forest where eastern indigo snakes have been documented in recent surveys (Enge *et al.* 2013). This Conservation Focus Area includes a significant part of the Big Scrub, a notable ecological area that supports many scrub endemic species. Uplands of approximately 445,997 ac (180,489 ha) of potential eastern indigo snake habitat include oak scrub, sand pine scrub, longleaf pine sandhills, xeric hammocks, and some mesic pine flatwoods. This area supports a very large gopher tortoise population (over 10,000+ individuals) and uplands are actively managed using prescribed fire. Eastern indigo snakes are widespread in this region but do not appear to be especially common. It is not known to what extent the eastern indigo snake depends on gopher tortoise burrows in this area, but it's likely that tortoise burrow use is common where the species overlap.

Osceola Plain

The Osceola Plain Conservation Focus Area occurs in Osceola County, Florida. It is part of the Holopaw-Indian Town Ridges and Swales and Kissimmee Valley physiographic province, a region of palmetto prairie and scrubby flatwoods habitats. The Conservation Focus Area contains approximately 238,384 ac (96,470 ha) of potential eastern indigo snake habitat. Eastern indigo snakes do not depend on gopher tortoise burrows in this area, but it's likely that tortoise burrow use is common where the species overlap. Conservation lands in this region with recent eastern indigo snake records include Bull Creek Wildlife Management Area, Three Lakes Wildlife Management Area, and Triple N Ranch Wildlife Management Area.

Lake Wales Ridge

The Lake Wales Ridge Conservation Focus Area occurs in Glades, Hardee, Highlands, and Polk counties, Florida. This south-central Florida Conservation Focus Area is centered on an ancient dune system which runs (north-to-south) for about 150 mi (240 km) and includes Lake Wales Ridge, Carlton Ranch Ridge, and Bombing Range Ridge physiographic regions. Intact habitats on the Lake Wales Ridge itself are predominantly scrub (oak scrub, sand pine scrub) and scrubby flatwoods, with lesser areas of sandhill habitat. Although at this latitude eastern indigo snakes do not absolutely require gopher tortoise burrows, many snake populations in this region are associated with xeric sandhills and large tortoise populations, and at these sites snakes exhibit frequent use of tortoise burrows (Layne and Steiner 1996, Bauder 2018). This region of approximately 645,361 ac (261,168 ha) of eastern indigo snake potential habitat is recognized as a significant population stronghold, despite historic habitat loss and fragmentation. Conservation lands eastern indigo snake populations in this Conservation Focus Area include the Avon Park Bombing Range, Lake Wales Ridge Wildlife and Environmental Area, Lake Wales Ridge State Forest, Highlands Hammock State Park, and Archbold Biological Station.

Merritt Island and Vicinity

The Merritt Island and Vicinity Conservation Focus Area occurs in Brevard County, Florida. This Conservation Focus Area, along the Atlantic Coast of central Florida, includes Merritt Island, as well as inland habitats located to the west, and on both sides of Interstate 95, in Brevard County. Physiographic regions within this area include Cape Canaveral, Central Atlantic Coastal Strip, and St. Johns Wet Prairie. Conservation lands supporting eastern indigo snake populations include Merritt Island National Wildlife Refuge, Seminole Ranch

Conservation Area, Buck Lake Conservation Area, Salt Lake Wildlife Management Area, Fox Lake Sanctuary, and Cape Canaveral National Seashore. Although this Conservation Focus Area encompasses brackish estuaries and marshes, the remaining habitats consisting of approximately 132,709 ac (53,706 ha) of coastal dunes, oak scrubs, pine flatwoods, oak hammocks, cabbage palm hammocks, and swamps are considered potential eastern indigo snake habitat. Eastern indigo snakes in this region are not dependent on the presence of tortoise burrows and use a wide variety of refuge types including debris piles, small mammal burrows and armadillo burrows. The eastern indigo snake population in this region has been well-studied including research using radio-telemetry (Breininger *et al*. 2004, 2011, 2012).

<u>*SOUTHEAST GEORGIA*</u>

Fort Stewart

The Fort Stewart Conservation Focus Area occurs in Candler, Bryan, Bulloch, Evans, Liberty, Long, and Tattnall counties, Georgia. It is located primarily within the Sea Island Flatwoods physiographic province of southern Georgia and includes all of the Fort Stewart Military Installation. This area includes extensive xeric sand ridge habitats adjacent to the Canoochee River and xeric sandhills associated with Beard’s Creek, an Altamaha River tributary. Habitats within this Conservation Focus Area include fire-managed longleaf pine sandhills that support large sizeable tortoise populations, mesic pine flatwoods, blackwater creek swamps and isolated depressional wetlands. Approximately 260,253 ac (105,432 ha) of potential eastern indigo snake habitat occurs within this Conservation Focus Area. The eastern indigo snake population on the Fort Stewart Military Installation has been monitored via mark-recapture methods for 15 years (1999-2014) (Stevenson *et al*. 2009, Hyslop *et al*. 2012) and was the site of a recent radio-telemetry study examining home range and habitat use (Hyslop 2007). There are numerous recent eastern indigo snake records for this area. Eastern indigo snakes in this region require gopher tortoise burrows excavated in well-drained xeric sands for cool-season shelter and other aspects of their ecology.

Altamaha River Sandhills

The Altamaha River Sandhills Conservation Focus Area occurs in Appling, Candler, Coffee, Emanuel, Glynn, Jeff Davis, Long, McIntosh, Montgomery, Tattnall, Telfair, Toombs, Wayne, and Wheeler counties, Georgia. It is located primarily within the Tifton Uplands with more southerly portions within the Sea Island Flatwoods physiographic province. It includes eastern indigo snake and gopher tortoise habitats within the Altamaha River Drainage from the lower Ocmulgee River and lower Oconee River (and their perennial tributaries) southeasterly and downstream along the Altamaha River to close to the coast. Approximately 620,253 ac (251,008 ha) of potential eastern indigo snake habitat occurs within this Conservation Focus Area. Because of the widespread distribution of the eastern indigo snake and local robust populations, this region has long been recognized as a population stronghold for the species in Georgia. This Conservation Focus Area includes some xeric sand ridge habitats that, historically, have been fire-suppressed or planted for commercial forestry; active management efforts are currently underway to restore these sites to longleaf pine – wiregrass habitats (e.g., Long and McIntosh counties). Eastern indigo snakes in this region require gopher tortoise burrows excavated in well-drained xeric sands for cool-season shelter and other aspects of the snakes' ecology. There are numerous recent eastern indigo snake records for this area, and substantial acreage of public and conservation lands within this Conservation Area which include the Griffin Ridge Wildlife Management Area, Orianne Indigo Snake Preserve, Sansavilla Wildlife Management Area, and Townsend Wildlife Management Area. Even so, acquisition and/or protection of additional eastern indigo snake habitat is needed, especially along the Ohoopee River and Little Ocmulgee River.

Alapaha River Sandhills

The Alapaha River Sandhills Conservation Focus Area occurs in Berrien, Coffee, Echols, Irwin, Lanier, Lowndes, and Turner counties, Georgia. It is located within the Tifton Uplands and Okefenokee Plains physiographic provinces of southern Georgia. This Conservation Focus Area includes vast areas of xeric sand ridge habitats, some of which are intact and in good condition with large numbers of gopher tortoises, adjacent to the Alapaha River. It also includes sandhills within the upper Satilla River Drainage along 17-Mile River. Approximately 283,837 ac (114,865 ha) of this Conservation Focus Area is considered potential eastern indigo snake habitat. Eastern indigo snakes in this region require gopher tortoise burrows excavated in well-drained xeric sands for cool-season shelter and other aspects of the snakes' ecology. There are numerous recent eastern indigo snake records for the Alapaha River Sandhills although public conservation lands within this Conservation Focus Area are limited to Alapaha River Wildlife Management Area, a Georgia Forestry Commission Conservation Easement in Berrien County, Grand Bay Wildlife Management Area, and Moody Air Force Base. Acquisition and/or protection of additional eastern indigo snake habitat are needed.

Cabin Bluff

This small Recovery Area is located entirely within Camden County and extends to the Atlantic Coast (Sea Islands Coastal Marsh and Sea Island Flatwoods physiographic provinces). Habitats here include a matrix of sandy uplands, pine flatwoods, wetlands and coastal marshes between the lower Satilla River and the Crooked River. Approximately 24,663 ac (9,981 ha) of this Conservation Focus Area is considered potential eastern indigo snake habitat. The region supports a large gopher tortoise population and is one of the few sites in Georgia where eastern indigo snakes occur in coastal habitats. Eastern indigo snakes in this region require gopher tortoise burrows excavated in well-drained xeric sands for cool-season shelter and other aspects of the snakes' ecology. Public conservation lands are very limited to Crooked River State Park although the nearby Kings Bay Navy Base may offer suitable habitat within this Conservation Focus Area. Acquisition and/or protection of additional eastern indigo snake habitat are needed.

Okefenokee and Vicinity

The Okefenokee and Vicinity Conservation Focus Area occurs in Brantley, Camden, Charlton, Clinch, Glynn, Ware, and Wayne counties, Georgia; and a small area of Nassau County, Florida. It is located mostly within the Okefenokee Swamp and Okefenokee Plains physiographic provinces, but also includes part of the Bacon Terraces. This area includes all of the Okefenokee National Wildlife Refuge (ONWR) and sandy uplands on the east side of the refuge associated with Trail Ridge; and areas of sandhill habitats north of ONWR and within the Satilla River and St. Mary's River Drainages. Recent field work has provided data documenting eastern indigo snakes from the east side of ONWR (Enge *et.al.* 2013), however, eastern indigo snakes are not currently known to inhabit any of the pine islands within the swamp interior, or any refuge lands on the west or north sides of the swamp. This Conservation Focus Area consists of approximately 351,861ac (142,395 ha) of potential eastern indigo snake habitat. Eastern indigo snakes in this region require gopher tortoise burrows excavated in well-drained xeric sands for cool-season shelter and other aspects of the snakes' ecology. Outside of ONWR, there is very limited acreage of public and conservation lands within this Conservation Focus Area, and acquisition and/or protection of additional eastern indigo snake habitat is needed, especially within the Satilla River Drainage.

Table E1. Eastern Indigo Snake Conservation Focus Areas. Conservation Areas which contain > 2,500 ac (1,000 ha) of appropriate habitat for the species are listed. X = Recent records of the species (since 2001), X* indicate sites where eastern indigo snakes are being repatriated.

CONSERVATION FOCUS AREA	Recent Eastern Indigo Snake Records	Total Acres (Hectares)
PANHANDLE		
Western Panhandle		
Conecuh National Forest	X*	83,001 ac (33,590 ha)
Blackwater River State Forest		189,590 ac (76,726 ha)
Eglin Air Force Base		463,439 ac (187,551 ha)
Nokuse Plantation		51,000 ac (20,639 ha)
Choctawhatchee River Wildlife Management Area		57,000 ac (23,068 ha)
Apalachicola National Forest and Vicinity		
Apalachicola National Forest		569,790 ac (230,591 ha)
Apalachicola Bluffs and Ravines Preserve	X*	6,247 ac (2,528 ha)
NORTH FLORIDA		
Suwannee River		
Goethe State Forest	X	53,019 ac (21,456 ha)
Watermelon Pond Wildlife and Environmental Area	X	4,231 ac (1,712 ha)
Trail Ridge		
Camp Blanding Joint Training Center	X	73,075 ac (29,573 ha)
Belmore State Forest	X	12,264 ac (4,963 ha)
Etoniah Creek State Forest	X	8,678 ac (3,512 ha)
PENINSULAR FLORIDA		
Brooksville Ridge and Vicinity		
Marjorie Carr Cross Florida Greenway	X	71,269 ac (28,841 ha)
Chassahowitzka National Wildlife Refuge	X	30,843 ac (12,482 ha)
Chassahowitzka Wildlife Management Area	X	33,917 ac (13,726 ha)
Ross Prairie State Forest	X	3,546 ac (1,435 ha)
Goethe State Forest	X	48,441 ac (19,604 ha)
Crystal River State Park	X	27,433 ac (11,102 ha)
Weekiwachee Preserve	X	11,199 ac (4,532 ha)
Lake Pansofftkee Wildlife Management Area	X	10,323 ac (4,177 ha)
Half Moon Wildlife Management Area	X	9,650 ac (3,905 ha)
Halpata Tastanaki Preserve	X	7,892 ac (3,194 ha)
Withlacoochee State Forest	X	138,455 ac (56,032 ha)

CONSERVATION FOCUS AREA	Recent Eastern Indigo Snake Records	Total Acres (Hectares)
Ocala		
Ocala National Forest	X	383,563 ac (155,226 ha)
Merritt Island and Vicinity		
Merritt Island National Wildlife Refuge	X	131,114 ac (53,061 ha)
Seminole Ranch Conservation Area	X	29,497 ac (11,937 ha)
Buck Lake Conservation Area	X	9,589 ac (3,880 ha)
Salt Lake Wildlife Management Area	X	5,041 ac (2,040 ha)
Fox Lake Sanctuary	X	3,048 ac (1,233 ha)
Canaveral National Seashore	X	16,242 ac (6,573 ha)
Gulf Coast		
Babcock Ranch Preserve	X	73,239 ac (29,638 ha)
Babcock-Webb Wildlife Management Area	X	67,570 ac (27,345 ha)
Myakka River State Park	X	37,198 ac (15,053 ha)
Duette Preserve	X	20,269 ac (8,202 ha)
Osceola Plain		
Three Lakes Wildlife Management Area	X	61,834 ac (25,024 ha)
Bull Creek Wildlife Management Area	X	23,495 ac (9,508 ha)
Triple N Ranch Wildlife Management Area	X	15,389 ac (6,228 ha)
Lake Wales Ridge		
Avon Park Bombing Range	X	106,097 ac (42,937 ha)
Lake Wales Ridge Wildlife and Environmental Area	X	18,461 ac (7,471 ha)
Lake Wales Ridge State Forest	X	22,113 ac (8,949 ha)
Highlands Hammock State Park	X	8,139 ac (3,294 ha)
Archbold Biological Station	X	5,239 ac (2,120 ha)
Everglades		
Everglades National Park	X	758,891 ac (307,119 ha)
Big Cypress National Preserve	X	728,982 ac (295,015 ha)
Rookery Bay National Estuarine Research Preserve	X	110,557 ac (44,742 ha)
Fakahatchee Strand Preserve State Park	X	78,379 ac (31,719 ha)
GEORGIA		
Fort Stewart		
Fort Stewart Military Installation	X	279,234 ac (113,000 ha)

CONSERVATION FOCUS AREA	Recent Eastern Indigo Snake Records	Total Acres (Hectares)
Altamaha River Sandhills		
Alligator Creek Wildlife Management Area	X	3,088 ac (1,250 ha)
Flat Tub Wildlife Management Area	X	3,514 ac (1,422 ha)
Griffin Ridge Wildlife Management Area	X	5,599 ac (2,266 ha)
Horse Creek Wildlife Management Area	X	8,100 ac (3,278 ha)
Long County Georgia Department of Transportation Mitigation Tract	X	7,215 ac (2,920 ha)
Moody Forest Natural Area Preserve	X	6,291 ac (2,546 ha)
Ohoopee Dunes Natural Area		3,153 ac (1,276 ha)
Orianne Indigo Snake Preserve	X	2,501 ac (1,012 ha)
Penholoway Swamp Wildlife Management Area	X	4,270 ac (1,728 ha)
Sansavilla Wildlife Management Area	X	19,598 ac (7,931 ha)
Townsend Bombing Range-Buffer Easement	X	11,129 ac (4,504 ha)
Townsend Wildlife Management Area	X	25,100 ac (10,158 ha)
Alapaha River Sandhills		
Alapaha River Wildlife Management Area	X	6,870 ac (2,780 ha)
Georgia Forestry Commission Conservation Easement	X	5,041 ac (2,040 ha)
Grand Bay Wildlife Management Area	X	8,698 ac (3,520 ha)
Moody Air Force Base		11,401 ac (4,614 ha)
Okefenokee and Vicinity		
Okefenokee National Wildlife Refuge	X	401,982 ac (162,680 ha)
Cabin Bluff		
Kings Bay Navy Base	X	14,462 ac (5,853 ha)
Crooked River State Park (adjacent to Kings Bay)	X	515 ac (208 ha)